Computers and Chemical Engineering 141 (2020) 106978

Contents lists available at ScienceDirect

Computers and Chemical Engineering

journal homepage: www.elsevier.com/locate/compchemeng

# Forty years of computers & chemical engineering: A bibliometric analysis

Nikunja Mohan Modak[a,*], Valeria Lobos[b], José M. Merigó[b,c], Bogdan Gabrys[d], Jay H. Lee[e]

[a] Palpara Vidyamandir, Chakdaha, West Bengal, 741222, India
[b] Department of Management Control and Information Systems, School of Economics and Business, University of Chile, Av. Diagonal Paraguay 257, Santiago, 8330015, Chile
[c] School of Information, Systems and Modelling, Faculty of Engineering and Information Technology, University of Technology Sydney, 81 Broadway, Ultimo, NSW, 2007, Australia
[d] Advanced Analytics Institute, Faculty of Engineering and Information Technology, University of Technology Sydney, 81 Broadway, Ultimo, NSW, 2007, Australia
[e] Korea Advanced Institute of Science and Technology (KAIST), 291 Daehak-ro, Yuseong-gu, Daejeon, 34141, KOREA

ARTICLE INFO

*Article history:*
Received 24 August 2019
Revised 15 May 2020
Accepted 14 June 2020
Available online 16 June 2020

*Keywords:*
Bibliometrics
Journal
Computers & chemical engineering
Web of Science
VOS viewer

ABSTRACT

Computers & Chemical Engineering (CCE) is one of the premier international journals in the field of chemical engineering. CCE published its first issue in 1977 and completed forty years in 2016. More than four decades of continuous and successful journey influenced us to celebrate its contribution through a comprehensive bibliometric study. Using the Web of Science Core Collection database we depict trends of the journal in terms of papers, topics, authors, institutions, and countries. Networks visualization of co-citation of journals and authors, bibliographic coupling institutions and countries, and co-occurrence of author keywords are prepared using the visualization of similarities (VOS) viewer software. The present analysis explores publication and citation patterns of the journal. Professor Ignacio E. Grossmann, Carnegie Mellon University, and USA respectively appear as the most productive and influential author, institution, and country in CCE publications. Optimization based research topics received most attention in CCE publications.



## 1. Introduction

The journal of Computers & Chemical Engineering (CCE) was established in 1977. The primary aim of this journal is to publish new findings in the application of computing and systems technology to chemical engineering problems. The journal's emphasis is put on new findings within various major areas, including: modeling, mathematical programming, cyber infrastructure, intelligent systems, process dynamics and control, abnormal events management, plant operations, enterprise-wide management and domain applications. It welcomes different types of research papers to cover different aspects including new applications of established methods, comparisons of methodologies, demonstrations of state-of-the-art industrial applications and noteworthy improvements in computation for training and education. CCE also welcomes general research papers on emerging new issues and topics. CCE publishes full-length articles, reviews, short notes and letters to the editor. Richard R. Hughes was the founding editor-in-chief of the journal along with Charles H. Ware, who acted as the editor of the special feature algorithms and programs. Richard R. Hughes edited CCE for 11 years until his death. In the inaugural editorial, Prof. Richard R. Hughes described the intention of the journal. The journal was created to provide the platform for new developments in the application of computers to chemical engineering problems. E.N. Pistikopoulos of Texas A&M University is currently working as the editor-in-chief and the editorial board is completed by four editors: J.H. Lee of Korea Advanced Institute of Science and Technology, A.B.P. Póvoa of Instituto Superior Técnico, V. Venkatasubramanian of Columbia University, and F. You of Cornell University and one associate editor: A. Mitsos of RWTH Aachen University. From the very beginning, the outstanding contributions and dedication of its editors have made this journal a success. The journal is now indexed in all well-established databases including Science Citation Index (SCI), Scopus, Current Contents, Engineering Index. According to Scopus, CCE has a CiteScore 3.98 in 2018. As per Journal Citation Reports from Clarivate Analytics the journal has an impact factor 3.334 and 5-year impact factor 3.373 in 2018. The Eigenfactor® and Article influence of CCE in 2018 are 0.011 and 0.609, respectively.

* Corresponding author.
*E-mail addresses:* jmerigo@fen.uchile.cl, nikunja.modak@gmail.com (N.M. Modak).

https://doi.org/10.1016/j.compchemeng.2020.106978
0098-1354/

**Table 1**
List of bibliometric studies to celebrate anniversary of academic/scientific journals.

| Publisher | Bibliometric Study | Anniversary | Name of the Journal |
|---|---|---|---|
| Elsevier | Merigó et al., (2015) | 40 year | Journal of Business Research |
| | Merigó et al. (2018b) | 50 year | Information Sciences |
| | Cancino et al. (2017) | 40 years | Computers & Industrial Engineering |
| | Laengle et al. (2017) | 40 years | European Journal of Operational Research |
| | Merigó et al., 2019a | 40 years | Safety Science |
| | Merino et al. (2006) | 25 years | Technovation |
| | Cobo et al. (2015) | 25 years | Knowledge-Based Systems |
| | Modak et al. (2019) | 50 years | Transportation Research Part A: Policy and Practice |
| Springer | Mas-Tur et al. (2018) | 50 Years | Quality & Quantity |
| | Laengle et al. (2018c) | 25 years | Group Decision and Negotiation |
| Wiley | Merigó et al. (2017) | 30 years | International Journal of Intelligent Systems |
| | Ramos-Rodríguez and Ruíz-Navarro (2004) | 20 years | Strategic Management Journal |
| | Biemans et al. (2007) | 20 years | Journal of Product Innovation Management |
| Emerald | Martínez-López et al. (2018) | 50 years | European Journal of Marketing |
| | Valenzuela et al. (2017) | 30 years | Journal of Business & Industrial Marketing |
| | Gaviria-Marin (2018) | 20 years | Journal of Knowledge Management |
| Taylor & Francis | Laengle et al. (2018b) | 30 years | International Journal of Computer Integrated Manufacturing |
| World Scientific | Wang et al. (2018) | 25 years | International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems |

**Table 2**
Annual citation structure of CCE.

| Year | TP | TC | >200 | >100 | >50 | >20 | >10 | >5 | >1 |
|---|---|---|---|---|---|---|---|---|---|
| 1977 | 22 | 365 | 0 | 0 | 3 | 6 | 11 | 14 | 19 |
| 1978 | 25 | 356 | 0 | 0 | 2 | 5 | 8 | 13 | 24 |
| 1979 | 77 | 1050 | 1 | 3 | 5 | 13 | 26 | 30 | 55 |
| 1980 | 29 | 474 | 1 | 1 | 1 | 3 | 8 | 15 | 25 |
| 1981 | 34 | 345 | 0 | 0 | 1 | 5 | 10 | 14 | 30 |
| 1982 | 39 | 418 | 0 | 1 | 1 | 4 | 7 | 20 | 33 |
| 1983 | 49 | 1526 | 2 | 3 | 7 | 13 | 23 | 35 | 48 |
| 1984 | 43 | 808 | 1 | 2 | 2 | 11 | 24 | 27 | 37 |
| 1985 | 53 | 1267 | 1 | 3 | 7 | 18 | 28 | 37 | 47 |
| 1986 | 56 | 913 | 0 | 0 | 4 | 18 | 28 | 36 | 51 |
| 1987 | 70 | 1562 | 1 | 2 | 8 | 24 | 34 | 50 | 65 |
| 1988 | 132 | 2537 | 3 | 3 | 10 | 34 | 58 | 83 | 120 |
| 1989 | 127 | 2952 | 2 | 8 | 16 | 35 | 61 | 86 | 118 |
| 1990 | 112 | 5683 | 4 | 14 | 34 | 61 | 82 | 93 | 107 |
| 1991 | 80 | 2238 | 0 | 6 | 13 | 32 | 52 | 61 | 76 |
| 1992 | 141 | 2851 | 1 | 6 | 14 | 35 | 56 | 75 | 121 |
| 1993 | 174 | 4747 | 3 | 8 | 18 | 42 | 61 | 90 | 151 |
| 1994 | 204 | 3566 | 2 | 6 | 18 | 51 | 76 | 108 | 183 |
| 1995 | 218 | 3711 | 3 | 7 | 15 | 45 | 80 | 136 | 204 |
| 1996 | 385 | 6309 | 1 | 7 | 24 | 91 | 158 | 257 | 355 |
| 1997 | 313 | 5236 | 0 | 4 | 25 | 85 | 147 | 223 | 295 |
| 1998 | 337 | 6925 | 5 | 10 | 28 | 97 | 160 | 246 | 327 |
| 1999 | 333 | 5237 | 2 | 12 | 23 | 56 | 87 | 130 | 260 |
| 2000 | 341 | 8152 | 2 | 9 | 37 | 128 | 212 | 269 | 330 |
| 2001 | 135 | 3430 | 0 | 4 | 18 | 57 | 100 | 122 | 133 |
| 2002 | 134 | 4576 | 1 | 11 | 30 | 66 | 97 | 119 | 132 |
| 2003 | 132 | 6902 | 5 | 9 | 29 | 67 | 98 | 120 | 128 |
| 2004 | 238 | 9704 | 6 | 19 | 54 | 124 | 187 | 218 | 235 |
| 2005 | 214 | 4999 | 0 | 4 | 22 | 91 | 150 | 190 | 208 |
| 2006 | 121 | 4236 | 3 | 7 | 19 | 55 | 84 | 105 | 117 |
| 2007 | 131 | 2866 | 0 | 3 | 15 | 53 | 80 | 106 | 128 |
| 2008 | 236 | 6186 | 1 | 6 | 30 | 110 | 174 | 211 | 232 |
| 2009 | 196 | 5361 | 1 | 9 | 22 | 81 | 131 | 171 | 194 |
| 2010 | 195 | 4377 | 0 | 3 | 18 | 76 | 137 | 175 | 194 |
| 2011 | 244 | 5001 | 0 | 3 | 20 | 85 | 154 | 200 | 235 |
| 2012 | 225 | 4584 | 0 | 3 | 22 | 83 | 139 | 183 | 219 |
| 2013 | 239 | 3525 | 1 | 2 | 9 | 50 | 124 | 179 | 230 |
| 2014 | 255 | 3404 | 1 | 2 | 7 | 46 | 121 | 184 | 247 |
| 2015 | 211 | 2430 | 0 | 0 | 2 | 33 | 80 | 158 | 207 |
| 2016 | 296 | 1839 | 0 | 0 | 0 | 13 | 59 | 155 | 274 |
| 2017 | 310 | 1110 | 0 | 0 | 0 | 2 | 17 | 89 | 258 |
| 2018 | 320 | 253 | 0 | 0 | 0 | 0 | 2 | 10 | 120 |
| Total | 7226 | 144,011 | 54 | 200 | 633 | 2004 | 3431 | 4843 | 6572 |
| % | 100% | | 0.75% | 2.77% | 8.76% | 27.73% | 47.48% | 67.02% | 90.95% |

Abbreviations: TP and TC = Total papers and citations; >200, >100, >50, >20, >10, >5, >1 = Number of papers with more than 200, 100, 50, 25, 10, 5 and 1 citations.

**Table 3**
The 50 most cited documents in CCE.

| R | TC | **TC (Scopus)** | Title | Author/s | Year | C/Y | C/Y (Scopus) |
|---|---|---|---|---|---|---|---|
| 1 | 1174 | **1745** | A Plant-Wide Industrial-Process Control Problem | Downs, JJ; Vogel, EF | 1993 | 48.92 | 67.12 |
| 2 | 1145 | **1762** | A Review Of Process Fault Detection And Diagnosis Part I: Quantitative Model-Based Methods | Venkatsubramanian, V; Rengaswamy, R; Yin, K; et al. | 2003 | 81.79 | 110.13 |
| 3 | 989 | **1384** | Model Predictive Control: Past, Present And Future | Morari, M; Lee, JH | 1999 | 54.94 | 69.20 |
| 4 | 813 | **1229** | A Review Of Process Fault Detection And Diagnosis Part Iii: Process History Based Methods | Venkatasubramanian, V; Rengaswamy, R; Kavuri, SN; et al. | 2003 | 58.07 | 76.81 |
| 5 | 679 | **862** | A General Algorithm For Short-Term Scheduling Of Batch-Operations 0.1. Milp Formulation | Kondili, E; Pantelides, Cc; Sargent, RWH | 1993 | 28.29 | 33.15 |
| 6 | 583 | **831** | Simultaneous-Optimization Models For Heat Integration 0.2. Heat-Exchanger Network Synthesis | Yee, TF; Grossmann, IE; Kravanja, Z | 1990 | 21.59 | 28.66 |
| 7 | 575 | **892** | Data-Driven Soft Sensors In The Process Industry | Kadlec, P; Gabrys, B; Strandt, S | 2009 | 71.88 | 89.20 |
| 8 | 559 | **767** | Optimization Under Uncertainty: State-Of-The-Art And Opportunities | Sahinidis, NV | 2004 | 43.00 | 51.13 |
| 9 | 537 | **812** | A Review Of Process Fault Detection And Diagnosis Part Ii: Quantitative Model And Search Strategies | Venkatasubramanian, V; Rengaswamy, R; Kavuri, SN | 2003 | 38.36 | 50.75 |
| 10 | 479 | **561** | A Combined Penalty-Function And Outer-Approximation Method For Minlp Optimization | Viswanathan, J; Grossmann, IE | 1990 | 17.74 | 19.34 |
| 11 | 456 | **609** | State-Of-The-Art Review Of Optimization Methods For Short-Term Scheduling Of Batch Processes | Mendez, CA; Cerda, J; Grossmann, IE; et al. | 2006 | 41.45 | 46.85 |
| 12 | 447 | **583** | A Structural Optimization Approach In Process Synthesis 0.2. Heat-Recovery Networks | Papoulias, SA; Grossmann, IE | 1983 | 13.15 | 16.19 |
| 13 | 429 | **528** | Use Of Neural Nets For Dynamic Modeling And Control Of Chemical Process Systems | Bhat, N; Mcavoy, TJ | 1990 | 15.89 | 18.21 |
| 14 | 369 | **493** | Nonlinear Principal Component Analysis - Based On Principal Curves And Neural Networks | Dong, D; Mcavoy, TJ | 1996 | 17.57 | 21.43 |
| 15 | 364 | **494** | Recursive Pls Algorithms For Adaptive Data Modeling | Qin, SJ | 1998 | 19.16 | 23.52 |
| 16 | 363 | **469** | Continuous-Time Versus Discrete-Time Approaches For Scheduling Of Chemical Processes: A Review | Floudas, CA; Lin, XX | 2004 | 27.92 | 31.27 |
| 17 | 329 | **415** | Retrospective On Optimization | Biegler, LT; Grossmann, IE | 2004 | 25.31 | 27.67 |
| 18 | 311 | **413** | Nonlinear Model Predictive Control: Current Status And Future Directions | Henson, MA | 1998 | 16.37 | 19.67 |
| 19 | 309 | **385** | A Review Of Recent Design Procedures For Water Networks In Refineries And Process Plants | Bagajewicz, M | 2000 | 18.18 | 20.26 |
| 20 | 302 | **381** | Modeling And Computational Techniques For Logic-Based Integer Programming | Raman, R; Grossmann, IE | 1994 | 13.13 | 15.24 |
| 21 | 293 | **368** | A Global Optimization Method, Alpha Bb, For General Twice-Differentiable Constrained Nlps - I. Theoretical Advances | Adjiman, CS; Dallwig, S; Floudas, CA; et al. | 1998 | 15.42 | 17.52 |
| 22 | 292 | **374** | New Insights In Solving Distributed System Equations By The Quadrature Method 0.1. Analysis | Quan, JR; Chang, CT | 1989 | 10.43 | 12.47 |
| 23 | 291 | **343** | Generic Model Control (Gmc) | Lee, PL; Sullivan, GR | 1988 | 10.03 | 11.06 |
| 24 | 288 | **371** | Nonlinear Pls Modeling Using Neural Networks | Qin, SJ; Mcavoy, TJ | 1992 | 11.52 | 13.74 |
| 25 | 286 | **335** | Global Optimization For The Synthesis Of Integrated Water Systems In Chemical Processes | Karuppiah, R; Grossmann, IE | 2006 | 26.00 | 25.77 |
| 26 | 283 | **327** | Sensitivity Analysis Of Initial-Value Problems With Mixed Odes And Algebraic Equations | Caracotsios, M; Stewart, WE | 1985 | 8.84 | 9.62 |
| 27 | 276 | **368** | Plant-Wide Control Of The Tennessee Eastman Problem | Lyman, PR; Georgakis, C | 1995 | 12.55 | 15.33 |
| 28 | 274 | **476** | A Modular Simulation Package For Fed-Batch Fermentation: Penicillin Production | Birol, G; Undey, C; Cinar, A | 2002 | 18.27 | 28.00 |
| 29 | 273 | **385** | Fault Diagnosis Based On Fisher Discriminant Analysis And Support Vector Machines | Chiang, LH; Kotanchek, ME; Kordon, AK | 2004 | 21.00 | 25.67 |
| 30 | 264 | **328** | Optimal Water Allocation In A Petroleum Refinery | Takama, N; Kuriyama, T; Shiroko, K; et al. | 1980 | 7.14 | 8.41 |
| 31 | 248 | **428** | Distributed Model Predictive Control: A Tutorial Review And Future Research Directions | Christofides, PD; Scattolini, R; Munoz De La Pena, D; et al. | 2013 | 62.00 | 71.33 |
| 32 | 247 | **362** | Managing Demand Uncertainty In Supply Chain Planning | Gupta, A; Maranas, CD | 2001 | 15.44 | 20.11 |
| 33 | 246 | **367** | An Overview Of Subspace Identification | Qin, SJ | 2006 | 22.36 | 28.23 |
| 34 | 239 | **340** | Data-Based Process Monitoring, Process Control, And Quality Improvement: Recent Developments And Applications In Steel Industry | Kano, M; Nakagawa, Y | 2008 | 26.56 | 30.91 |
| 35 | 233 | **298** | Planning And Scheduling Models For Refinery Operations | Pinto, JM; Joly, M; Moro, LFL | 2000 | 13.71 | 15.68 |

(*continued on next page*)

**Table 3** (*continued*)

| R | TC | **TC (Scopus)** | Title | Author/s | Year | C/Y | C/Y (Scopus) |
|---|---|---|---|---|---|---|---|
| 36 | 233 | **278** | A General Algorithm For Short-Term Scheduling Of Batch-Operations 0.2. Computational Issues | Shah, N; Pantelides, CC; Sargent, RWH | 1993 | 9.71 | 10.69 |
| 37 | 232 | **292** | Active Constraint Strategy For Flexibility Analysis In Chemical Processes | Grossmann, IE; Floudas, CA | 1987 | 7.73 | 9.13 |
| 38 | 229 | **315** | Control Structure Design For Complete Chemical Plants | Skogestad, S | 2004 | 17.62 | 21.00 |
| 39 | 229 | **265** | Simultaneous-Optimization And Solution Methods For Batch Reactor Control Profiles | Cuthrell, JE; Biegler, LT | 1989 | 8.18 | 8.83 |
| 40 | 229 | **272** | Solution Of Dynamic Optimization Problems By Successive Quadratic-Programming And Orthogonal Collocation | Biegler, LT | 1984 | 6.94 | 7.77 |
| 41 | 226 | **299** | Control Performance Monitoring - A Review And Assessment | Qin, SJ | 1998 | 11.89 | 14.24 |
| 42 | 226 | **279** | Artificial Neural Network Models Of Knowledge Representation In Chemical-Engineering | Hoskins, JC; Himmelblau, DM | 1988 | 7.79 | 9.00 |
| 43 | 225 | **299** | Simultaneous-Optimization Models For Heat Integration 0.1. Area And Energy Targeting And Modeling Of Multi-Stream Exchangers | Yee, TF; Grossmann, IE; Kravanja, Z | 1990 | 8.33 | 10.31 |
| 44 | 223 | **270** | Global Optimization Of Nonconvex Nlps And Minlps With Applications In-Process Design | Ryoo, HS; Sahinidis, NV | 1995 | 10.14 | 11.25 |
| 45 | 222 | **296** | A Structural Optimization Approach In Process Synthesis 0.1. Utility Systems | Papoulias, SA; Grossmann, IE | 1983 | 6.53 | 8.22 |
| 46 | 220 | **318** | Dynamic Optimization Of Batch Processes - I. Characterization Of The Nominal Solution | Srinivasan, B; Palanki, S; Bonvin, D | 2003 | 15.71 | 19.88 |
| 47 | 216 | **264** | The Synthesis Of Cost Optimal Heat-Exchanger Networks - An Industrial Review Of The State Of The Art | Gundersen, T; Naess, L | 1988 | 7.45 | 8.52 |
| 48 | 213 | **364** | Biomass-To-Bioenergy And Biofuel Supply Chain Optimization: Overview, Key Issues And Challenges | Yue, D; You, F; Snyder, SW | 2014 | 71.00 | 72.80 |
| 49 | 212 | **368** | A Global Optimization Method, Alpha Bb, For General Twice-Differentiable Constrained Nlps - Ii. Implementation And Computational Results | Adjiman, CS; Androulakis, IP; Floudas, CA | 1998 | 11.16 | 17.52 |
| 50 | 211 | **288** | Multi-Objective Optimization Of Multi-Echelon Supply Chain Networks With Uncertain Product Demands And Prices | Chen, CL; Lee, WC | 2004 | 16.23 | 19.20 |

Abbreviations: $R$ = Rank; TC = Total citations; C/$Y$ = Citations per year.

In 2018, the journal recorded a total of 1129 submissions and 318 papers were accepted for publication. During last five year the journal has consistently shown an acceptance rate around one third of submissions, which proves its efficiency in editorial processes.

In 2018, CCE completed its forty two years' journey. This study aims to examine the performance of the journal during those years. More specifically, its aim is to discover the consequence, productivity and influence of CCE in new research findings in the application of computers to chemical engineering problems. A general bibliometric study is used to classify statistical information of its publications and then to analyze its performance. Bibliometric studies use a procedure to measure the quality of scientific information using different qualitative as well as quantitative indexes. Library and information sciences provide the basic concepts of bibliometric study. Ideas from computer science and statistics have helped to advance its methodological and data processing procedures. This type of study is useful in surveys, reviews and big data analysis. It is commonly used to analyze influence of a topic in literature, contribution of a journal in a particular discipline, tribute to legends, contribution of an institution and a country. For instances; Bornmann et al. (2015) use bibliometric study to measure contributions of different countries; Linton (2004) uses this type of study to quantify contributions of universities; and Merigó et al. (2018) use the study to measure contributions of journals. Bibliometric studies are also common to use in the analysis of a topic based research works. Merigó et al., (2019b) and Laengle et al. (2018a) presented a bibliometric analysis to measure performances of universities on Production & Operations Management (POM) and Operations Research and Management Science (OR-MS) respectively. Using a bibliometric study, Kazemi et al. (2018) analyzed research publications on reverse logistics and closed-loop supply chain published in the International Journal of Production Research. Examples of some notable topics based bibliometric studies are: natural resource (Zhong et al., 2016), innovation (Merigó et al., 2016), fuzzy research (Blanco-Mesa et al., 2017), sustainability (Franceschini et al., 2016), etc. In early years, citation analysis was the main reputed tool to identify influential journals in a particular discipline. Generally, scientific journals have some explicit objectives, aims and scopes. Journals publish research works to fulfill their aims which in turn helps to enhance scientific understanding and innovations. Journals oftentimes modify their aims and scopes due to the ever changing scientific environment. Occasionally, it is useful to reassess performance of a journal during its journey. Bibliometric study can help to re-examine a journal's performance. The trends to revisit journals' performance in their important anniversaries have started more than three decades ago. In 1986, Hech and Bremser (1986) demonstrated sixty years' publication details of the journal The Accounting Review and analyzed its performance. Later in 2008, Weiss and Qiu (2008) investigated the publication outline of The Journal of Risk and Insurance to celebrate its platinum jubilee. There are several examples from almost all well-established publishers which used bibliometric studies to reassess performance of their journals during their significant anniversaries (Please see Table 1).

Table 1 illustrates journals from six well-established publishers including Elsevier, Springer, Wiley, Emerald, Taylor & Francis and World Scientific which analyzed their publications during their important anniversaries. Four journals in Table 1 (Information Sciences, Transportation Research Part A, Quality & Quantity, European Journal of Marketing) celebrate their half century through bibliometric studies. Four well-established journals from

**Table 4**
Top 40 most cited documents in CCE publications.

| Rank | Year | First Author | Reference | Vol | Page | Type | TC | Co-citations |
|---|---|---|---|---|---|---|---|---|
| 1 | 1993 | Kondili E | Comput Chem Eng | v17 | p211 | A | 177 | 144 |
| 2 | 1988 | Douglas JM | Conceptual Design Ch | | | B | 156 | 91 |
| 3 | 1990 | Viswanathan J | Comput Chem Eng | v14 | p769 | A | 134 | 121 |
| 4 | 1986 | Duran MA | Math Program | v36 | p307 | A | 132 | 124 |
| 5 | 1983 | Papoulias SA | Comput Chem Eng | v7 | p707 | A | 110 | 100 |
| 6 | 1997 | Biegler LT | Systematic Methods C | | | B | 106 | 83 |
| 7 | 1983 | Linnhoff B | Chem Eng Sci | v38 | p745 | A | 106 | 95 |
| 8 | 1990 | Yee TF | Comput Chem Eng | v14 | p1165 | A | 100 | 93 |
| 9 | 1972 | Geoffrion AM | Journal Of Optimization Theory And Applications | v10 | p237 | A | 99 | 94 |
| 10 | 1995 | Floudas CA | Nonlinear Mixed Inte | | | B | 97 | 90 |
| 11 | 1978 | Villadsen J | Solution Differentia | | | B | 96 | 43 |
| 12 | 2006 | Mendez CA | Comput Chem Eng | v30 | p913 | A | 93 | 88 |
| 13 | 1989 | Morari M | Robust Process Contr | | | B | 90 | 49 |
| 14 | 1993 | Downs JJ | Comput Chem Eng | v17 | p245 | A | 89 | 41 |
| 15 | 1989 | Goldberg DE | Genetic Algorithms S | | | B | 87 | 43 |
| 16 | 1982 | Linnhoff B | User Guide Process I | | | B | 86 | 65 |
| 17 | 1986 | Floudas CA | AIChE J | v32 | p276 | A | 84 | 79 |
| 18 | 2004 | Floudas CA | Comput Chem Eng | v28 | p2109 | A | 83 | 81 |
| 19 | 1998 | Ierapetritou MG | Ind Eng Chem Res | v37 | p4341 | A | 80 | 79 |
| 20 | 1985 | Swaney RE | AIChE J | v31 | p621 | A | 80 | 65 |
| 21 | 2005 | Grossmann I | AIChE J | v51 | p1846 | A | 77 | 69 |
| 22 | 1994 | Raman R | Comput Chem Eng | v18 | p563 | A | 77 | 73 |
| 23 | 1988 | Brooke A | Gams Users Guide | | | B | 76 | 57 |
| 24 | 2004 | Sahinidis NV | Comput Chem Eng | v28 | p971 | A | 76 | 57 |
| 25 | 2006 | Wachter A | Math Program | v106 | p25 | A | 76 | 53 |
| 26 | 1987 | Reid RC | Properties gases Liq | | | B | 72 | 48 |
| 27 | 1993 | Shah N | Comput Chem Eng | v17 | p229 | A | 69 | 66 |
| 28 | 1983 | Kirkpatrick S | Science | v220 | p671 | A | 68 | 37 |
| 29 | 1980 | Finlayson BA | Nonlinear Anal Chem | | | B | 66 | 33 |
| 30 | 2003 | Qin SJ | Control Eng Pract | v11 | p733 | A | 66 | 44 |
| 31 | 1986 | Duran MA | AIChE J | v32 | p123 | A | 64 | 59 |
| 32 | 1995 | Pinto JM | Ind Eng Chem Res | v34 | p3037 | A | 63 | 54 |
| 33 | 1981 | Nishida N | AIChE J | v27 | p321 | A | 62 | 46 |
| 34 | 1978 | Linnhoff B | AIChE J | v24 | p633 | A | 61 | 58 |
| 35 | 1987 | Kocis GR | Ind Eng Chem Res | v26 | p1869 | A | 60 | 58 |
| 36 | 1989 | Kocis GR | Comput Chem Eng | v13 | p797 | A | 60 | 55 |
| 37 | 2005 | Benders JF | Comput Manag Sci | v2 | p3 | A | 56 | 52 |
| 38 | 1987 | Cuthrell JE | AIChE J | v33 | p1257 | A | 56 | 39 |
| 39 | 1987 | Grossmann IE | Comput Chem Eng | v11 | p675 | A | 56 | 53 |
| 40 | 1989 | El-Halwagi MM | AIChE J | v35 | p1233 | A | 55 | 44 |

Abbreviations: TC = Total citations; *A* = Article; *B* = Book.

Elsevier analyze their journey of four decades. During the last decade this type of studies have increased a lot due to easily accessible data from sources like Web of Science, Scopus, and Google Scholar. Zhang et al. (2019) used different text mining techniques to analyze all CCE publications for the period of 1977 to 2017. The present article differs from Zhang et al. (2019) in many aspects. Using computing technology, Zhang et al. (2019) presented a topic analysis of the published articles in CCE while the present article uses the bibliometric methods to explore exclusively publication pattern, citation structure, most cited articles, leading authors, institutions and countries. Moreover, the present article presents the network visualizations of the bibliographic coupling among countries and institutions, co-citation among the journals & authors, and co-occurrence of keywords of all the CCE publications.

The purpose of the present bibliometric study is to celebrate the four decades of CCE and analyze all articles published in this journal from 1977 to 2018. Its aims are to reveal the most influential and contributing authors, universities and countries in CCE publications. The study intends to analyze publication and citation details, highly cited articles, and collaborations among the authors, institutions and countries. Moreover, it divulges analysis of bibliographic coupling (Kessler, 1963) among the countries and institutions, co-citation (Small, 1973) of journals & authors, and co-occurrence of keywords in the CCE publications. More specifically, this work intends to answer the following questions. During the journey since 1977, what is the publication and citation pattern of CCE? Which publications and issues have received high attention? Which authors, institutions and countries contribute the most? Which authors, universities, and countries receive the highest number of citations in the publications of CCE? Which journals have close links with CCE? In the published research in CCE, which universities and countries are involved in collaborative works? Which keywords are most often used in the publications? The aim of this study is not only to find answers to the above questions but also celebrate the journal's achievements. The study commemorates the contribution of the editors, authors, institutions, and countries during the forty years journey of the journal. It also provides entire information of the publications of the journal, which will be helpful to the young researchers for their future research planning. Moreover, it will be helpful to the editors of the journal to assess those topics which have the most potential and which, in turn, may help to decide future strategies of the journal.

Remaining parts of the paper are arranged as follows. The second section discusses the method of the study. Section 3 demonstrates details of publication pattern, citation structure, and most often cited articles, leading authors, institutions and countries of CCE. Section 4 presents a discussion with the network visualizations of the bibliographic coupling among countries and institutions, co-citation among the journals & authors, and co-occurrence of keywords. Final section summarizes the key conclusions of the work.

**Table 5a**
List of authors who published most papers in CCE.

| R | Full Name | University | Country | TC | TP | H | C/P | >100 | >50 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Ignacio E. Grossmann | Carnegie Mellon U | USA | 12,380 | 206 | 62 | 60.10 | 34 | 78 |
| 2 | Stratos Pistikopoulos | Texas A&M U | USA | 2653 | 98 | 29 | 27.07 | 4 | 18 |
| 3 | Lorenz T. Biegler | Carnegie Mellon U | USA | 3561 | 97 | 34 | 36.71 | 8 | 18 |
| 4 | Rafiqul Gani | Technical U Denmark | DEN | 2059 | 83 | 27 | 24.81 | 3 | 10 |
| 5 | Christodoulos A. Floudas | Texas A&M Energy Institute | USA | 4672 | 78 | 37 | 59.90 | 15 | 34 |
| 6 | Luis Puigjaner | Polytechnic U Catalonia | ESP | 1297 | 68 | 22 | 19.07 | 1 | 4 |
| 7 | Wolfgang Marquardt | RWTH Aachen U | GER | 1747 | 65 | 24 | 26.88 | 2 | 9 |
| 8 | Gintaras V. (Rex) Reklaitis | Purdue U | USA | 1485 | 58 | 24 | 25.60 | 2 | 8 |
| 9 | Antonio Espuna | Polytechnic U Catalonia | ESP | 958 | 49 | 19 | 19.55 | 1 | 3 |
| 10 | Venkat Venkatasubramanian | Columbia U | USA | 2867 | 48 | 23 | 59.73 | 4 | 11 |
| 11 | Nilay Shah | Imperial College London | UK | 1505 | 45 | 19 | 33.44 | 4 | 6 |
| 12 | Manfred Morari | U Pennsylvania | USA | 2071 | 41 | 19 | 50.51 | 2 | 7 |
| 13 | Sigurd Skogestad | Norwegian U Sci Tech | NOR | 1032 | 41 | 18 | 25.17 | 1 | 4 |
| 14 | Mark A. Stadtherr | U Illinois Urbana-Champaign | USA | 653 | 41 | 15 | 15.93 | 0 | 2 |
| 15 | José A. Romagnoli | Louisiana State U | USA | 444 | 41 | 12 | 10.83 | 0 | 0 |
| 16 | Ramesh Srinivasan | U California, Irvine | USA | 1022 | 40 | 19 | 25.55 | 1 | 4 |
| 17 | Constantinos Pantelides | Imperial College London | UK | 2176 | 39 | 21 | 55.79 | 5 | 8 |
| 18 | Jay H. Lee | KAIST | SWI | 2064 | 39 | 18 | 52.92 | 3 | 8 |
| 19 | Zdravko Kravanja | U Maribor | SLN | 1234 | 39 | 21 | 31.64 | 1 | 8 |
| 20 | Arthur W. Westerberg | Carnegie Mellon U | USA | 991 | 38 | 18 | 26.08 | 1 | 7 |
| 21 | Iftekhar A Karimi | National U Singapore | SGP | 668 | 38 | 17 | 17.58 | 0 | 2 |
| 22 | Sebastian Engell | Dortmund U Technology | GER | 920 | 37 | 15 | 24.86 | 1 | 5 |
| 23 | Thomas F. Edgar | U Texas Austin | USA | 855 | 37 | 16 | 23.11 | 2 | 2 |
| 24 | Sandro Macchietto | Imperial College London | UK | 702 | 36 | 16 | 19.50 | 1 | 3 |
| 25 | Iiro Harjunkoski | ABB Corporate Res | GER | 1795 | 34 | 21 | 52.79 | 5 | 11 |
| 26 | Angelo Lucia | U Rhode Island | USA | 332 | 34 | 10 | 9.76 | 0 | 0 |
| 27 | Serge Domenech | CNRS | FRA | 443 | 33 | 13 | 13.42 | 0 | 0 |
| 28 | Marianthi Ierapetritou | Ecolé Polytech Féd Lausanne | SWI | 806 | 32 | 16 | 25.19 | 1 | 3 |
| 29 | Jaime Cerda | U Nacional del Litoral | ARG | 1402 | 31 | 18 | 45.23 | 2 | 7 |
| 30 | Christos T. Maravelias | U Wisconsin-Madison | USA | 934 | 31 | 16 | 30.13 | 2 | 5 |
| 31 | Fengqi You | Cornell U | USA | 1353 | 30 | 19 | 45.10 | 3 | 10 |
| 32 | John Perkins | Imperial College London | UK | 751 | 30 | 15 | 25.03 | 1 | 5 |
| 33 | Luc Pibouleau | CNRS | FRA | 370 | 30 | 11 | 12.33 | 0 | 0 |
| 34 | Gregory Stephanopoulos | MIT | USA | 1098 | 28 | 18 | 39.21 | 2 | 7 |
| 35 | Joseph Pekny | Purdue U | USA | 908 | 28 | 17 | 32.43 | 2 | 5 |
| 36 | David WT Rippin | ETH Zurich | SWI | 771 | 28 | 16 | 27.54 | 0 | 6 |
| 37 | Rubens Maciel | U Estadual do Oeste do Parana | BRA | 484 | 28 | 10 | 17.29 | 1 | 2 |
| 38 | Dominique Bonvin | Rutgers U | USA | 846 | 27 | 12 | 31.33 | 3 | 4 |
| 39 | David Bogle | U College London | UK | 257 | 27 | 9 | 9.52 | 0 | 1 |
| 40 | Jose Mauricio Pinto | U Sao Paulo | BRA | 1211 | 26 | 16 | 46.58 | 4 | 7 |
| 41 | Karl Tapio Westerlund | Åbo Akademi U | FIN | 664 | 26 | 14 | 25.54 | 0 | 4 |
| 42 | Prodromos Daoutidis | U Minnesota | USA | 596 | 26 | 14 | 22.92 | 0 | 5 |
| 43 | Daniel R. Lewin | Technion Israel Inst Tech | ISR | 492 | 26 | 13 | 18.92 | 1 | 2 |
| 44 | Gunter Wozny | Technical U Berlin | GER | 470 | 26 | 12 | 18.08 | 1 | 2 |
| 45 | Eric S. Fraga | U College London | UK | 256 | 26 | 9 | 9.85 | 0 | 0 |
| 46 | Panagiotis D. Christofides | U California, Los Angeles | USA | 712 | 25 | 12 | 28.48 | 1 | 4 |
| 47 | Liang-Tseng Fan | Kansas State U | USA | 462 | 25 | 12 | 18.48 | 1 | 2 |
| 48 | Lazaros Papageorgiou | U College London | UK | 629 | 24 | 12 | 26.21 | 1 | 4 |
| 49 | Warren D. Seider | U Pennsylvania | USA | 386 | 24 | 10 | 16.08 | 0 | 2 |
| 50 | Ian Cameron | National U South / CONICET | ARG | 343 | 24 | 10 | 14.29 | 0 | 2 |

## 2. Methods

Data collection is an important part of a bibliometric study. Details of each CCE publication from 1977 to 2018 are accessed from the Web of Science (WoS) core collection database. Presently, there are several databases of scientific publications including Scopus, Google Scholar and WoS. In this study, we use the WoS core collection database and Scopus due to their reliability and easily accessible citation data. WoS is a modified form of the first ever scientific publication and citation databank, the SCI (Science Citation Index). Institute of Scientific Information (ISI) established the SCI database. Later, Thomson and Reuters took the ownership of this database and presently it is owned and managed by Clarivate Analytics. WoS has six citation indexes which are: Science Citation Index Expanded, Social Sciences Citation Index, Arts & Humanities Citation Index, Emerging Sources Citation Index, Book Citation Index, and Conference Proceedings Citation Index. WoS provides more than 100 years coverage of more than 18,000 journals, 180,000 conference proceedings, and 80,000 books. WoS offers several different types of data which are necessary to depict and measure performance of CCE including the number of publications, number of citations, most contributing authors and countries, most frequently discussed topics, and linking among those topics. Although WoS has a long successful history as an authenticate data source but recently Scopus emerges significantly to complement the WoS. The list of the most cited papers is updated using the database Scopus. Moreover, list of the most influential authors is prepared using the Scopus citation data. We have captured citation data using the Scopus database up to April 2020.

Collected data from WoS are classified and presented based on several bibliometric indicators including total number of publications (TP), total number of citations (TC), H-index, citation per paper (C/P), and different citation thresholds (250, 100, 50, 25, 10, 5 and 1 citations). TP and TC are the two basic indicators used for assessing the overall volume and impact of scientific publications. Both H-index and C/P offer further, more granular information on

**Table 5b**
List of top 50 influential authors in CCE.

| R | Author's Name | University | Country | TC (Scopus) | TP | H | C/P | >100 | >50 |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Grossmann, I.E. | Carnegie Mellon U | USA | 16,370 | 206 | 72 | 79.5 | 46 | 104 |
| 2 | Venkatasubramanian, V. | Columbia U | USA | 5855 | 48 | 27 | 122.0 | 8 | 18 |
| 3 | Floudas, C.A. | Texas A&M Energy Institute | USA | 5769 | 78 | 41 | 74.0 | 22 | 35 |
| 4 | Biegler, L.T. | Carnegie Mellon U | USA | 4817 | 97 | 39 | 49.7 | 9 | 32 |
| 5 | Rengaswamy, R. | IIT, Madras | India | 4257 | 21 | 11 | 202.7 | 3 | 6 |
| 6 | Kavuri, S. N. | Purdue University | USA | 3895 | 6 | 6 | 649.2 | 3 | 3 |
| 7 | Pistikopoulos, E.N. | Texas A&M U | USA | 3742 | 98 | 32 | 38.2 | 8 | 23 |
| 8 | Yin, K | University of Minnesota | USA | 3049 | 6 | 6 | 508.2 | 2 | 2 |
| 9 | Gani, R. | Technical U Denmark | Den | 2976 | 83 | 32 | 35.9 | 6 | 18 |
| 10 | Pantelides, C.C. | Imperial College London | UK | 2836 | 39 | 23 | 72.7 | 7 | 17 |
| 11 | Morari, M. | U Pennsylvania | USA | 2829 | 41 | 21 | 69.0 | 3 | 10 |
| 12 | Harjunkoski, I. | ABB Corporate Res | GER | 2541 | 34 | 22 | 74.7 | 7 | 16 |
| 13 | Marquardt, W. | RWTH Aachen U | GER | 2352 | 65 | 29 | 36.2 | 6 | 13 |
| 14 | You, F. | Cornell U | USA | 2258 | 30 | 26 | 75.3 | 6 | 20 |
| 15 | Reklaitis, G.V. | Purdue U | USA | 2026 | 58 | 27 | 34.9 | 3 | 13 |
| 16 | Qin, SJ | University of Texas at Austin | USA | 2014 | 11 | 11 | 183.1 | 5 | 8 |
| 17 | Cerdá, J. | U Nacional del Litoral | ARG | 1959 | 31 | 21 | 63.2 | 6 | 11 |
| 18 | Sahinidis, N.V. | Carnegie Mellon U | USA | 1933 | 22 | 16 | 87.9 | 5 | 7 |
| 19 | Mcavoy, TJ | University of Maryland | USA | 1911 | 11 | 10 | 173.7 | 4 | 7 |
| 20 | Downs, JJ | Eastman Chemical Company | USA | 1824 | 3 | 3 | 608.0 | 1 | 2 |
| 21 | Ierapetritou, M.G. | Ecolé Polytech Féd Lausanne | SWI | 1785 | 32 | 24 | 55.8 | 4 | 13 |
| 22 | Vogel, EF | Tennessee Eastman Company | USA | 1754 | 2 | 2 | 877.0 | 1 | 1 |
| 23 | Puigjaner, L. | Polytechnic U Catalonia | ESP | 1736 | 68 | 26 | 25.5 | 1 | 10 |
| 24 | Kravanja, Z. | U Maribor | SLN | 1736 | 39 | 24 | 44.5 | 2 | 13 |
| 25 | Pinto, J.M. | U Sao Paulo | BRA | 1663 | 26 | 17 | 64.0 | 6 | 10 |
| 26 | Shah, N. | Imperial College London | UK | 1649 | 45 | 20 | 36.6 | 4 | 7 |
| 27 | Sargent, R.W.H. | University of London | UK | 1603 | 18 | 11 | 89.1 | 3 | 6 |
| 28 | Méndez, C.A. | Carnegie Mellon U | USA | 1588 | 22 | 14 | 72.2 | 6 | 9 |
| 29 | Skogestad, S. | Norwegian U Sci Tech | NOR | 1511 | 41 | 21 | 36.9 | 1 | 9 |
| 30 | Maravelias, C.T. | U Wisconsin-Madison | USA | 1462 | 31 | 20 | 47.2 | 3 | 8 |
| 31 | Engell, S. | Dortmund U Technology | GER | 1423 | 37 | 21 | 38.5 | 2 | 8 |
| 32 | Lee, J.H. | KAIST | SWI | 1393 | 39 | 19 | 35.7 | 3 | 8 |
| 33 | Srinivasan, R. | U California, Irvine | USA | 1365 | 40 | 22 | 34.1 | 2 | 8 |
| 34 | Stephanopoulos, G. | MIT | USA | 1299 | 28 | 19 | 46.4 | 4 | 8 |
| 35 | Bonvin, D. | Rutgers U | USA | 1277 | 27 | 14 | 47.3 | 3 | 5 |
| 36 | Yee, TF | Carnegie Mellon U | USA | 1241 | 3 | 3 | 413.7 | 3 | 3 |
| 37 | Espuña, A. | Polytechnic U Catalonia | ESP | 1217 | 49 | 20 | 24.8 | 1 | 8 |
| 38 | Westerberg, A.W. | Carnegie Mellon U | USA | 1212 | 39 | 20 | 31.1 | 2 | 9 |
| 39 | Edgar, T.F. | U Texas Austin | USA | 1193 | 37 | 18 | 32.2 | 2 | 7 |
| 40 | Pekny, J.F. | Purdue U | USA | 1186 | 28 | 18 | 42.4 | 3 | 8 |
| 41 | Gabrys, B | Bournemouth U Fern Barrow | UK | 1179 | 3 | 3 | 393.0 | 2 | 2 |
| 42 | Christofides, P.D. | U California, Los Angeles | USA | 1051 | 25 | 15 | 42.0 | 1 | 4 |
| 43 | Karimi, I.A. | National U Singapore | SGP | 1040 | 38 | 20 | 27.4 | 0 | 8 |
| 44 | Lin, X | Princeton University | USA | 1019 | 5 | 5 | 203.8 | 4 | 4 |
| 45 | Westerlund, T. | Åbo Akademi U | FIN | 996 | 26 | 16 | 38.3 | 2 | 8 |
| 46 | Adjiman, C.S. | Princeton University | USA | 996 | 13 | 9 | 76.6 | 3 | 6 |
| 47 | Papoulias, SA | Carnegie-Mellon U | USA | 970 | 3 | 3 | 323.3 | 2 | 3 |
| 48 | Perkins, J.D. | Imperial College London | UK | 937 | 30 | 16 | 31.2 | 1 | 5 |
| 49 | Kadlec, P | Bournemouth University | UK | 935 | 3 | 3 | 311.7 | 1 | 2 |
| 50 | Morris, A.J. | University of Newcastle | UK | 930 | 17 | 12 | 54.7 | 4 | 8 |

the journal publications' impact. The indicator TP gives information about number of publications which is necessary to analyze publication pattern and depict productive authors, institutions, and countries. TC is a well-established, purely citation based indicator to measure quality of scientific papers. It is useful to acknowledge and trace the original source and authorship of a concept or an idea. The C/P indicator captures average citations per paper and it is useful in comparative studies. H-index is a matrix representation of the indicators TP and TC. If an author has an H-index of h, it means that h publications of that author have received at least h citations or more (Hirsch, 2005).

In this review we use the visualization of similarities (VOS) software (Van Eck and Waltman, 2010) to prepare network visualization of bibliographic coupling (Kessler, 1963) of institutions and countries, co-citation (Small, 1973) of authors & journals, and co-occurrence of keywords used by the authors in the papers published in CCE. The focus on the analysis of bibliographic coupling, co-citations, and co-words is not only to explore the bibliographic connections among the authors, institutions, journals and countries but also to find those topics that are most often used by authors in the papers published in CCE. Bibliographic coupling analysis provides information on closely linked institutions and countries in CCE research. Two institutions/countries are said to be bibliographically coupled if they are jointly involved in research works. Two documents receive a point in the co-citation index when both the documents are commonly referenced by a third document (Small, 1973). Co-occurrence of author keywords explores frequently and concurrently used research topics in the papers published in CCE.

## 3. Results

CCE started its journey in 1977 with the 100 pages inaugural issue. The inaugural issue consisted of seven original articles, two short communications and one review article. The opening volume of CCE had three issues. Each year starting from 1978 up to 1982, i.e., from the 2nd to the 6th volume, it published four issues in each volume. From the 7th volume (1983) to the 11th

**Table 6**
The most productive and influential institutions in CCE.

| R | University | Country | TC | TP | H | C/P | >50 | >10 | ARWU | QS |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Carnegie Mellon U | USA | 17,113 | 384 | 68 | 44.57 | 42 | 104 | 91 | 47 |
| 2 | Imperial College London | UK | 7320 | 272 | 44 | 26.91 | 14 | 37 | 24 | 8 |
| 3 | Purdue U | USA | 6461 | 154 | 37 | 41.95 | 8 | 23 | 70 | 105 |
| 4 | Technical U Denmark | Denmark | 2675 | 125 | 28 | 21.40 | 4 | 12 | 151–200 | 116 |
| 5 | Norwegian U Sci Tech | Norway | 1907 | 113 | 24 | 16.88 | 2 | 7 | 101–150 | 259 |
| 6 | Texas A&M U College Station | USA | 1296 | 99 | 22 | 13.09 | 0 | 4 | 151–200 | 195 |
| 7 | RWTH Aachen U | Germany | 1854 | 93 | 24 | 19.94 | 2 | 7 | 201–300 | 141 |
| 8 | U Manchester | UK | 1994 | 91 | 23 | 21.91 | 6 | 10 | 34 | 34 |
| 9 | U College London | UK | 1384 | 91 | 20 | 15.21 | 1 | 5 | 17 | 7 |
| 10 | U Toulouse | France | 824 | 88 | 15 | 9.36 | 0 | 1 | 201–300 | 751–800 |
| 11 | U Fed Toulouse Midi Pyrenees | France | 809 | 87 | 15 | 9.30 | 0 | 1 | – | – |
| 12 | Princeton U | USA | 4709 | 86 | 37 | 54.76 | 16 | 33 | 6 | 13 |
| 13 | MIT | USA | 2487 | 85 | 31 | 29.26 | 4 | 15 | 4 | 1 |
| 14 | ETH Zurich | Switzerland | 2593 | 84 | 26 | 30.87 | 1 | 9 | 19 | 10 |
| 15 | Inst National Polytech Toulouse | France | 796 | 84 | 15 | 9.48 | 0 | 1 | – | – |
| 16 | U Wisconsin Madison | USA | 2129 | 83 | 25 | 25.65 | 5 | 8 | 28 | 55 |
| 17 | Polytechnic U Catalonia | Spain | 1431 | 82 | 23 | 17.45 | 1 | 4 | – | 275 |
| 18 | U Texas Austin | USA | 2900 | 81 | 26 | 35.80 | 9 | 11 | 40 | 67 |
| 19 | National U Singapore | Singapore | 1569 | 81 | 24 | 19.37 | 1 | 4 | 85 | 15 |
| 20 | Dortmund U Technology | Germany | 1402 | 80 | 19 | 17.53 | 1 | 6 | – | 601–650 |
| 21 | Polytechnic U Milan | Italy | 1279 | 80 | 18 | 15.99 | 2 | 3 | 201–300 | 170 |
| 22 | U Estadual de Campinas | Brazil | 1066 | 75 | 18 | 14.21 | 1 | 3 | 301–400 | 182 |
| 23 | National U the South | Argentina | 1003 | 70 | 18 | 14.33 | 0 | 3 | – | – |
| 24 | National U the Littoral | Argentina | 1995 | 68 | 22 | 29.34 | 3 | 10 | – | – |
| 25 | McMaster U | Canada | 1291 | 68 | 18 | 18.99 | 3 | 9 | 86 | 140 |
| 26 | U Alberta | Canada | 1325 | 65 | 18 | 20.38 | 2 | 6 | 101–150 | 90 |
| 27 | Tsinghua U | China | 939 | 65 | 18 | 14.45 | 0 | 3 | 45 | 25 |
| 28 | U Pannonia | Hungary | 857 | 62 | 14 | 13.82 | 2 | 4 | – | – |
| 29 | U Leeds | UK | 722 | 59 | 14 | 12.24 | 0 | 4 | 101–150 | 101 |
| 30 | U Sydney | Australia | 749 | 55 | 16 | 13.62 | 0 | 2 | 68 | 50 |
| 31 | U Toulouse III Paul Sabatier | France | 576 | 54 | 14 | 10.67 | 0 | 0 | 201–300 | 501–550 |
| 32 | Northwestern U | USA | 1730 | 53 | 25 | 32.64 | 2 | 11 | 25 | 28 |
| 33 | Rutgers State U New Brunswick | USA | 971 | 53 | 16 | 18.32 | 2 | 3 | 101–150 | 283 |
| 34 | U Federal Do Rio de Janeiro | Brazil | 715 | 53 | 16 | 13.49 | 0 | 2 | 301–400 | 311 |
| 35 | U Maribor | Slovenia | 1072 | 51 | 20 | 21.02 | 0 | 7 | – | 801–1000 |
| 36 | Georgia Institute of Technology | USA | 872 | 50 | 15 | 17.44 | 1 | 2 | 79 | 70 |
| 37 | U Edinburgh | UK | 524 | 49 | 14 | 10.69 | 0 | 0 | 32 | 23 |
| 38 | Seoul National U | South Korea | 411 | 49 | 11 | 8.39 | 0 | 0 | 101–150 | 36 |
| 39 | U Illinois Urbana Champaign | USA | 1699 | 47 | 18 | 36.15 | 3 | 6 | 41 | 69 |
| 40 | Delft U Technology | Netherlands | 692 | 46 | 15 | 15.04 | 0 | 4 | 151–200 | 54 |
| 41 | Abo Akademi U | Finland | 908 | 45 | 18 | 20.18 | 0 | 4 | – | 551–600 |
| 42 | U Porto | Portugal | 797 | 44 | 16 | 18.11 | 1 | 3 | 301–400 | 301 |
| 43 | U Lisboa | Portugal | 709 | 44 | 16 | 16.11 | 0 | 3 | 151–200 | 305 |
| 44 | U California Los Angeles | USA | 1102 | 43 | 18 | 25.63 | 2 | 4 | 11 | 33 |
| 45 | Ecole Polytech Fed Lausanne | France | 1206 | 41 | 17 | 29.41 | 3 | 6 | 401–500 | 12 |
| 46 | Otto Von Guericke U | Germany | 477 | 41 | 12 | 11.63 | 0 | 2 | – | – |
| 47 | Newcastle U | UK | 1190 | 40 | 21 | 29.75 | 1 | 10 | 201–300 | 161 |
| 48 | U Waterloo | Canada | 732 | 40 | 14 | 18.30 | 1 | 1 | 151–200 | 152 |
| 49 | Zhejiang U | China | 495 | 40 | 12 | 12.38 | 0 | 1 | 67 | 87 |
| 50 | Budapest U Tech Econ | Hungary | 422 | 40 | 13 | 10.55 | 0 | 2 | – | 751–800 |

Abbreviations are available in previous tables except for: ARWU and QS = Academic Ranking of World Universities and QS University Ranking.

**Table 7**
Other productive and influential institutions in CCE.

| R | Institution | Country | TC | TP | H | TC/TP | >100 | >50 |
|---|---|---|---|---|---|---|---|---|
| 1 | CONICET | Argentina | 3166 | 161 | 28 | 19.66 | 3 | 13 |
| 2 | CNRS | France | 1471 | 148 | 21 | 9.94 | 0 | 2 |
| 3 | CSIR India | India | 877 | 56 | 18 | 15.66 | 0 | 4 |
| 4 | CNRS Inst Engineering Systems Sciences | France | 712 | 56 | 16 | 12.71 | 0 | 1 |
| 5 | United States Department of Energy | USA | 1079 | 54 | 19 | 19.98 | 2 | 4 |
| 6 | Max Planck Society | Germany | 482 | 44 | 10 | 10.95 | 0 | 3 |
| 7 | Dow Chemical Company | USA | 1215 | 41 | 16 | 29.63 | 4 | 6 |
| 8 | ABB | Switzerland | 1474 | 30 | 17 | 49.13 | 3 | 8 |

volume (1987), it published six issues per year. From the 12th volume (1988) to the 27th volume (2003) the journal published 12 issues per year. From 2004 to 2006 the journal published two volumes in each year and all of those volumes had 12 issues. Next five years, i.e., from 2007 to 2011, it again released one 12 issued volume in each year. From 2012 to 2018, it published twelve volumes per year. “Steady-state cascade simulation in multiple effect evaporation” authored by G. Stewart (Heriot-Watt University), and G.S.G. Beveridge (University of Strathclyde), was the very first research article published in this journal. The first review article entitled “Analysis of a complex plant-steady state and transient behavior” written by V. Hlaváček from the Institute of Chemical

**Table 8**
The most productive institutions in CCE: Temporal evolution.

| R | Institution | TC | TP | R | Institution | TC | TP |
|---|---|---|---|---|---|---|---|
| | 1977–1988 | | | | 1999–2008 | | |
| 1 | Carnegie Mellon U | 2718 | 46 | 1 | Carnegie Mellon U | 5582 | 101 |
| 2 | U Wisconsin Madison | 602 | 23 | 2 | Imperial College London | 2123 | 59 |
| 3 | Washington U St Louis | 220 | 17 | 3 | Purdue U | 4173 | 52 |
| | 1989–1998 | | | 4 | CONICET | 1649 | 43 |
| 1 | Imperial College London | 3947 | 135 | 5 | U Estadual Campinas | 572 | 42 |
| 2 | Carnegie Mellon U | 6277 | 108 | 6 | CNRS | 569 | 41 |
| 3 | CNRS | 519 | 65 | 7 | U College London | 783 | 37 |
| 4 | Purdue U | 1620 | 54 | 8 | RWTH Aachen U | 941 | 33 |
| 5 | Norwegian U Sci Tech | 562 | 43 | 9 | National U Singapore | 984 | 31 |
| 6 | ETH Zurich | 797 | 40 | 10 | CNRS Inst Eng Syst Sci INSIS | 481 | 31 |
| 7 | U Fed Toulouse Midi Pyrenees | 278 | 40 | 11 | U Manchester | 540 | 30 |
| 8 | U Toulouse | 278 | 40 | | 2009–2018 | | |
| 9 | Inst National Polytech Toulouse | 271 | 38 | 1 | Carnegie Mellon U | 2624 | 129 |
| 10 | CONICET | 397 | 37 | 2 | CONICET | 931 | 69 |
| 11 | MIT | 1585 | 36 | 3 | Imperial College London | 1006 | 67 |
| 12 | U Manchester | 1217 | 35 | 4 | Texas A&M U College Station | 887 | 67 |
| 13 | U Sydney | 429 | 35 | 5 | Technical U Denmark | 1227 | 60 |
| 14 | Technical U Denmark | 409 | 35 | 6 | National U Singapore | 565 | 44 |
| 15 | Princeton U | 2420 | 34 | 7 | U Alberta | 684 | 43 |
| 16 | Norwegian U Sci Tech | 430 | 31 | 8 | Polytechnic U Milan | 647 | 42 |
| 17 | U Texas Austin | 1497 | 30 | 9 | RWTH Aachen U | 601 | 42 |
| 18 | Polytechnic U Catalonia | 380 | 28 | 10 | Norwegian U Science Tech | 494 | 42 |
| 19 | U Edinburgh | 359 | 27 | 11 | U Wisconsin Madison | 808 | 38 |
| 20 | Dortmund U Technology | 237 | 26 | 12 | McMaster U | 541 | 38 |
| 21 | U Estadual Campinas | 242 | 23 | 13 | Tsinghua U | 511 | 38 |
| 22 | Polytechnic U Milan | 334 | 22 | 14 | Purdue U | 518 | 37 |
| 23 | National U the South | 192 | 22 | 15 | National U the Littoral | 666 | 36 |
| 24 | U Maryland College Park | 1743 | 21 | 16 | USA Department of Energy | 643 | 36 |
| 25 | U Maribor | 420 | 20 | 17 | CNRS | 339 | 36 |
| 26 | Abo Akademi U | 417 | 20 | 18 | U College London | 417 | 34 |
| 27 | U Stuttgart | 361 | 20 | 19 | U Lisboa | 492 | 33 |
| 28 | U Pannonia | 207 | 20 | 20 | Ecole Polytech Fed Lausanne | 656 | 32 |
| 29 | U College London | 198 | 20 | 21 | Rutgers State U New Brunswick | 469 | 32 |
| | | | | 22 | Princeton U | 808 | 30 |
| | | | | 23 | Polytechnic U Catalonia | 516 | 30 |

Abbreviations are available in previous tables. Note that for the period of 1977–1988, the table only shows those universities with at least fifteen papers. For the period 1989–1998, the table shows those universities with at least twenty papers and for the last periods of 1999–2008 and 2009–2018, only those with at least thirty papers are listed.

Technology was published in the first issue of volume one. Next sub-section analyzes year wise publication and citation structure of CCE.

### 3.1. Publication and citation structure of CCE

According to the WoS Core Collection search engine, from 1977 to 2018, CCE has published a total of 7226 documents. The search engine also discloses that the publications of the journal have received a total of 144,011 citations up to 31st December 2018. Fig. 1 presents the number of papers published annually in the journal since 1977.

The publication pattern of CCE is increasing during the first two decades. Fig. 1 displays that annual number of publications increased remarkably in the period of 1996 to 2000. Annual number of publications drops sharply in 2001 compared to its previous year and that pattern continued up to 2003. Annual number of publications improves in the next two years but it falls again in 2006 and 2007. After the year 2010, annual numbers of publications in CCE are consistently higher than two hundred. It shows the largest number of published papers in the year 1996 with 385 publications followed by the year 2000. WoS database confirms that 7226 documents of CCE have a total of 144,011 citations. To assess the citation pattern of the journal, collected data are summarized and organized in an year-wise pattern and is presented in Table 2. Table 2 demonstrates citation related information of the publications of CCE for several categories including TP, TC, and citation thresholds including more than one, five, ten, twenty, fifty, one hundred and two hundred citations.

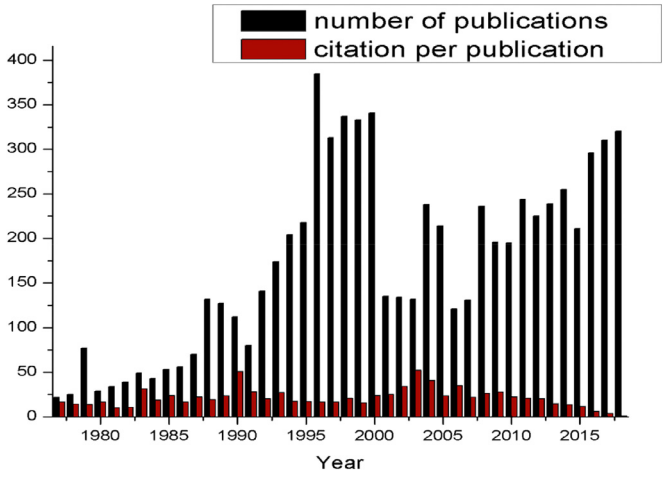


**Fig. 1.** Annual number of publications vs citation per publication published in CCE.

CCE published a total of 427 papers, 42.7 papers per year on average, during its first ten years. Thirteen papers among those 427 papers have more than one hundred citations. Note that, the number of publications in the year 1979 is 77, which is more than three times of the number of publications in the previous year. The journal published 1643, 2298, and 2228 articles in the second, third, and fourth decade respectively. The journal published

**Table 9**
The most productive and influential countries in CCE.

| R | Country | TC | TP | H | C/P | >50 | >10 | Population | TC/Pop | TP/Pop |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | USA | 69,148 | 2352 | 112 | 29.40 | 129 | 337 | 328,128,000 | 21.07 | 0.72 |
| 2 | UK | 16,677 | 819 | 61 | 20.36 | 27 | 78 | 66,040,229 | 25.25 | 1.24 |
| 3 | Germany | 9019 | 500 | 45 | 18.04 | 9 | 36 | 82,793,800 | 10.89 | 0.60 |
| 4 | China | 6173 | 437 | 37 | 14.13 | 4 | 19 | 1418,607,488 | 0.44 | 0.03 |
| 5 | Canada | 6029 | 345 | 37 | 17.48 | 8 | 26 | 37,275,900 | 16.17 | 0.93 |
| 6 | France | 3140 | 275 | 30 | 11.42 | 0 | 10 | 67,348,000 | 4.66 | 0.41 |
| 7 | Spain | 4062 | 237 | 32 | 17.14 | 5 | 14 | 46,659,302 | 8.71 | 0.51 |
| 8 | Argentina | 4108 | 236 | 31 | 17.41 | 3 | 17 | 44,494,502 | 9.23 | 0.53 |
| 9 | Brazil | 3531 | 215 | 32 | 16.42 | 4 | 12 | 209,811,000 | 1.68 | 0.10 |
| 10 | Italy | 2747 | 191 | 27 | 14.38 | 4 | 7 | 60,404,843 | 4.55 | 0.32 |
| 11 | India | 3237 | 188 | 32 | 17.22 | 3 | 15 | 1339,200,000 | 0.24 | 0.01 |
| 12 | Japan | 3329 | 175 | 27 | 19.02 | 6 | 14 | 126,440,000 | 2.63 | 0.14 |
| 13 | Australia | 2215 | 168 | 24 | 13.18 | 1 | 5 | 25,115,200 | 8.82 | 0.67 |
| 14 | South Korea | 2160 | 165 | 23 | 13.09 | 3 | 5 | 51,635,256 | 4.18 | 0.32 |
| 15 | Denmark | 3018 | 155 | 30 | 19.47 | 4 | 14 | 5789,957 | 52.12 | 2.68 |
| 16 | Norway | 2675 | 155 | 26 | 17.26 | 3 | 10 | 5312,343 | 50.35 | 2.92 |
| 17 | Netherlands | 2311 | 147 | 24 | 15.72 | 3 | 13 | 17,268,800 | 13.38 | 0.85 |
| 18 | Switzerland | 3910 | 139 | 32 | 28.13 | 4 | 14 | 8508,904 | 45.95 | 1.63 |
| 19 | Hungary | 1537 | 136 | 19 | 11.30 | 2 | 6 | 9771,000 | 15.73 | 1.39 |
| 20 | Portugal | 2444 | 131 | 27 | 18.66 | 3 | 12 | 10,291,027 | 23.75 | 1.27 |
| 21 | Finland | 1701 | 122 | 23 | 13.94 | 0 | 6 | 5520,535 | 30.81 | 2.21 |
| 22 | Mexico | 1974 | 121 | 24 | 16.31 | 1 | 7 | 119,938,473 | 1.65 | 0.10 |
| 23 | Belgium | 1988 | 116 | 24 | 17.14 | 2 | 12 | 11,428,164 | 17.40 | 1.02 |
| 24 | Singapore | 1830 | 95 | 26 | 19.26 | 1 | 5 | 5638,700 | 32.45 | 1.68 |
| 25 | Greece | 1629 | 89 | 24 | 18.30 | 0 | 8 | 10,768,193 | 15.13 | 0.83 |
| 26 | Iran | 856 | 80 | 16 | 10.70 | 0 | 1 | 81,931,500 | 1.04 | 0.10 |
| 27 | South Africa | 745 | 71 | 14 | 10.49 | 1 | 2 | 57,725,600 | 1.29 | 0.12 |
| 28 | Slovenia | 1301 | 69 | 22 | 18.86 | 0 | 7 | 2070,050 | 62.85 | 3.33 |
| 29 | Israel | 779 | 55 | 17 | 14.16 | 1 | 2 | 8942,420 | 8.71 | 0.62 |
| 30 | Sweden | 846 | 54 | 15 | 15.67 | 0 | 5 | 10,196,177 | 8.30 | 0.53 |
| 31 | Turkey | 603 | 50 | 16 | 12.06 | 0 | 1 | 80,810,525 | 0.75 | 0.06 |
| 32 | Poland | 438 | 48 | 14 | 9.13 | 0 | 0 | 38,433,600 | 1.14 | 0.12 |
| 33 | Czech Republic | 407 | 47 | 11 | 8.66 | 0 | 1 | 10,625,449 | 3.83 | 0.44 |
| 34 | Malaysia | 877 | 44 | 18 | 19.93 | 0 | 4 | 32,524,300 | 2.70 | 0.14 |
| 35 | Romania | 796 | 44 | 15 | 18.09 | 1 | 5 | 19,524,000 | 4.08 | 0.23 |
| 36 | Austria | 656 | 43 | 12 | 15.26 | 1 | 2 | 8857,960 | 7.41 | 0.49 |
| 37 | Chile | 400 | 37 | 13 | 10.81 | 0 | 0 | 17,574,003 | 2.28 | 0.21 |
| 38 | Saudi Arabia | 370 | 37 | 10 | 10.00 | 0 | 1 | 33,413,660 | 1.11 | 0.11 |
| 39 | Russia | 219 | 30 | 9 | 7.30 | 0 | 0 | 146,877,088 | 0.15 | 0.02 |
| 40 | Thailand | 197 | 21 | 7 | 9.38 | 0 | 1 | 69,183,173 | 0.28 | 0.03 |
| 41 | Bulgaria | 259 | 19 | 8 | 13.63 | 0 | 1 | 7050,034 | 3.67 | 0.27 |
| 42 | Colombia | 176 | 19 | 6 | 9.26 | 0 | 1 | 50,025,000 | 0.35 | 0.04 |
| 43 | Serbia | 126 | 16 | 6 | 7.88 | 0 | 1 | 7001,444 | 1.80 | 0.23 |
| 44 | Kuwait | 135 | 14 | 7 | 9.64 | 0 | 0 | 4226,920 | 3.19 | 0.33 |
| 45 | Slovakia | 97 | 14 | 6 | 6.93 | 0 | 0 | 5443,120 | 1.78 | 0.26 |
| 46 | Egypt | 144 | 13 | 7 | 11.08 | 0 | 0 | 97,847,700 | 0.15 | 0.01 |
| 47 | Qatar | 82 | 11 | 6 | 7.45 | 0 | 0 | 2717,886 | 3.02 | 0.40 |
| 48 | Venezuela | 71 | 10 | 5 | 7.10 | 0 | 0 | 31,828,110 | 0.22 | 0.03 |
| 49 | Philippines | 213 | 8 | 6 | 26.63 | 0 | 2 | 106,719,000 | 0.20 | 0.01 |
| 50 | Ireland | 79 | 8 | 6 | 9.88 | 0 | 0 | 4857,000 | 1.63 | 0.16 |

Abbreviations are available in previous tables except for: TP/Pop and TC/Pop = Total papers and citations per 100 thousand of inhabitants.

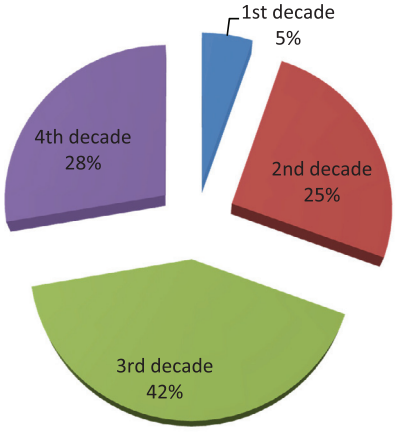


**Fig. 2.** Citation distribution of CCE publications over the four decades.

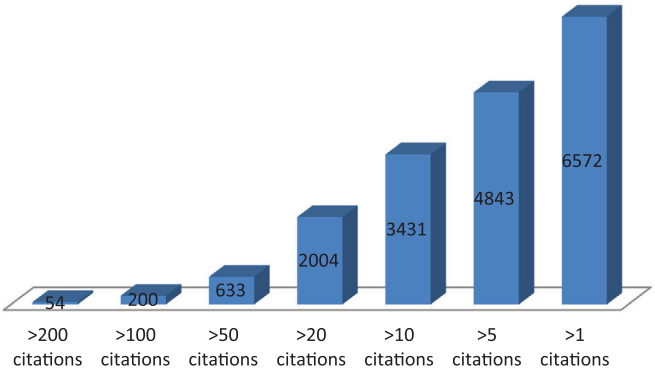


**Fig. 3.** Number of publications above the seven citation thresholds.

**Table 10**
Countries with the highest number of papers: Annual evolution.

| R | COUNTRY | Pre 99 | 1999 | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | USA | 978 | 66 | 121 | 30 | 53 | 56 | 85 | 79 | 43 | 25 | 73 | 54 | 69 | 63 | 54 | 73 | 91 | 66 | 73 | 98 | 102 | 2352 |
| 2 | UK | 359 | 63 | 32 | 16 | 16 | 7 | 19 | 20 | 9 | 17 | 11 | 22 | 16 | 26 | 18 | 25 | 26 | 20 | 39 | 31 | 27 | 819 |
| 3 | Germany | 159 | 20 | 17 | 13 | 2 | 7 | 16 | 20 | 11 | 12 | 24 | 21 | 11 | 23 | 12 | 16 | 17 | 22 | 26 | 29 | 22 | 500 |
| 4 | China | 41 | 6 | 33 | 4 | 5 | 11 | 18 | 10 | 12 | 12 | 19 | 19 | 12 | 19 | 14 | 27 | 28 | 20 | 36 | 38 | 53 | 437 |
| 5 | Canada | 61 | 13 | 10 | 6 | 5 | 8 | 17 | 11 | 12 | 5 | 21 | 12 | 12 | 11 | 15 | 17 | 19 | 8 | 29 | 23 | 30 | 345 |
| 6 | France | 138 | 16 | 6 | 8 | 1 | 5 | 5 | 5 | 6 | 6 | 8 | 8 | 3 | 8 | 9 | 8 | 9 | 6 | 7 | 7 | 6 | 275 |
| 7 | Spain | 47 | 8 | 5 | 7 | 7 | 0 | 6 | 4 | 4 | 12 | 12 | 6 | 11 | 12 | 18 | 10 | 16 | 10 | 14 | 14 | 14 | 237 |
| 8 | Argentina | 78 | 12 | 14 | 6 | 4 | 6 | 8 | 5 | 1 | 4 | 6 | 9 | 6 | 11 | 10 | 13 | 12 | 8 | 9 | 8 | 6 | 236 |
| 9 | Brazil | 44 | 16 | 24 | 8 | 4 | 9 | 7 | 12 | 0 | 4 | 4 | 4 | 6 | 5 | 12 | 11 | 7 | 6 | 11 | 8 | 13 | 215 |
| 10 | Italy | 76 | 4 | 4 | 6 | 3 | 4 | 5 | 1 | 1 | 2 | 4 | 7 | 4 | 13 | 7 | 9 | 9 | 6 | 12 | 7 | 7 | 191 |
| 11 | India | 34 | 4 | 8 | 2 | 2 | 5 | 10 | 10 | 10 | 5 | 6 | 7 | 8 | 9 | 6 | 10 | 5 | 6 | 13 | 15 | 13 | 188 |
| 12 | Japan | 71 | 12 | 26 | 6 | 4 | 2 | 11 | 3 | 1 | 3 | 4 | 1 | 4 | 2 | 1 | 6 | 3 | 3 | 2 | 4 | 6 | 175 |
| 13 | Australia | 78 | 9 | 11 | 6 | 2 | 2 | 2 | 4 | 0 | 7 | 6 | 1 | 2 | 2 | 6 | 4 | 6 | 2 | 6 | 8 | 4 | 168 |
| 14 | South Korea | 40 | 12 | 24 | 3 | 3 | 2 | 4 | 2 | 0 | 1 | 2 | 0 | 3 | 2 | 8 | 5 | 6 | 10 | 12 | 10 | 16 | 165 |
| 15 | Denmark | 54 | 8 | 6 | 3 | 4 | 1 | 5 | 3 | 0 | 1 | 2 | 5 | 9 | 3 | 7 | 12 | 5 | 9 | 5 | 7 | 6 | 155 |
| 16 | Norway | 73 | 7 | 2 | 1 | 1 | 1 | 9 | 2 | 1 | 2 | 5 | 5 | 6 | 0 | 4 | 6 | 5 | 3 | 6 | 5 | 11 | 155 |
| 17 | Netherlands | 50 | 14 | 9 | 5 | 3 | 4 | 6 | 0 | 1 | 2 | 6 | 9 | 4 | 4 | 4 | 2 | 8 | 1 | 6 | 7 | 2 | 147 |
| 18 | Switzerland | 61 | 5 | 1 | 1 | 1 | 2 | 1 | 1 | 1 | 0 | 6 | 5 | 2 | 2 | 1 | 5 | 10 | 8 | 11 | 9 | 6 | 139 |
| 19 | Hungary | 62 | 22 | 7 | 4 | 3 | 0 | 3 | 6 | 0 | 0 | 2 | 5 | 7 | 3 | 0 | 4 | 0 | 4 | 1 | 3 | 0 | 136 |
| 20 | Portugal | 33 | 3 | 6 | 4 | 5 | 0 | 7 | 8 | 1 | 2 | 3 | 6 | 2 | 7 | 7 | 5 | 8 | 3 | 9 | 6 | 6 | 131 |
| 21 | Finland | 52 | 13 | 4 | 4 | 3 | 1 | 3 | 4 | 3 | 2 | 5 | 3 | 3 | 6 | 0 | 3 | 3 | 2 | 3 | 1 | 4 | 122 |
| 22 | Mexico | 13 | 5 | 3 | 0 | 4 | 3 | 5 | 5 | 1 | 5 | 7 | 5 | 5 | 9 | 7 | 3 | 9 | 8 | 10 | 9 | 5 | 121 |
| 23 | Belgium | 43 | 2 | 2 | 2 | 1 | 2 | 3 | 5 | 1 | 5 | 5 | 2 | 3 | 4 | 7 | 3 | 8 | 3 | 7 | 4 | 4 | 116 |
| 24 | Singapore | 6 | 2 | 2 | 3 | 4 | 5 | 4 | 2 | 2 | 4 | 6 | 6 | 3 | 10 | 4 | 6 | 5 | 2 | 4 | 6 | 9 | 95 |
| 25 | Greece | 34 | 2 | 1 | 1 | 3 | 1 | 3 | 1 | 2 | 1 | 1 | 3 | 3 | 7 | 3 | 5 | 3 | 2 | 5 | 1 | 7 | 89 |
| 26 | Iran | 3 | 1 | 1 | 1 | 0 | 0 | 0 | 3 | 2 | 1 | 7 | 4 | 2 | 5 | 5 | 3 | 5 | 4 | 5 | 18 | 10 | 80 |
| 27 | South Africa | 20 | 2 | 6 | 1 | 1 | 0 | 5 | 3 | 1 | 2 | 3 | 3 | 3 | 2 | 3 | 2 | 2 | 3 | 4 | 4 | 1 | 71 |
| 28 | Slovenia | 31 | 5 | 4 | 3 | 2 | 0 | 4 | 2 | 0 | 3 | 4 | 0 | 1 | 2 | 1 | 0 | 1 | 3 | 0 | 3 | 0 | 69 |
| 29 | Israel | 33 | 4 | 4 | 0 | 4 | 2 | 1 | 0 | 1 | 0 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 55 |
| 30 | Sweden | 21 | 2 | 1 | 0 | 1 | 3 | 1 | 2 | 2 | 1 | 1 | 1 | 1 | 0 | 2 | 4 | 1 | 3 | 3 | 1 | 3 | 54 |
| 31 | Turkey | 17 | 3 | 0 | 2 | 2 | 3 | 4 | 3 | 4 | 1 | 2 | 0 | 0 | 0 | 0 | 1 | 2 | 3 | 2 | 1 | 0 | 50 |
| 32 | Poland | 27 | 3 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 6 | 2 | 1 | 0 | 2 | 0 | 2 | 0 | 48 |
| 33 | Czech Republic | 31 | 2 | 0 | 2 | 1 | 0 | 0 | 2 | 2 | 0 | 1 | 0 | 1 | 2 | 2 | 0 | 0 | 0 | 0 | 1 | 0 | 47 |
| 34 | Malaysia | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 4 | 0 | 2 | 3 | 0 | 2 | 2 | 7 | 5 | 1 | 6 | 3 | 3 | 2 | 44 |
| 35 | Romania | 11 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 1 | 9 | 1 | 4 | 2 | 4 | 0 | 3 | 2 | 2 | 1 | 44 |
| 36 | Austria | 18 | 4 | 2 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 2 | 0 | 0 | 1 | 0 | 2 | 4 | 1 | 3 | 43 |
| 37 | Chile | 4 | 2 | 2 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 3 | 1 | 1 | 2 | 3 | 1 | 4 | 2 | 4 | 2 | 1 | 37 |
| 38 | Saudi Arabia | 10 | 0 | 1 | 0 | 0 | 2 | 1 | 1 | 0 | 0 | 0 | 1 | 0 | 2 | 4 | 3 | 2 | 2 | 2 | 3 | 3 | 37 |
| 39 | Russia | 18 | 4 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 3 | 0 | 1 | 0 | 1 | 30 |
| 40 | Thailand | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 3 | 0 | 1 | 1 | 0 | 0 | 2 | 1 | 2 | 1 | 1 | 2 | 3 | 4 | 21 |

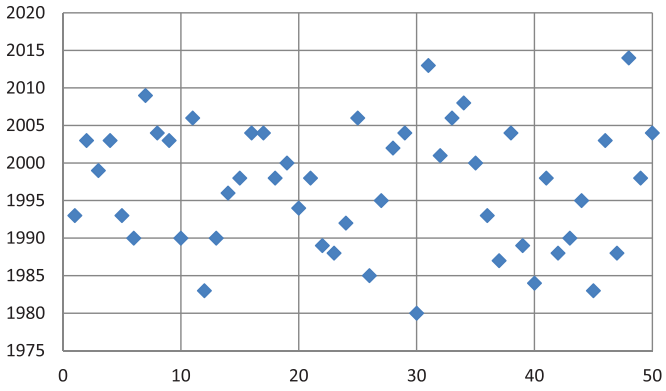


**Fig. 4.** Temporal visualization of the 50 most cited documents in CCE.

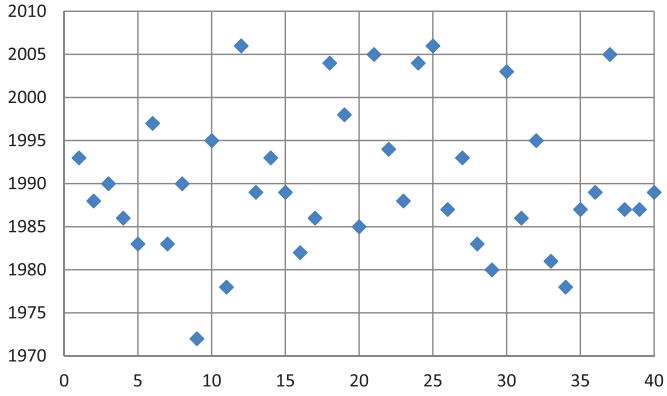


**Fig. 5.** Time-based visualization of the most cited documents in CCE.

310 and 320 articles in 2017 and 2018 respectively. The journal got a total of 7522, 36,156, 59,397, and 39,573 total citations from the publications in the first, second, third, and fourth decade respectively. Fig. 2 presents pie diagram of distribution of citations over the four decades.

Publications during the third decade that is from 1997 to 2006 received the highest number of citations, which makes more than 40 percent of the total citations of CCE. Publications received an average of 17.62, 22.01, 25.85, and 17.76 citations per paper published during the first, second, third, and fourth decade. The 238 papers published in the year 2004 got 9704 citations and it is the highest citation receiving publication year for CCE. Note that, six papers of 2004 have more than 250 citations and these six papers are also listed in the fifty most influential documents of CCE. Numbers of citations in the most recent years are low due to limited time for their accumulation. Fig. 3 presents graphical representation of the number of articles with citations above several specified thresholds.

Around nine percent of articles have not yet received any citation up to 31st December 2018. Note that, the last year (i.e. 2018) has 200 documents out of the total of 654 documents which have not been cited yet. If we exclude the publications of the last two

**Table 11**
The most productive and influential super-regions in CCE.

| R | Region | TC | TP | H | TC/TP | >100 | >50 |
|---|---|---|---|---|---|---|---|
| 1 | North America | 75,691 | 2751 | 113 | 27.51 | 134 | 363 |
| 2 | Europe | 53,670 | 3175 | 85 | 16.90 | 60 | 225 |
| 3 | Asia | 20,651 | 1377 | 57 | 15.00 | 18 | 71 |
| 4 | Central and South America | 8261 | 516 | 41 | 16.01 | 7 | 30 |
| 5 | Middle East | 2983 | 268 | 29 | 11.13 | 1 | 6 |
| 6 | Oceania | 2253 | 172 | 24 | 13.10 | 1 | 5 |
| 7 | Africa | 1062 | 97 | 17 | 10.95 | 1 | 3 |

Abbreviations are available in previous tables.

**Table 12**
Citing articles of CCE: Authors, universities, countries and journals.

| R | Author | TP | University | TP | Country | TP | Journal | TP |
|---|---|---|---|---|---|---|---|---|
| 1 | Grossmann, IE | 512 | CNRS | 1284 | USA | 13,703 | Computers Chemical Engineering | 4915 |
| 2 | Floudas, CA | 288 | Carnegie Mellon U | 1125 | China | 13,122 | Industrial Engineering Chemistry Res | 4274 |
| 3 | Pistikopoulos, EN | 287 | Imperial College London | 1075 | UK | 5124 | Computer Aided Chemical Engineering | 2538 |
| 4 | Biegler, LT | 282 | Zhejiang U | 1044 | Germany | 4061 | Chemical Engineering Science | 1939 |
| 5 | Gani, R | 269 | Tsinghua U | 727 | Canada | 3116 | Aiche Journal | 1724 |
| 6 | Marquardt, W | 247 | CONICET | 694 | India | 2699 | J Process Control | 1081 |
| 7 | Zhang, J | 233 | Technical U Denmark | 660 | France | 2641 | Chemical Engineering Research Design | 962 |
| 8 | Engell, S | 195 | Purdue U | 629 | Iran | 2480 | Proc American Control Conf | 671 |
| 9 | You, FQ | 187 | Texas AM U College Station | 628 | Spain | 2265 | Energy | 660 |
| 10 | Zhang, Y | 186 | Chinese Acad Sci | 612 | Italy | 2094 | Ifac Papersonline | 602 |
| 11 | El-Halwagi, MM | 185 | USA Department of Energy | 603 | Brazil | 2043 | Applied Thermal Engineering | 517 |
| 12 | Christofides, PD | 181 | Northeastern U China | 591 | South Korea | 1646 | J Cleaner Production | 512 |
| 13 | Puigjaner, L | 181 | U Manchester | 587 | Australia | 1479 | Applied Energy | 486 |
| 14 | Marechal, F | 176 | National U Singapore | 577 | Netherlands | 1346 | Chemical Engineering Journal | 484 |
| 15 | Wang, Y | 176 | Norwegian U Sci Tech | 565 | Japan | 1269 | Chemical Engineering Transactions | 484 |
| 16 | Liu, Y | 172 | MIT | 555 | Mexico | 1265 | Chemical Engineering and Processing | 428 |
| 17 | Kravanja, Z | 164 | U Alberta | 549 | Switzerland | 1108 | Chinese J Chemical Engineering | 408 |
| 18 | Ponce-Ortega, JM | 160 | Polytechnic U Milan | 541 | Malaysia | 1095 | Canadian J Chemical Engineering | 390 |
| 19 | Wozny, G | 156 | ETH Zurich | 522 | Portugal | 1026 | Control Engineering Practice | 358 |
| 20 | Shah, N | 153 | China U Petroleum | 500 | Argentina | 977 | Chemical Engineering Technology | 347 |
| 21 | Segovia-Hernandez, JG | 152 | U Toulouse | 485 | Poland | 976 | Chemometrics and Intelligent Laboratory Systems | 346 |
| 22 | Barton, PI | 151 | U College London | 482 | Singapore | 947 | IEEE Conf Decision and Control | 342 |
| 23 | Skogestad, S | 148 | Delft U Technology | 481 | Belgium | 926 | Powder Technology | 327 |
| 24 | Li, J | 147 | RWTH Aachen U | 480 | Denmark | 896 | Lecture Notes in Computer Science | 316 |
| 25 | Braatz, RD | 141 | East China U Sci Tech | 469 | Norway | 839 | Fluid Phase Equilibria | 307 |
| 26 | Huang, B | 141 | Shanghai Jiao Tong U | 462 | Turkey | 815 | Int J Production Research | 298 |
| 27 | Song, ZH | 141 | Dortmund U Technology | 429 | Finland | 789 | Chemical Engineering Communications | 296 |
| 28 | Espuna, A | 139 | U Fed Toulouse Midi Pyrenees | 425 | Sweden | 756 | European J Operational Research | 282 |
| 29 | Lee, JH | 135 | CSIR India | 407 | Greece | 718 | Int J Hydrogen Energy | 276 |
| 30 | Li, Y | 133 | Princeton U | 406 | Hungary | 657 | ISA Transactions | 256 |
| 31 | Li, P | 131 | Islamic Azad U | 402 | Romania | 564 | J Chemical Engineering of Japan | 249 |
| 32 | Wang, L | 131 | U Waterloo | 396 | South Africa | 531 | Chinese Control Conference | 248 |
| 33 | Reklaitis, GV | 130 | CNRS Inst Eng Syst Sci | 388 | Saudi Arabia | 496 | Korean J Chemical Engineering | 245 |
| 34 | Tan, RR | 130 | Tianjin U | 386 | Russia | 462 | Expert Systems With Applications | 237 |
| 35 | Srinivasan, R | 128 | Xi An Jiaotong U | 385 | Slovenia | 453 | Automatica | 234 |
| 36 | Papageorgiou, LG | 124 | U Estadual Campinas | 378 | Colombia | 372 | Chemie Ingenieur Technik | 233 |
| 37 | Wang, J | 124 | Indian Inst Tech Bombay | 370 | Austria | 371 | Energy Conversion And Management | 231 |
| 38 | Karimi, IA | 123 | Inst National Polytech Toulouse | 369 | Czech Republic | 370 | J Chromatography A | 224 |
| 39 | Zhang, L | 123 | U Pannonia | 366 | Chile | 360 | J Global Optimization | 214 |
| 40 | Edgar, TF | 122 | Max Planck Society | 364 | Thailand | 354 | Energy Fuels | 203 |

Abbreviations are available in previous tables.

years, then 94.5 percent documents of CCE have at least one citation. 54 publications have more than 200 citations and 200 publications more than 100 citations. More than two thirds of the documents have more than 5 citations. 3431 documents of CCE are in the i10 index club, i.e., these documents have at least ten citations. Next sub-section discusses fifty most cited papers published in the journal.

### 3.2. Influential papers in CCE

The present sub-section discusses those research papers which have received the largest number of citations. Table 3 presents fifty most cited research papers published in CCE with their respective TC, title, name of the authors, and the average citation rate per year.

The research work entitled “A Plant-Wide Industrial-Process Control Problem” jointly written by J. J. Downs, & E. F Vogel, has received the largest number of citations and tops the list in Table 3 according to the WoS data up to 2018. Downs and Vogel (1993) developed an industrial chemical process model for benchmarking process control technologies. The developed model in the leading article can be fitted for both the multivariable control and plant-wide control problems. The review article entitled “A Review of Process Fault Detection and Diagnosis Part I: Quantitative Model-Based Methods” written by V Venkatsubramanian, R Rengaswamy and K. Yin is in the second position in the

**Table 13**
Co-citation of journals in CCE: Global and temporal analysis.

| | Global | | | 2009–2018 | | | 1999–2008 | | | 1989–1998 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R | Journal | Cit | CLS | Journal | Cit | CLS | Journal | Cit | CLS | Journal | Cit | CLS |
| 1 | Comput Chem Eng | 21,490 | 14,936.81 | Comput Chem Eng | 11,118 | 8087.44 | Comput Chem Eng | 5828 | 3796.2 | Comput Chem Eng | 3986 | 2536.21 |
| 2 | Ind Eng Chem Res | 10,708 | 8678.05 | Ind Eng Chem Res | 6682 | 5446.27 | Ind Eng Chem Res | 2857 | 2257.44 | Aiche J | 2170 | 1712.6 |
| 3 | Aiche J | 10,110 | 8471.94 | Aiche J | 4501 | 3974.45 | Aiche J | 2631 | 2162.2 | Chem Eng Sci | 1533 | 1174.08 |
| 4 | Chem Eng Sci | 8003 | 6407.05 | Chem Eng Sci | 3812 | 3122.64 | Chem Eng Sci | 2192 | 1722.21 | Ind Eng Chem Res | 1167 | 945.85 |
| 5 | J Process Contr | 1919 | 1695.46 | J Process Contr | 1506 | 1309.93 | Automatica | 550 | 463.48 | Ind Eng Chem Proc Dd | 407 | 359.04 |
| 6 | Automatica | 1737 | 1493.65 | Chem Eng Res Des | 1049 | 993.13 | J Process Contr | 377 | 349.29 | Automatica | 331 | 281.55 |
| 7 | Chem Eng Res Des | 1548 | 1465.25 | Eur J Oper Res | 766 | 690.6 | IEEE T Automat Contr | 357 | 308.51 | IEEE T Automat Contr | 270 | 232.81 |
| 8 | IEEE T Automat Contr | 1129 | 995.13 | Automatica | 744 | 655.15 | Chem Eng Res Des | 310 | 295.93 | Chem Eng Prog | 257 | 241.3 |
| 9 | Math Program | 1066 | 982.77 | Comput-Aided Chem En | 663 | 624.54 | Biotechnol Bioeng | 251 | 188.57 | Ind Eng Chem Fund | 204 | 192.83 |
| 10 | Eur J Oper Res | 1015 | 913.54 | Energy | 612 | 556.7 | Can J Chem Eng | 222 | 209.55 | Chem Eng Commun | 200 | 189.17 |
| 11 | Ind Eng Chem Proc Dd | 982 | 888.44 | Chem Eng Process | 610 | 576.67 | Eur J Oper Res | 217 | 191.07 | Int J Control | 198 | 178.54 |
| 12 | Fluid Phase Equilibr | 857 | 700.24 | Math Program | 595 | 556.8 | Math Program | 210 | 194.83 | Math Program | 192 | 170.26 |
| 13 | Chem Eng Process | 769 | 729.23 | Chem Eng J | 512 | 488.87 | Int J Control | 207 | 191.55 | Can J Chem Eng | 189 | 176.95 |
| 14 | Can J Chem Eng | 724 | 686.01 | J Global Optim | 497 | 454.31 | Fluid Phase Equilibr | 205 | 177.41 | Chem Eng Res Des | 180 | 167.65 |
| 15 | Chem Eng Prog | 720 | 682.68 | Powder Technol | 478 | 369.38 | J Comput Phys | 192 | 159.41 | Biotechnol Bioeng | 155 | 87.9 |
| 16 | J Global Optim | 720 | 651.22 | Fluid Phase Equilibr | 469 | 380.56 | Ind Eng Chem Proc Dd | 187 | 178.45 | Fluid Phase Equilibr | 154 | 118.68 |
| 17 | Biotechnol Bioeng | 703 | 557.93 | Appl Therm Eng | 457 | 418.72 | Chem Eng Prog | 172 | 164.57 | Siam J Numer Anal | 145 | 127.02 |
| 18 | Comput-Aided Chem En | 674 | 634.5 | Appl Energ | 446 | 414.16 | Science | 156 | 138.86 | Chem Eng | 134 | 107.24 |
| 19 | Int J Control | 643 | 589.74 | IEEE T Automat Contr | 415 | 378.86 | J Global Optim | 154 | 135.26 | Manage Sci | 117 | 100.34 |
| 20 | Chem Eng J | 642 | 616.24 | Control Eng Pract | 406 | 380.7 | Control Eng Pract | 150 | 138.39 | Oper Res | 116 | 104.51 |
| 21 | Energy | 633 | 573.21 | Thesis | 350 | 323.23 | Chem Eng Commun | 147 | 144.16 | Chem Process Control | 105 | 100.1 |
| 22 | Powder Technol | 608 | 473.53 | Int J Hydrogen Energ | 344 | 269.78 | Manage Sci | 145 | 135.87 | J Chem Phys | 103 | 89.44 |
| 23 | Oper Res | 598 | 555.18 | J Clean Prod | 330 | 303.31 | Oper Res | 136 | 126.49 | Technometrics | 97 | 88.82 |
| 24 | Control Eng Pract | 567 | 531.1 | J Membrane Sci | 329 | 222.96 | P Natl Acad Sci Usa | 128 | 108.58 | Acm T Math Software | 94 | 85.18 |
| 25 | J Comput Phys | 566 | 495.11 | Oper Res | 319 | 299.63 | Chem Eng Process | 122 | 118.99 | Artificial Intell | 94 | 78.27 |
| 26 | Manage Sci | 555 | 514.29 | Chemometr Intell Lab | 294 | 259.9 | Ind Eng Chem Fund | 121 | 114.56 | Siam J Sci Stat Comp | 92 | 84.09 |
| 27 | Chem Eng Commun | 539 | 520.85 | J Comput Phys | 293 | 259.98 | J Membrane Sci | 120 | 75.14 | Gams Users Guide | 77 | 76 |
| 28 | Ind Eng Chem Fund | 535 | 504.09 | Biotechnol Bioeng | 288 | 253.34 | Powder Technol | 115 | 89.92 | Thesis U London | 77 | 68.27 |
| 29 | Appl Therm Eng | 486 | 446.45 | Desalination | 282 | 197.97 | J Fluid Mech | 108 | 82.92 | J Optimiz Theory App | 75 | 71.24 |
| 30 | J Membrane Sci | 471 | 318.84 | J Chromatogr A | 278 | 193.32 | J Chem Phys | 107 | 94.06 | J Phys Chem-Us | 73 | 61.31 |
| 31 | Appl Energ | 449 | 415.8 | Energ Fuel | 277 | 260.21 | Aiche S Series | 105 | 99.82 | J Electrochem Soc | 72 | 19.38 |
| 32 | Chemometr Intell Lab | 441 | 388.37 | Fuel | 277 | 249.6 | Nature | 101 | 90.35 | J Chem Eng Jpn | 71 | 64.88 |
| 33 | J Chem Phys | 428 | 370.74 | Bioresource Technol | 275 | 242.26 | Chemometr Intell Lab | 96 | 83.95 | Neural Networks | 70 | 58.22 |
| 34 | Science | 407 | 374.1 | Chem Eng Technol | 275 | 267.09 | Hydrocarb Process | 93 | 82.71 | J Global Optim | 69 | 59.38 |
| 35 | Chem Eng Technol | 396 | 379.34 | Manage Sci | 255 | 241.43 | Chem Eng J | 89 | 86.71 | Conceptual Design Ch | 65 | 64 |
| 36 | Siam J Numer Anal | 371 | 344.62 | J Power Sources | 254 | 173.93 | Chem Eng Technol | 89 | 83.59 | J Comput Phys | 65 | 55.92 |
| 37 | Thesis | 366 | 337.53 | Renew Sust Energ Rev | 245 | 232.95 | J Electrochem Soc | 87 | 52.77 | Chem Eng J Bioch Eng | 63 | 60.95 |
| 38 | J Chromatogr A | 365 | 259.3 | Comput Oper Res | 244 | 231.44 | J Chromatogr A | 83 | 59.96 | Chem Eng-New York | 62 | 54.72 |
| 39 | Technometrics | 364 | 339.02 | Can J Chem Eng | 227 | 219.93 | Biotechnol Progr | 82 | 75.32 | Robust Process Contr | 60 | 59 |
| 40 | Int J Hydrogen Energ | 359 | 279.29 | Catal Today | 223 | 202.86 | Technometrics | 82 | 76.91 | Aiche S Ser | 59 | 55.91 |

Abbreviations: *R* = Rank; Cit = Citations; CLS = Citation link strength.

**Table 14**
Most common author keyword occurrences in CCE.

| | Global | | | 2009–2018 | | | 1999–2008 | | | 1989–1998 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| R | Keyword | Oc | Co | Keyword | Oc | Co | Keyword | Oc | Co | Keyword | Oc | Co |
| 1 | Optimization | 366 | 288 | Optimization | 194 | 131 | Optimization | 111 | 78 | Optimization | 61 | 41 |
| 2 | Simulation | 168 | 130 | Simulation | 72 | 48 | Simulation | 64 | 43 | Dynamic Simulation | 39 | 29 |
| 3 | Scheduling | 141 | 119 | Model Predictive Control | 70 | 36 | Scheduling | 58 | 36 | Process Synthesis | 32 | 22 |
| 4 | Model Predictive Control | 114 | 73 | Scheduling | 64 | 48 | Process Control | 43 | 24 | Simulation | 32 | 21 |
| 5 | Process Synthesis | 112 | 90 | Uncertainty | 55 | 38 | Genetic Algorithm | 42 | 29 | Modeling | 24 | 15 |
| 6 | Process Control | 107 | 83 | Multi-Objective Optimization | 53 | 29 | Model Predictive Control | 42 | 20 | Neural Networks | 20 | 12 |
| 7 | Uncertainty | 103 | 85 | Global Optimization | 51 | 31 | Design | 36 | 28 | Process Control | 19 | 11 |
| 8 | Modeling | 100 | 75 | Process Synthesis | 47 | 34 | Modeling | 36 | 17 | Scheduling | 19 | 17 |
| 9 | Global Optimization | 94 | 67 | Process Design | 46 | 32 | optimization | 36 | 24 | Process Design | 18 | 16 |
| 10 | Process Design | 93 | 76 | Dynamic Optimization | 45 | 33 | Uncertainty | 36 | 24 | Design | 16 | 16 |
| 11 | Dynamic Simulation | 91 | 61 | Process Control | 45 | 33 | Global Optimization | 35 | 17 | Distillation | 15 | 9 |
| 12 | Dynamic Optimization | 82 | 65 | CFD | 43 | 19 | Neural Networks | 34 | 21 | Batch Process | 14 | 10 |
| 13 | Minlp | 80 | 63 | MINLP | 43 | 32 | Dynamic Optimization | 33 | 22 | Data Reconciliation | 14 | 5 |
| 14 | Parameter Estimation | 78 | 45 | Parameter Estimation | 41 | 17 | Process Synthesis | 33 | 25 | Flexibility | 14 | 12 |
| 15 | Design | 74 | 68 | Modeling | 40 | 28 | Reactive Distillation | 33 | 18 | Batch Distillation | 13 | 8 |
| 16 | Distillation | 71 | 55 | Process Optimization | 38 | 28 | Distillation | 31 | 17 | Heat Integration | 13 | 12 |
| 17 | optimization | 68 | 52 | Mathematical Modeling | 37 | 27 | MINLP | 29 | 20 | Process Simulation | 12 | 9 |
| 18 | Reactive Distillation | 68 | 44 | MILP | 37 | 28 | Parameter Estimation | 29 | 18 | Uncertainty | 12 | 12 |
| 19 | Multi-Objective Optimization | 67 | 42 | Computational Fluid Dynamics | 36 | 22 | Process Design | 29 | 17 | Process Modeling | 11 | 8 |
| 20 | Genetic Algorithm | 66 | 49 | Heat Integration | 33 | 19 | Optimal Control | 28 | 21 | Control | 10 | 8 |
| 21 | MILP | 64 | 54 | Process Intensification | 30 | 19 | Dynamic Simulation | 27 | 12 | modeling | 10 | 6 |
| 22 | CFD | 63 | 28 | Mixed Integer Linear Programming | 27 | 18 | Fault Diagnosis | 27 | 21 | Process Optimization | 10 | 7 |
| 23 | Neural Networks | 61 | 46 | Process Monitoring | 26 | 12 | modeling | 26 | 19 | Reactive Distillation | 10 | 5 |
| 24 | modeling | 59 | 48 | Process Simulation | 26 | 16 | MILP | 22 | 18 | Artificial Intelligence | 9 | 4 |
| 25 | Process Optimization | 58 | 49 | Distillation | 25 | 15 | Batch Process | 21 | 11 | Controllability | 9 | 6 |
| 26 | Fault Diagnosis | 55 | 40 | Dynamic Simulation | 25 | 15 | Control | 21 | 16 | Genetic Algorithms | 9 | 7 |
| 27 | Heat Integration | 55 | 45 | Reactive Distillation | 25 | 10 | Fault Detection | 20 | 11 | Batch Processes | 8 | 6 |
| 28 | Optimal Control | 54 | 41 | optimization | 24 | 16 | Supply Chain Management | 19 | 14 | Batch Reactor | 8 | 7 |
| 29 | Control | 52 | 48 | Supply Chain | 24 | 13 | Batch Distillation | 18 | 12 | Differential-Algebraic Equations | 8 | 6 |
| 30 | Computational Fluid Dynamics | 51 | 30 | modeling | 23 | 16 | CFD | 18 | 3 | Fault Diagnosis | 8 | 4 |
| 31 | Mathematical Modeling | 51 | 39 | Real-Time Optimization | 23 | 17 | Distributed Parameter Systems | 17 | 8 | Flowsheeting | 8 | 7 |
| 32 | Batch Process | 47 | 33 | Design | 22 | 20 | Genetic Algorithms | 17 | 13 | Global Optimization | 8 | 3 |
| 33 | Process Simulation | 47 | 30 | Process Integration | 22 | 17 | Nonlinear Control | 17 | 12 | MINLP | 8 | 8 |
| 34 | Process Monitoring | 45 | 29 | Robust Optimization | 22 | 9 | Principal Component Analysis | 17 | 12 | Nonlinear Control | 8 | 5 |
| 35 | Data Reconciliation | 43 | 24 | Sensitivity Analysis | 22 | 13 | Synthesis | 17 | 14 | optimization | 8 | 6 |
| 36 | Mathematical Programming | 40 | 31 | Control | 21 | 18 | Mathematical Programming | 16 | 10 | Parameter Estimation | 8 | 4 |
| 37 | Nonlinear Programming | 40 | 35 | Crystallization | 21 | 11 | Process Monitoring | 16 | 12 | Simulated Annealing | 8 | 3 |
| 38 | Fault Detection | 39 | 28 | Mixed-Integer Linear Programming | 21 | 8 | Data Reconciliation | 15 | 7 | Synthesis | 8 | 6 |
| 39 | Supply Chain Management | 39 | 30 | Nonlinear Programming | 21 | 14 | Nonlinear Systems | 15 | 9 | Energy Integration | 7 | 5 |
| 40 | Mixed Integer Linear Programming | 38 | 29 | Stochastic Programming | 21 | 14 | Artificial Neural Networks | 14 | 9 | Expert System | 7 | 5 |

Abbreviations: $R$ = Rank; Oc = Author keyword occurrences; Co = Author keyword co-occurrences links.

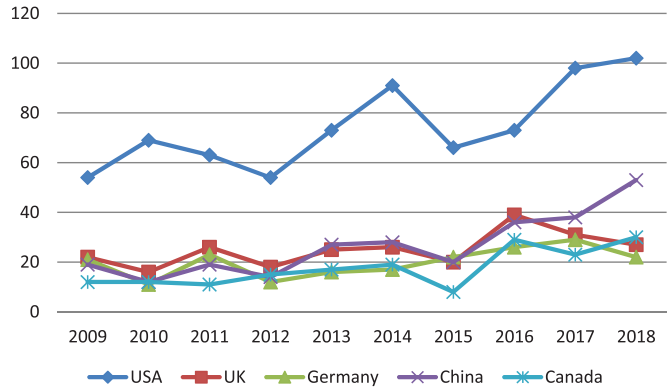


**Fig. 6.** Annual performance of top five countries in the last ten years.

Table 3. Note that, this document received most citation according to the Scopus citation data. This document also has been receiving most citations per year on average. Venkatsubramanian et al., (2003) presents a high quality review on the quantitative model-based scientific methods applied in the process fault detection and diagnosis area; its direct relation with highly relevant industrial problems helps it to gain a high rate of acknowledgement from other researchers. The article entitled "Model Predictive Control: Past, Present and Future" (Morari and Lee, 1999) presents a comprehensive literature review of model predictive control and it is the third in the list with 989 citations. Morari and Lee (1999) pointed out research gaps in subject areas including system identification, state estimation, monitoring and diagnostics. Moreover it overviewed many important practical and theoretical problems in the MPC framework. The fourth article in Table 3 is again a review paper which has 813 citations. Note that, this is the third part of the series of review papers on Process Fault Detection and Diagnosis. Each of the top nine articles has more than 500 citations. Most of the top ten articles are review of the state-of-the-art type. Seventeen articles out of the top 50 are focused on optimization. Besides the review works on optimization, there are also several papers on different types of optimization including "Simultaneous-Optimization" "Structural Optimization", "Global Optimization", "Dynamic Optimization", and "Multi-objective Optimization". Fourteen articles from Table 3 discussed different types

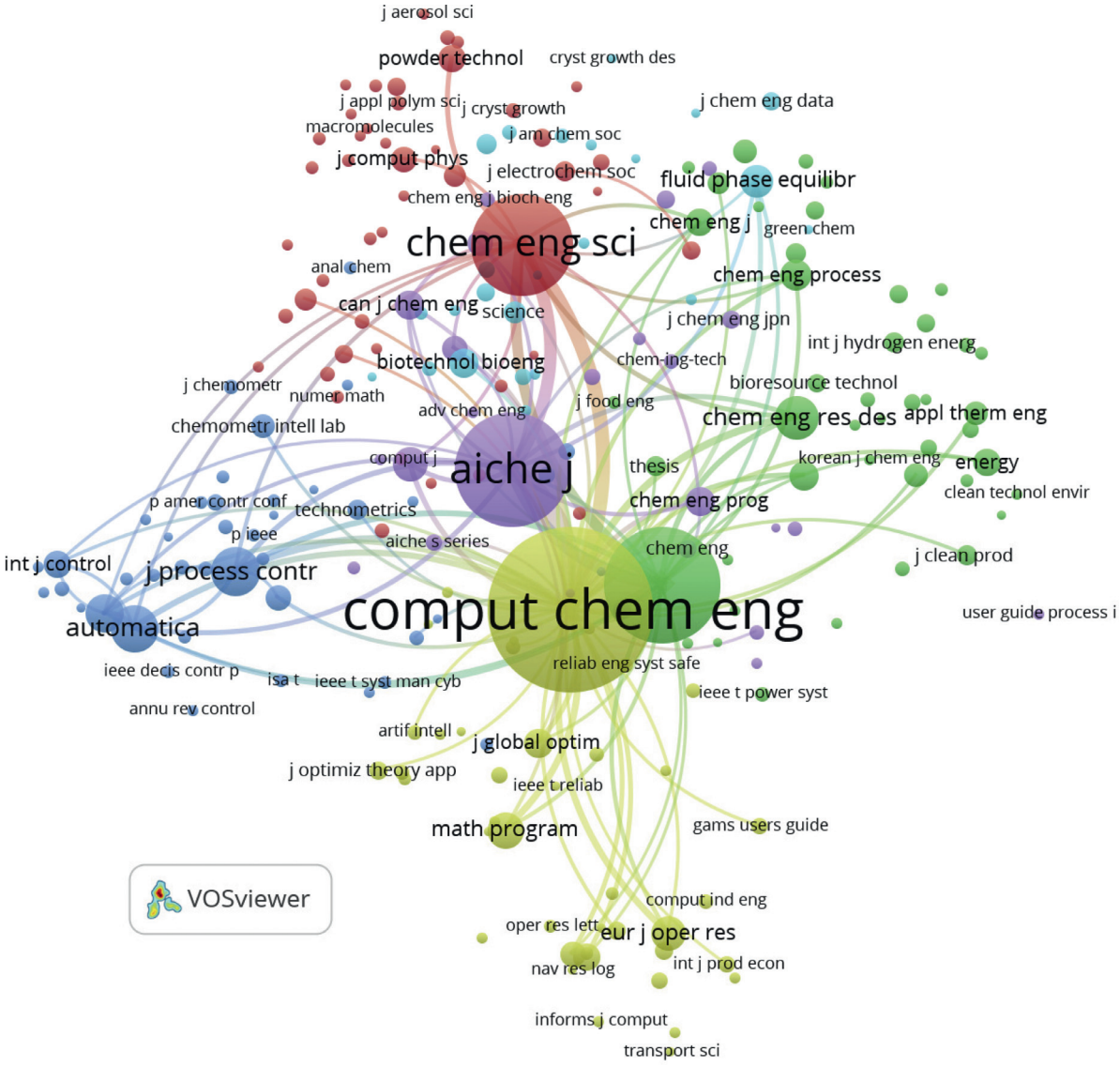


**Fig. 7.** Co-citation of journals in CCE: minimum citation threshold of 80 and 100 links.

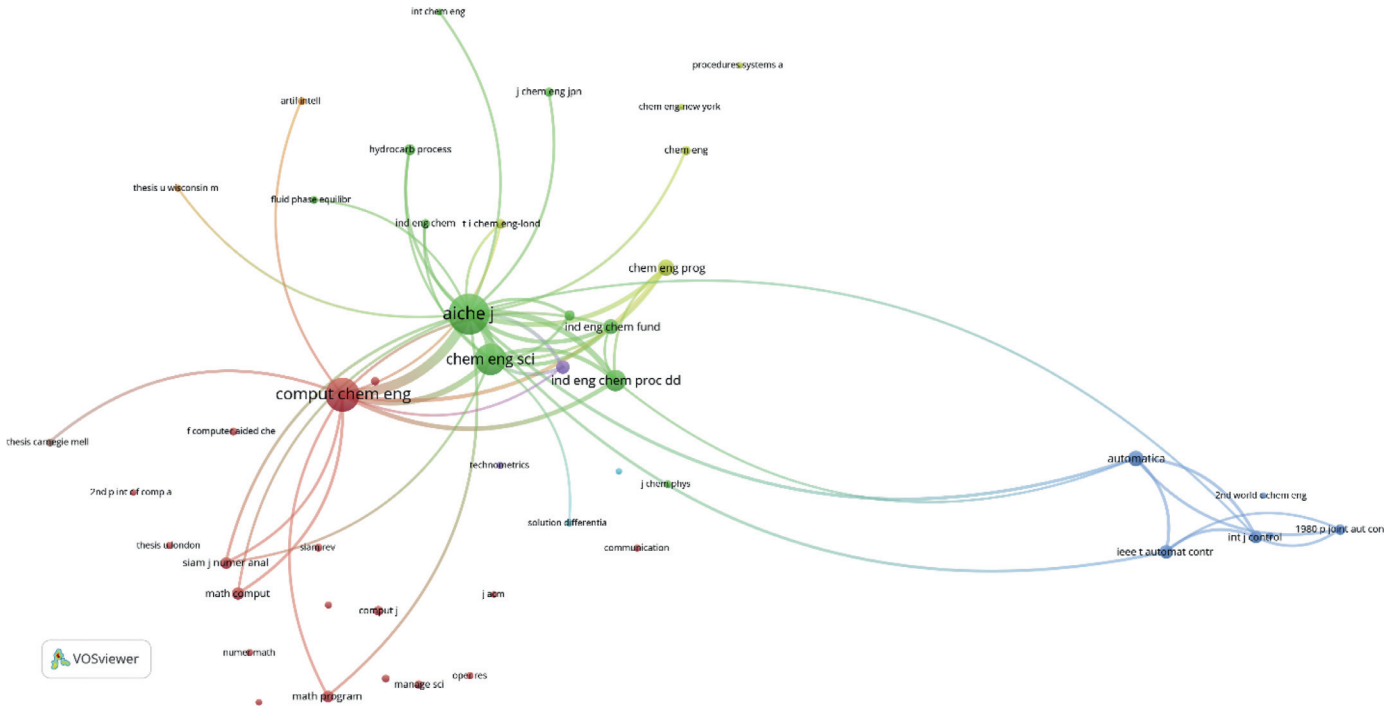


**Fig. 8.** Co-citation of journals in CCE: 1977–1988 (minimum citation threshold of 20 and 50 links).

of models which include "Quantitative Model", "Simultaneous-Optimization Models", "Dynamic Modeling", "Adaptive Data Modeling", "Model Predictive Control", "Generic Model Control", "Models For Refinery Operations", and "Simultaneous-Optimization Models". There are six documents in Table 3 from the year 2003 which appears as the most productive year in terms of highly cited articles. The year 1998 is the second most productive year with 5 documents in the list of 50 most cited documents. Fig. 4 shows the distribution of the 50 most cited documents over the years.

Please note that, twenty three out of the top 50 most cited documents were published during the period of 1995 to 2005. The paper entitled "Biomass-To-Bioenergy and Biofuel Supply Chain Optimization: Overview, Key Issues and Challenges" (Yue et al., 2014) is the youngest paper in Table 3 (in the 48th position) with the third highest citation rate per year on average. The 30th paper entitled "Optimal Water Allocation in a Petroleum Refinery" (Takama et al., 1980) is the oldest paper in Table 3. Thirty influential papers have more than three hundred citations and twenty among them have more than 250 citations. Note that, Table 3 has six such articles which are receiving more than 50 citations per year on average. From Table 3 one may easily observe that state-of-art and review based research articles are the most often cited and are heavily represented. Next table presents 40 of the articles which have been most frequently cited in the papers published in CCE.

The article, Kondili et al. (1993), entitled "A general algorithm for short-term scheduling of batch operations—I. MILP formulation" published in CCE has a comfortable lead over the rest in Table 4. The research ideas demonstrated in Kondili et al. (1993) have been used and referenced in 177 documents of CCE. Note that, Kondili et al. (1993) has a total of 679 citations and it is placed in the fifth position in Table 3. The book published in the McGraw-Hill Chemical Engineering Series, entitled "Conceptual Design of Chemical Processes" and authored by James Douglas (Douglas, 1988), is listed in the second place. Kondili et al. (1993) and Douglas (1988) have 144 and 91 co-citations respectively with the CCE publications. Four papers have more than one hundred co-citations with CCE. Geoffrion (1972) is the oldest paper in the list. It was published in the 'Journal of Optimization Theory and Applications'. According to WoS, 99 documents published in CCE referenced Geoffrion (1972) and as per Google Scholar it has more than two thousand two hundred citations. Fig. 5 presents chronological visualization of the most cited documents in CCE.

In Fig. 5 one can see that sixteen documents out of the forty most cited documents in CCE publications were published between 1985 and 1990. Top eight documents of Table 3 have been referenced in more than one hundred documents of CCE. The top 40 most cited documents by the CCE publications comprise ten books and thirty articles. Note that Table 4 lists 12 documents published in CCE and eight articles from AIChE J. The outcome shows close connection between CCE and AIChE J. The following sub-section reveals top authors, institutions and countries of CCE.

### 3.3. Leading authors, institutions and countries

This part of the manuscript is dedicated to those authors, institutions and countries who have contributed most to CCE's collection of articles. Table 5a acknowledges fifty most productive authors and ranks them according to their number of CCE publications. In addition, the Table captures other relevant information about the leading authors including their affiliations, TC, H-index, C/P and citation thresholds. Note that, TC, TP, H-index, C/P and citation thresholds of the authors are prepared solely on the basis of their publications in CCE.

Ignacio E. Grossmann of Carnegie Mellon University tops Table 5a with more than two hundred publications. Ignacio Grossmann is the most influential author of the journal as he leads in three basic categories TP, TC and H-index with a huge margin in comparison to the other listed authors. Note that, ten articles of Professor Grossmann have also been listed in the 50 most cited

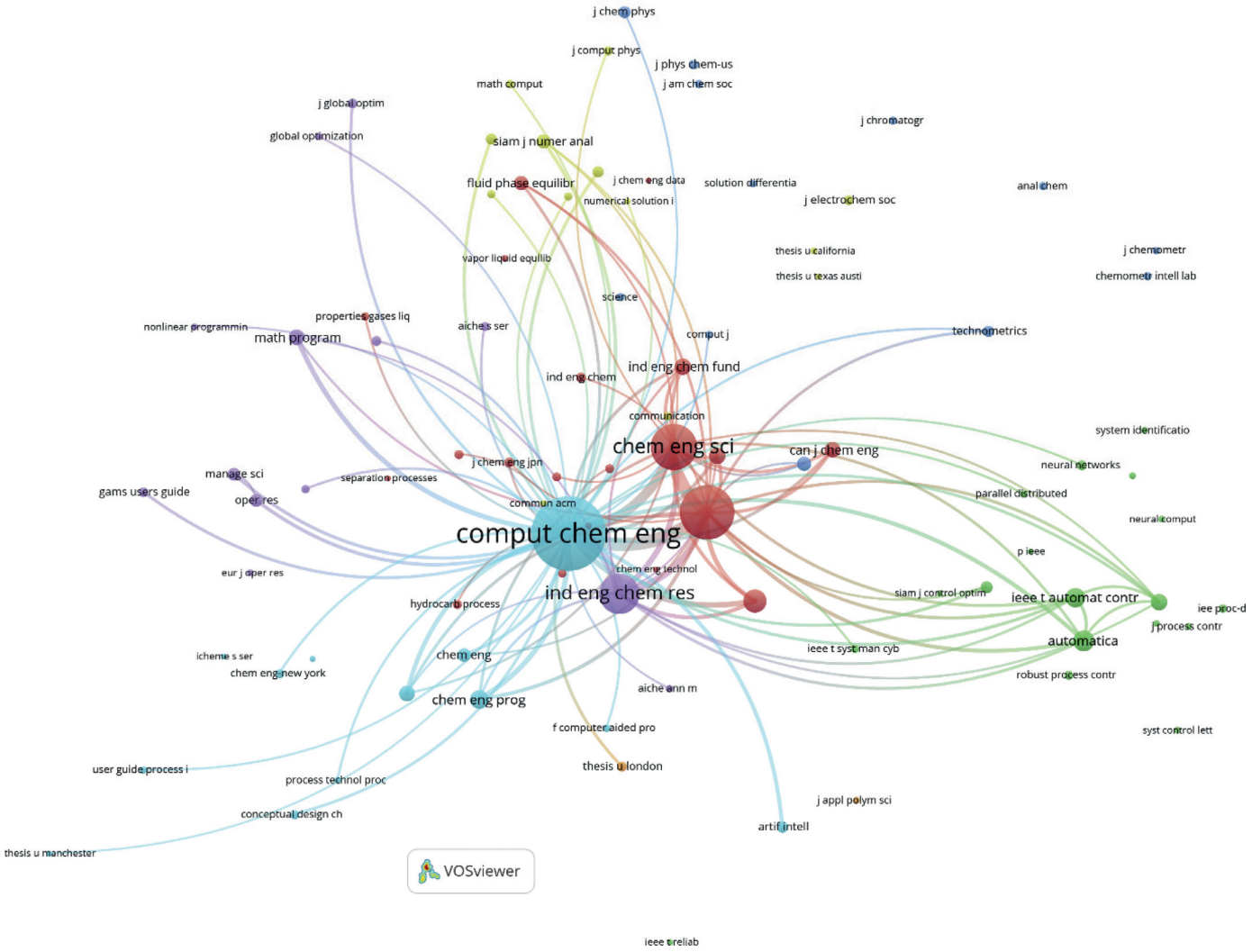


**Fig. 9.** Co-citation of journals in CCE: 1989–1998 (minimum citation threshold of 30 and 100 links).

documents of CCE (see Table 3). Stratos Pistikopoulos of Texas A&M University is listed in the second position with 98 publications. Lorenz T. Biegler of Carnegie Mellon University who has 97 publications in CCE is closely following Stratos Pistikopoulos. Note that only six authors in Table 4 have more than fifty citations per paper. I. Grossmann again leads in the C/P index closely followed by Christodoulos A. Floudas and Venkat Venkatasubramanian. C. Floudas and V. Venkatasubramanian have four and three papers, respectively, in the list of 50 most cited documents of CCE (see Table 3). Note that, 48 documents of V. Venkatasubramanian accumulated a total of 2867 citations and the top three among them, which are listed in Table 3, have received a total of 2495 citations. I. Grossmann and C. Floudas have thirty four and fifteen documents, respectively, with more than 100 citations. Leading 50 authors contributed 63.5% of the published documents with more than 100 citations. USA based authors are in the top three positions and dominate the Top 50 list with a total of twenty two. The Top 50 list of authors is completed by twenty seven members from different European countries and only one Asian author.

Table 5b orders the top fifty influential authors based on the number of citations received by their CCE papers. Note that, Table 5b is totally prepared based on the Scopus citation data up to April 2020. I.E. Grossmann tops Table 5b with 16,370 citations followed by V. Venkatasubramanian with 5855 citations. Note that, V. Venkatasubramanian is in the 10th position in Table 5a. R. Rengaswamy of Indian Institution of Technology (Madras) and S. N. Kavuri of Purdue University are in the fifth and sixth positions in this table although they do not get a position in the Table 5a. There exist sixteen such authors in Table 5b who are not in Table 5a. USA leads Table 5b with twenty-eight authors followed by the UK. Now, we will extend the analysis from author to the institution basis with Table 6 presenting the most productive and influential institutions in CCE.

Table 6 provides information on fifty most productive and influential universities in CCE. It gives information on country, citation structure, ARWU and QS ranking of these Top 50 institutions. Carnegie Mellon University from the USA leads the ranking in Table 6 followed by Imperial College London from the UK. Note that the significant contributions of two authors: Ignacio E. Grossmann and Stratos Pistikopoulos from the Carnegie Mellon University, who have contributed 206 and 98 papers respectively. Four authors (Nilay Shah, Constantinos Pantelides, Sandro Macchietto and John Perkins) from the Imperial College London are also listed in the top fifty leading authors of the CCE and their contribution helps the Imperial College London to achieve the second position in Table 6. European institutions are dominating Table 6 with

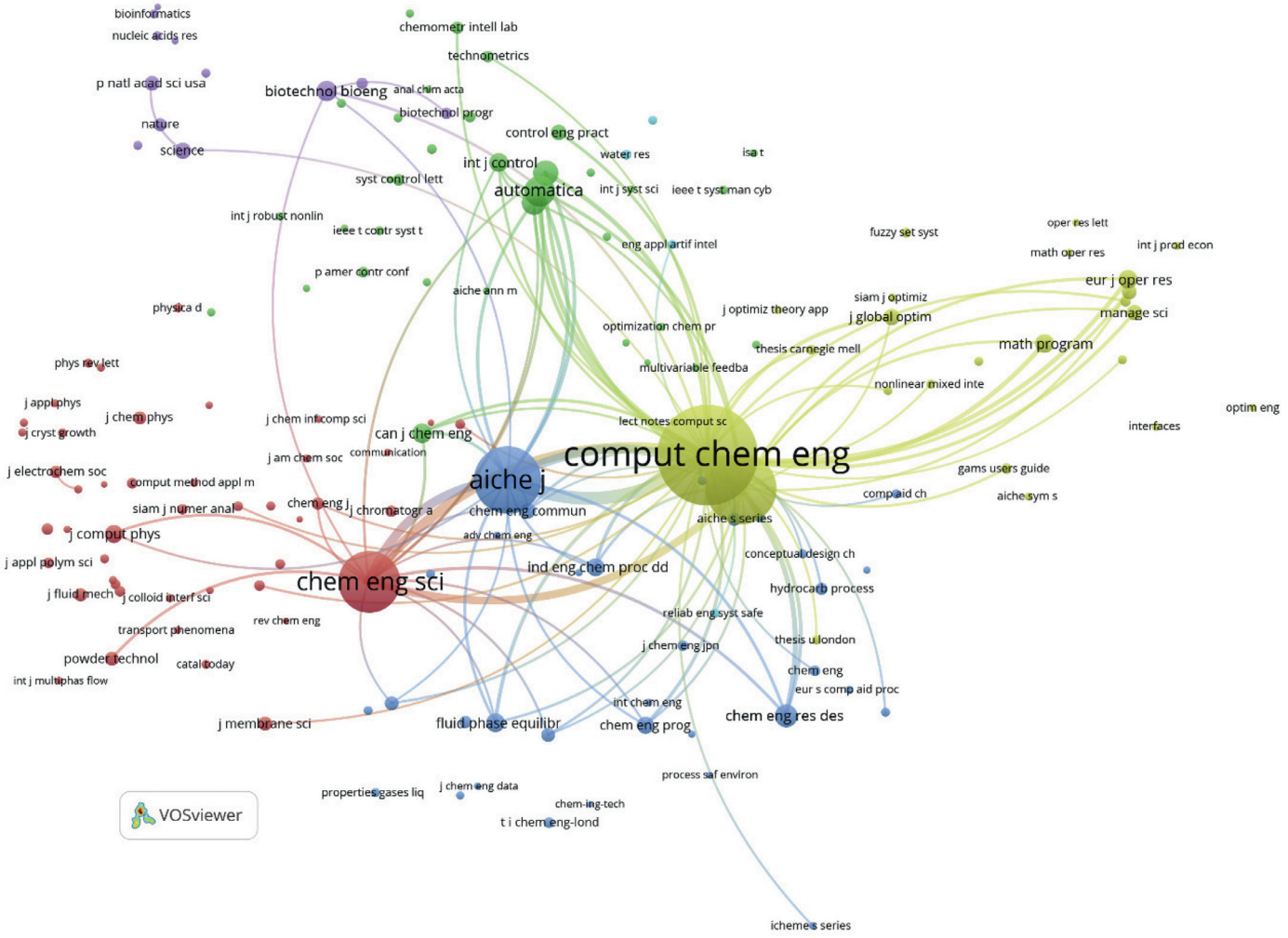


**Fig. 10.** Co-citation of journals in CCE: 1999–2008 (minimum citation threshold of 40 and 100 links).

twenty six representatives. Top 50 has also fourteen North American, four South American and four Asian universities. Five institutions (Carnegie Mellon University, Imperial College London, Purdue University, Technical University Denmark, and Norwegian University of Science and Technology) have all more than one hundred publications in CCE. Massachusetts Institute of Technology (MIT) of the USA, the best university of world according to the QS ranking, is in the thirteenth position with eighty five publications. Table 7 presents a list of productive and influential institutions other than universities.

CONICET of Argentina leads Table 7 followed by CNRS of France. CONICET and CNRS have 161 and 148 publications in CCE, respectively. To analyze the performance of institutions in more detail, Table 8 presents temporal evolution of the most productive institutions in CCE.

As expected Carnegie Mellon University from the USA has been the top performing institution in 3 out of 4 analyzed periods (coming second in the fourth period) with Imperial College London from UK performing the best during the years from 1989 to 1998 (and coming the second and the third in the last two decades respectively). CONICET of Argentina has been continuously improving its performance and ranking. The number of publications of CNRS France has been decreasing in the last three decades. During the initial twelve years of CCE, only three universities have more than fifteen publications. In recent years, CCE has been publishing papers from much more diverse geographical world-wide locations. To illustrate a country based performance, Table 9 presents the fifty most productive and influential countries for the journal.

Ranking of the countries has been prepared based on the total publications (TP) indicator. The USA leads by a large margin in all the considered measures of performance. The USA has 2352 publications, 69,148 citations, 112 H-index, 29.40 citations per paper, and 129 papers with more than fifty citations. The UK has also performed well and is ranked in the second position in all major categories. The UK has 819 publications, 16,677 citations, 61 H-index, 20.36 citations per paper, and 27 papers with more than fifty citations. Six institutions in the UK (Imperial College London, University of Manchester, University College London, University of Leeds, University of Edinburgh and Newcastle University) which are listed in the top 50 institutions, contribute 75% of the total UK publications. Germany, China and Canada are in the third, fourth and fifth position respectively. Note that, only two universities from China (Tsinghua University and Zhejiang University) have made it to the Table 6 of Top 50 institutions and these two universities contributed 105 papers of the 437 papers from China. This result shows that there are several institutions in China which are not in the top 50 but significantly contributed to the country's achieving

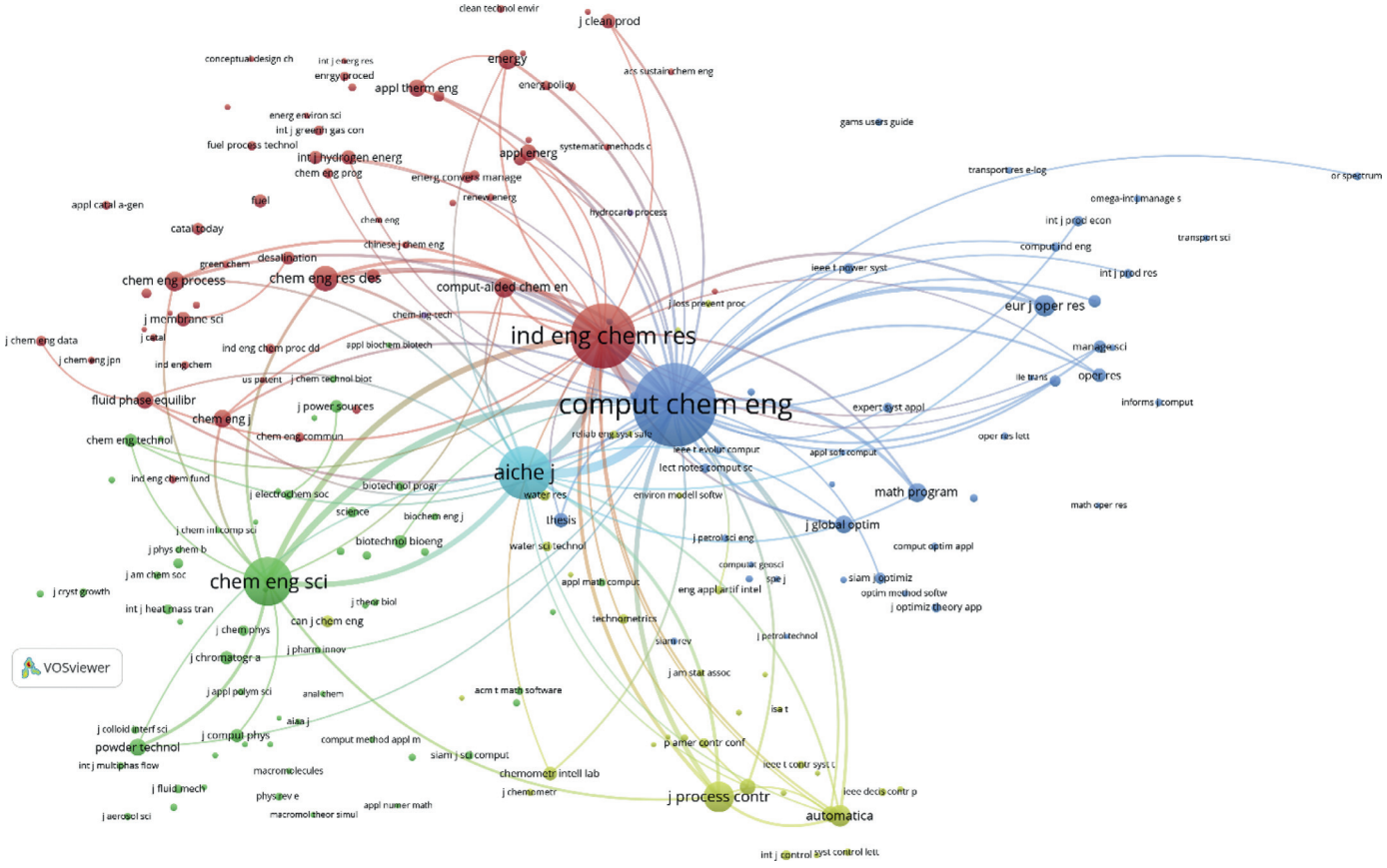


**Fig. 11.** Co-citation of journals in CCE: 2009–2018 (minimum citation threshold of 50 and 100 links).

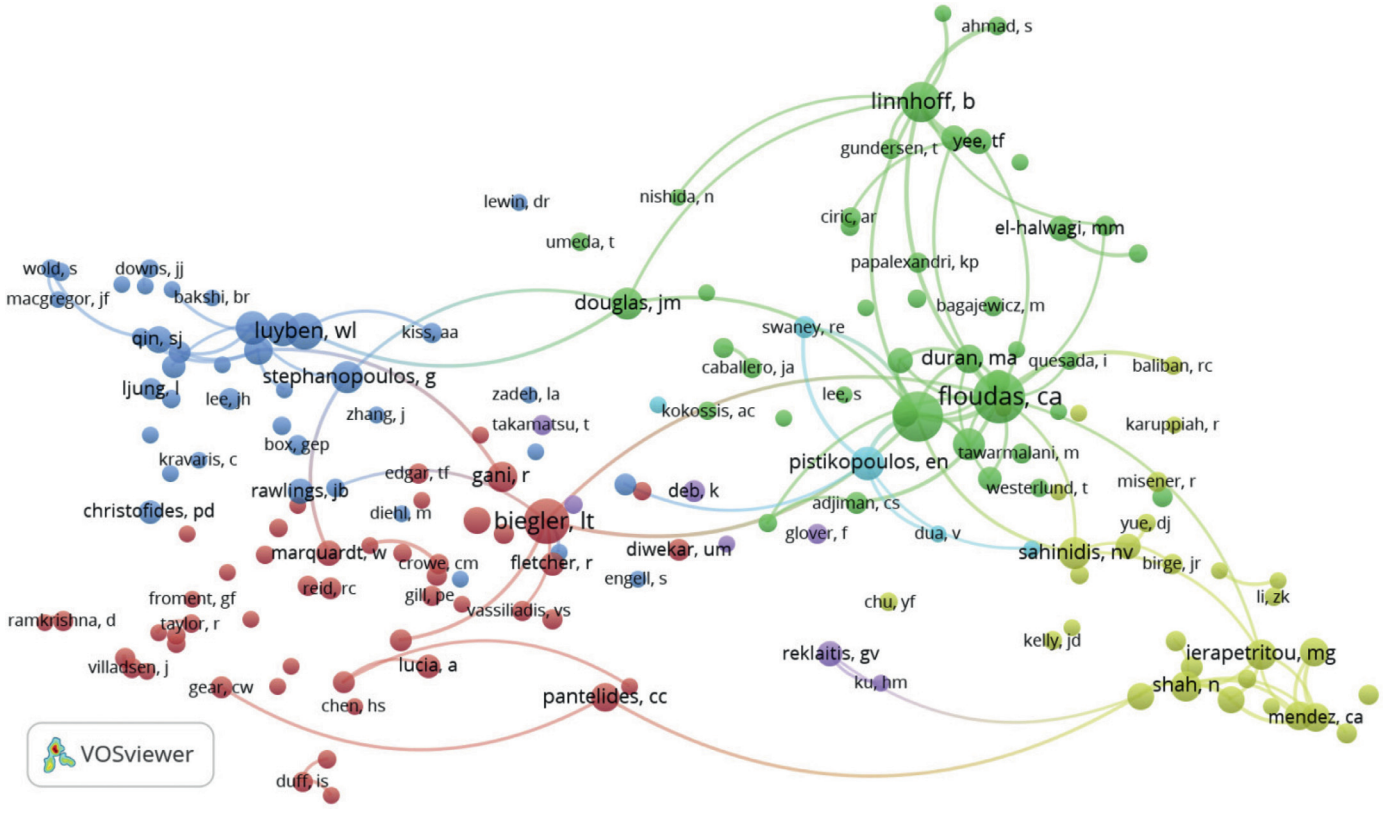


**Fig. 12.** Co-citation of authors in CCE: minimum citation threshold of 5 and 100 links.

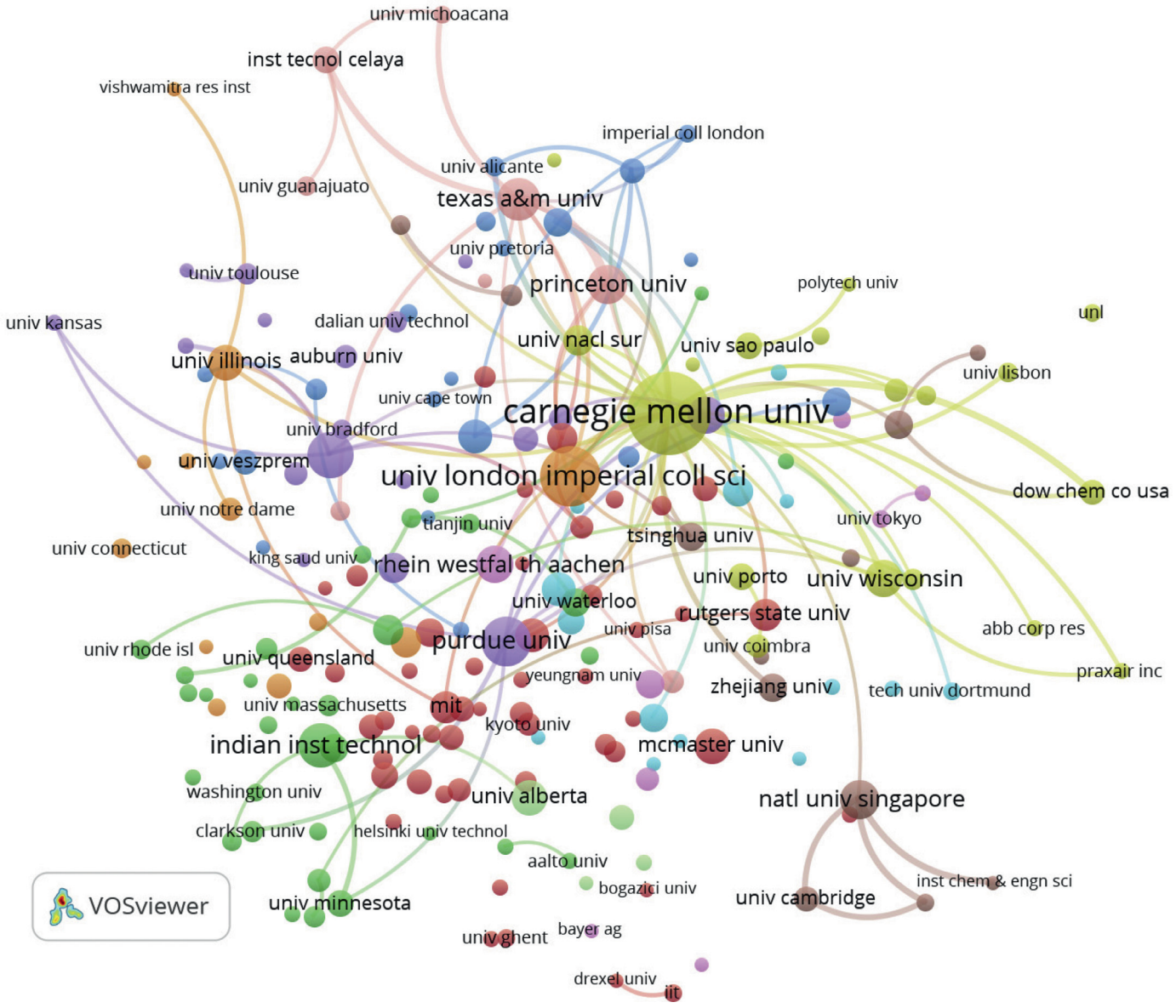


**Fig. 13.** Bibliographic coupling of institutions publishing in CCE: minimum publication threshold of 10 documents and 100 links.

the fourth position. In the top ten places there are five countries from Europe (UK, Germany, France, Spain, and Italy), two countries from North America (USA and Canada), two countries from South America (Argentina and Brazil) and one country from Asia (China). Twenty three countries have more than one hundred publications in CCE and the top nine have more than two hundred publications. Beside the presentation of citation structure of leading countries, Table 9 also presents publication and citation data relative to the country's population. The indicator 'TP/POP' provides the ratio of the total number of publications per 100 thousand of people while 'TC/POP' gives the ratio of the total number of citations per 100 thousand of people. Slovenia leads in the 'TP/POP' category followed by Denmark. Slovenia again leads in the 'TC/POP' category followed by Norway. Table 10 presents the annual evaluation of leading countries to examine their performance with the progress of time. Fig. 6 presents performance of the top five countries during the last ten years. As expected, the USA has been in the leading position throughout the whole period. The UK and China have been the primary two countries competing for the second position during the last decade. However, China has been significantly improving its performance during the last fifteen years with the last year resulting in 53 published papers taking it to the clear second position. Let us now take a closer look at the most productive and influential super-regions in CCE.

Table 11 confirms the participation of all super-regions in CCE. North America leads in all citation indexes but Europe leads in the total publications index. The top three super-regions, which are North America, Europe and Asia, have more than 1000 publications each. Africa has only ninety seven publications in CCE. Europe and North America received almost 75 percent of the total number of citations. Finally, let us also more closely examine the citing articles of all CCE publications.

Table 12 depicts the top forty of the authors, universities, countries and journals that have cited the highest number of CCE articles. IE Grossmann is the most contributing author as he referenced CCE articles in 512 of his research publications. Leading

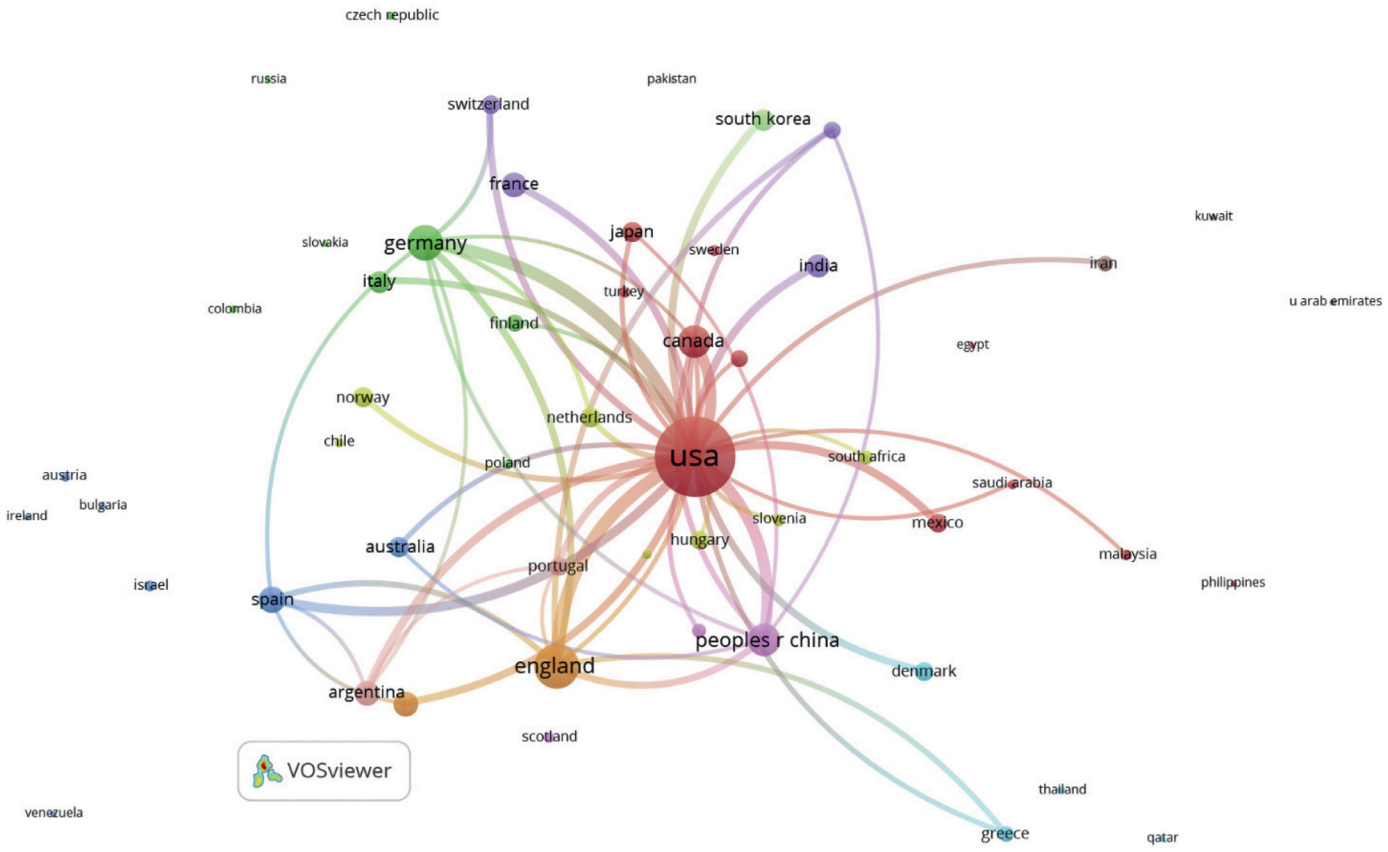


**Fig. 14.** Bibliographic coupling of countries publishing in CCE: minimum publication threshold of 5 documents and 50 links.

authors as listed in Table 5 are also represented in this table. In the list of leading universities, interestingly, CNRS of France comprehensively beats the top two universities (Carnegie Mellon University and Imperial College London) from Table 6. Two Chinese universities, Tsinghua University and Zhejiang University, heavily referenced CCE articles in their research works. They secure the fourth and fifth positions for China. The USA referenced CCE publications in more than 13,000 articles. The UK, Germany and France are present in this Table in the third, fourth and fifth position, respectively. The self-citations of CCE (i.e. papers published in CCE citing other CCE papers) are closely followed by the citations from the Industrial Engineering Chemistry Research journal. Five journals have referenced CCE publications in more than 1000 documents (as extracted from WoS database). According to Table 12, six journals (Industrial Engineering Chemistry Research, Computer Aided Chemical Engineering, Chemical Engineering Science, AIChE Journal, Journal of Process Control, and Chemical Engineering Research Design) are closely connected with CCE. To obtain more detailed insights of the results, the following section presents graphical visualizations of bibliographic coupling, co-authorship, co-citation and co-occurrence of keywords.

## 4. Mapping CCE related information with VOS viewer software

This section presents graphical visualizations of co-citation of journals and authors, co-occurrence of keywords, and bibliographic coupling of institutions using the VOS viewer software. The VOS viewer software forms network visualization based on weight and link strength. The size of a node depends on its weight. The link strength of a node determines its connective edges with other nodes. Let us first concentrate on the co-citation of journals with CCE. Co-citation of journals occurs when two documents of two different journals receive a citation from a same third document (Small, 1973). Fig. 7 presents the co-citation of journals in CCE. Please note that, to construct this figure we have set the minimum co-citation threshold to 80 and link strength to 100. This means that we exclude those journals whose co-citations with CCE are less than 80 and/or link strength is less than 100.

Industrial Engineering Chemistry Research has 10,708 co-citations and 8678.05 link strength, which results in the best co-citation union with CCE. AIChE Journal and Chemical Engineering Science are the other two journals, the significant presence of which can be easily seen in Fig. 7. AIChE Journal and Chemical Engineering Science have 10,110 and 8003 co-citations with CCE, respectively. Journal of Process Control, Automatica, and Chemical Engineering Research Design are also highlighted in Fig. 7 as they have more than 1500 co-citations and 1400-link strength with CCE. For the temporal analysis of co-citation of journals with CCE, Figs. 8, 9, 10 and 11 depict co-citation of journals in CCE for the intervals of 1977–1988, 1989–1998, 1999–2008 and 2009–2018, respectively.

Self-citation within CCE is the most prominent in Figs. 9, 10 and 11. AIChE Journal had the best co- citations and co-citation link strength with CCE during 1977 to 1988 period. Excluding the self-citation, Industrial Engineering Chemistry Research leads in the intervals 2009–2018 and 1999–2008 while Aiche Journal leads in the interval 1989–1998. Figs. 8 to 11 ascertain that AIChE Journal, Chemical Engineering Science, Industrial Engineering Chemistry Research and CCE have had a very close bond over the years. Table 13 presents all the relevant data regarding co-citation

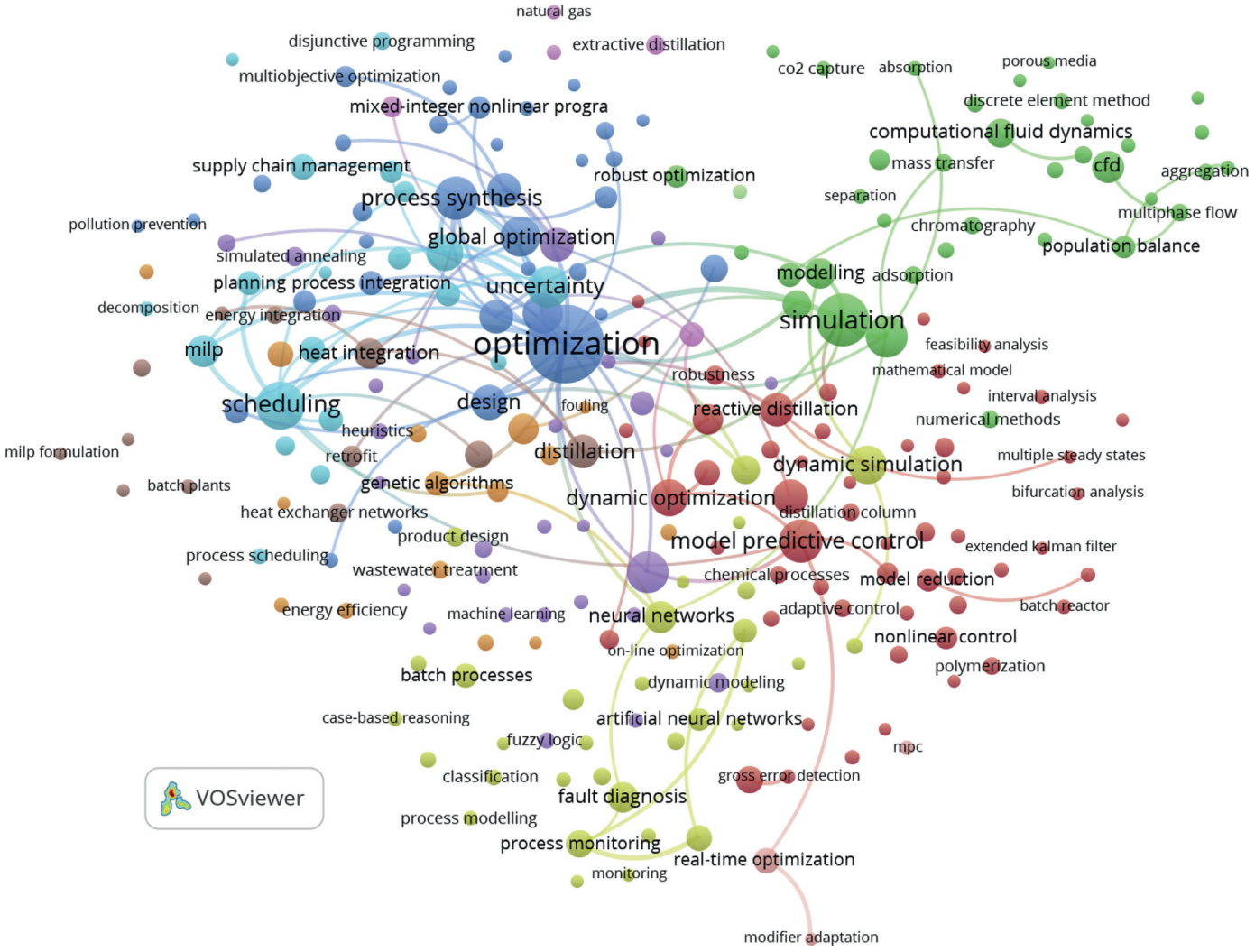


**Fig. 15.** Co-occurrence of author keywords in CCE: minimum occurrence threshold of 80 and 100 links.

and co-citation link strength of journals collaborations with CCE.

Fig. 12 presents a network visualization of co-citation of authors in CCE. There are three major clusters (Green, Red and Blue) in Fig. 12. Christodoulos A. Floudas, B Linnhoff, JM Douglas are the most important/dominant nodes in the green cluster. Lorenz T. Biegler, Rafiqul Gani, Wolfgang Marquardt, and Constantinos Pantelides play a vital role in the formation of red cluster. WL Luyben leads the blue cluster along with Gregory Stephanopoulos.

Let us now take a closer look at the Figs. 13 and 14 for bibliographic coupling of institutions and countries publishing in CCE. Bibliographic coupling occurs when two different studies cite a common reference of a third work in their bibliographies (Kessler, 1963).

To construct Fig. 13 we restricted the minimum publication threshold to 10 documents and minimum link strength to 100 links. Carnegie Mellon University, Imperial College London, Purdue University, and Texas A&M U College Station are showing their big presence in Fig. 13. National University of Singapore, Princeton University, University of Illinois, Indian Institute of Technology, and University of Wisconsin are also playing an important role for research collaboration in CCE. Specifically, we can say that the leading institutions from Table 6 are also playing the same role for research collaboration in CCE.

Fig. 14 presents bibliographic coupling of countries publishing in CCE. Note that, we exclude those countries from Fig. 14 whose number of publications in CCE is less than five documents. Moreover, we do not display those edges whose link strength is less than 50 links. USA, UK, Germany, Canada and China are showing their high influence in Fig. 14. Thus, most productive and influential countries listed in Table 9 are also appearing in Fig. 14. The difference is that Fig. 14 shows how the leading countries connect between each other while Table 9 presents a ranking according to the number of publications and citations. Note that from a general point of view, countries from a same region tend to connect more so they usually appear close to each other in the figures of bibliographic coupling. Finally, we construct graphical visualization of co-occurrence of keywords listed in CCE publications. Keywords provided by authors together with their publication help to categorize and outline the publication more easily and quickly. The keywords co-occurrence exploration helps to depict the most often discussed topics in the journal and their relation with others topics. Fig. 15 presents co-occurrence of keywords used by the authors in their publications in CCE from 1977 to 2018. Moreover, to

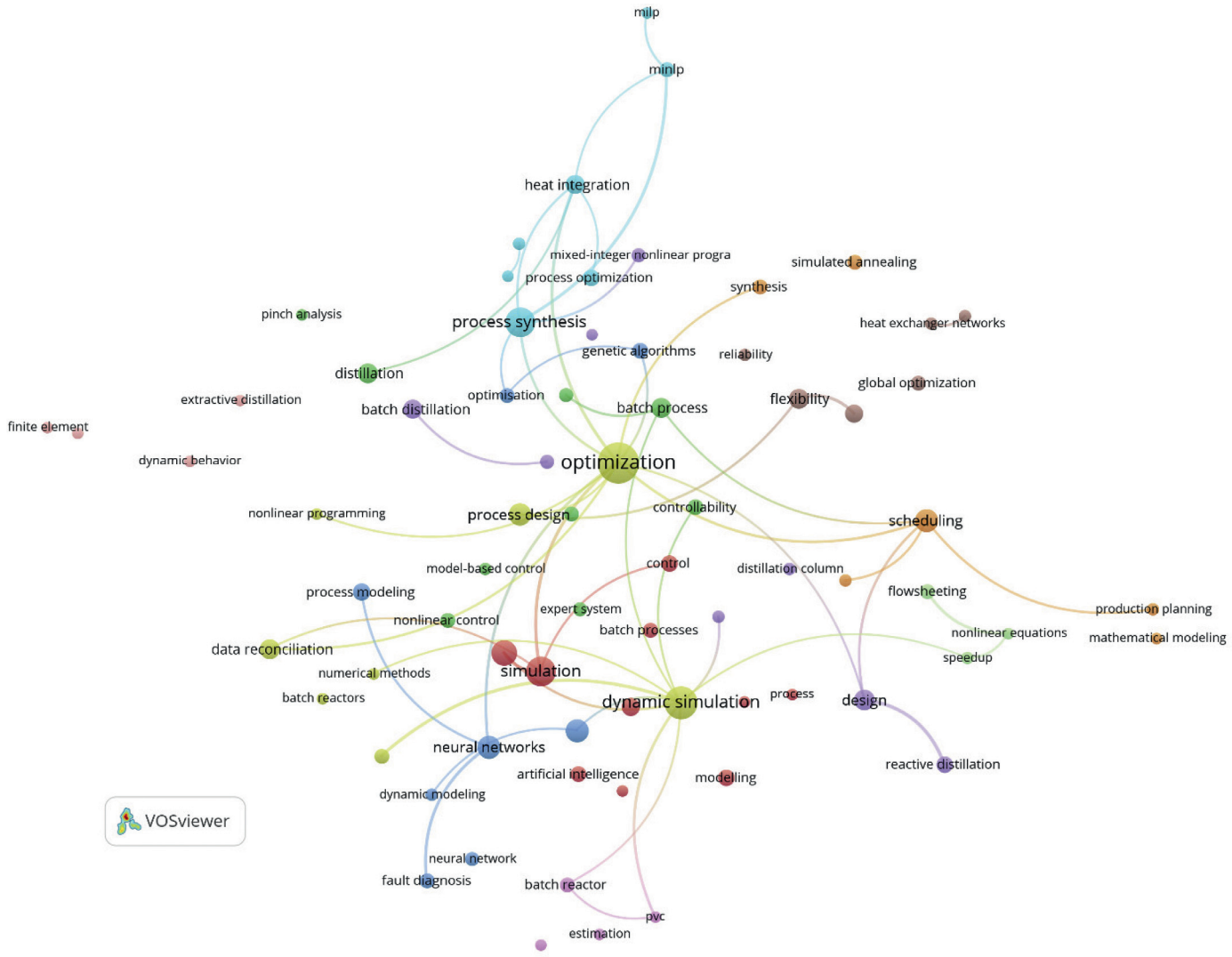


**Fig. 16.** Co-occurrence of author keywords in CCE: 1989–1998 (minimum occurrence threshold of 5 and 50 links).

depict the trends of topics with the progress of time, Figs. 16, 17, and 18 visualize the network of topics co-occurrence for the periods of 1989–1998, 1999 –2008 and 2009–2018, respectively.

Fig. 15 shows that Optimization, Simulation, Scheduling, Model Predictive Control, Process Synthesis, Process Control, Uncertainty and Modelling have been the most commonly used keywords by the authors in their publications in CCE. Recall that, 17 articles out of the top 50 most cited articles of CCE use optimization as the key subject. Optimization, Dynamic Simulation, Process Synthesis and Simulation are the top four keywords used by the authors during 1989 to 1998. Optimization, Simulation, Scheduling, Process Control, Genetic Algorithm, and Model Predictive Control are the most often discussed topics during 1999 to 2008. In the last decade (i.e. from 2009 to 2018), the keywords of Optimization, Simulation, Model Predictive Control, Scheduling, Uncertainty, Multi-Objective Optimization, and Global Optimization are discussed by the authors in more than 50 of the CCE publications. Optimization and Simulation are the heavily used keywords in the CCE publications throughout the time. Table 14 provides a more detailed data of the most often used keywords in the CCE publications.

## 5. Conclusions

CCE began its journey in 1977 and has already completed its forty eventful years. During this amazing journey, it has published a number of excellent research findings and established its high reputation in the field of chemical engineering. In 2017, this SCI indexed journal had an impact factor of 3.113. This bibliomeric retrospective study has analyzed CCE publications in celebration of its four very successful decades. The study has collected data from the WoS and summarized them using several well established performance measures. It has considered all publications in CCE from 1977 to the end of 2018 and explored the foremost developments in terms of impact, authors, universities, countries and subjects of research.

This study has revealed numerous interesting aspects about CCE publications and some of the main findings are as follows. The journal had the best publication rate during the 1996 to 2000 period. It published the largest number of articles in 1996. Publications from 1997 to 2006 period not only received the highest number of citations but also had the highest citation rate. The year 2004 was the year of publications receiving highest citations for

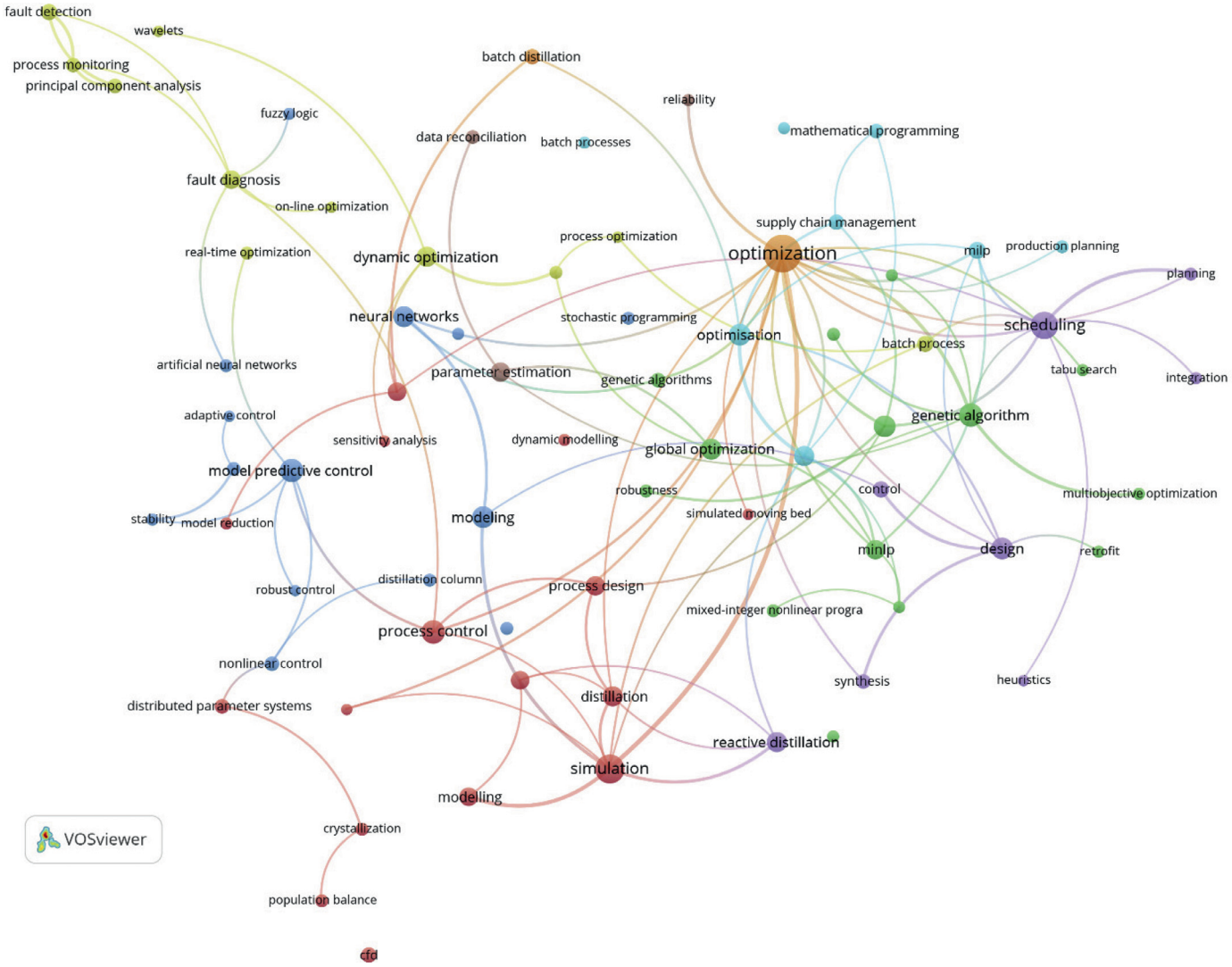


**Fig. 17.** Co-occurrence of author keywords in CCE: 1999–2008 (minimum occurrence threshold of 10 and 100 links).

CCE. Thirty CCE publications have crossed the threshold of 250 citations and thirteen among them have more than 400 citations. The research paper published in the year 1993 and written by J. J. Downs & E. F Vogel entitled "A Plant-Wide Industrial-Process Control Problem" has received the highest number of citations. Review and state-of-art based studies are likely to receive more citations and as a result these types of works are heavily present in the list of the top 50 most often cited CCE papers. One third of these top 50 papers discussed optimization related issues. Professor Ignacio E. Grossmann of Carnegie Mellon University has been the most influential author of the journal as he leads in all major categories with 206 publications, 12,380 citations and H-index of 62. Carnegie Mellon University of the USA has been the most productive university in CCE followed by the Imperial College London of the UK. The USA leads in all the major categories followed by the UK and Germany. Temporal analysis has shown the USA as the leading country throughout the years with China quickly emerging during last five years as the main competitor for the upcoming period. Among the all supranational regions, North America leads in all the performance indexes with the exception of the total number of publications in CCE where Europe tops the ranking. Co-citation analysis of journals has revealed that Industrial Engineering Chemistry Research, AIChE Journal, and Chemical Engineering Science are very closely bonded with CCE. The most productive authors, institutions, and countries have also dominated the bibliographic coupling analysis in CCE. Co-occurrence of authors' keywords has revealed that Optimization, Simulation, Scheduling, Model Predictive Control, Process Synthesis, Process Control, Uncertainty and Modelling are the most often used keywords by the authors in their CCE publications.

This bibliometric study has analyzed the publication and citation patterns of CCE using different performance related indexes. Beside celebrating and analyzing the contribution of the authors, institutions and countries, it has explored the most often covered and discussed topics in the CCE publications. It is hoped that the contribution of the present study will help young researchers and academics to appreciate the history of the field, identify potential research gaps and more easily find the relevant topics most suitable for the future dissemination and publication in CCE. This work has relied on the established and most often used publication related performance indexes with all their known strong and weak points. As such, any future analyses and rankings are likely to use

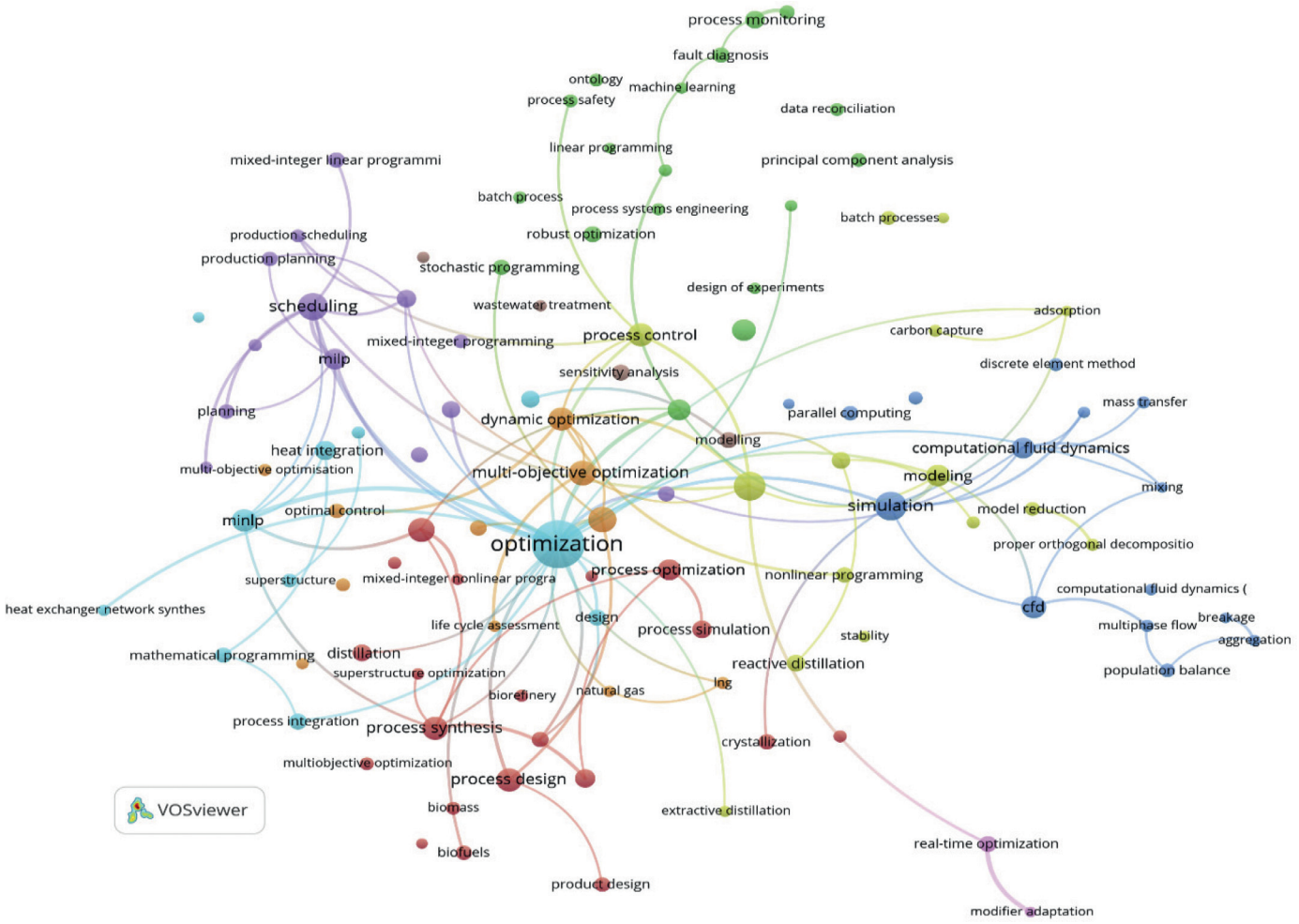


**Fig. 18.** Co-occurrence of author keywords in CCE: 2009–2018 (minimum occurrence threshold of 10 and 100 links).

an improved methodology in this very dynamically changing area of bibliometric analyses.

## Acknowledgment

The authors are grateful to the editor-in-chief and the anonymous referees for their useful suggestions to enhance the quality of the paper. The first author is always grateful to Shri Bibhas Chandra Das for giving endless support and encouragement.

## Declaration of Competing Interest

There is no conflict of interest with the subject matter or research presented in the manuscript.

## References

Biemans, W., Griffin, A., Moenaert, R., 2007. Twenty years of the Journal of Product Innovation Management: history, Participants and Knowledge Stocks and Flows. Journal of Product Innovation Management 24, 193–213.
Blanco-Mesa, F., Merigó, J.M., Gil-Lafuente, A.M., 2017. Fuzzy decision making: a bibliometric-based review. Journal of Intelligent & Fuzzy Systems 32, 2033–2050.
Bornmann, L., Wagner, C., Leydesdorff, L., 2015. BRICS countries and scientific excellence: a bibliometric analysis of most frequently cited papers. J Assoc Inf Sci Technol 66 (7), 1507–1513.
Cancino, C., Merigó, J.M., Coronado, F., Dessouky, Y., Dessouky, M., 2017. Forty years of Computers & Industrial Engineering: a bibliometric analysis. Computers & Industrial Engineering 113, 614–629.
Cobo, M.J., Martínez, M.A., Gutiérrez-Salcedo, M., Fujita, H., Herrera-Viedma, E., 2015. 25 years at Knowledge-Based Systems: a bibliometric analysis. Knowl Based Syst 80, 3–13.
Douglas, J.M., 1988. Conceptual Design of Chemical Processes (Vol. 1110). McGraw-Hill, New York.
Downs, J.J., Vogel, E.F., 1993. A plant-wide industrial process control problem. Comput Chem Eng 17 (3), 245–255.
Franceschini, S., Faria, L.G., Jurowetzki, R., 2016. Unveiling scientific communities about sustainability and innovation. A bibliometric journey around sustainable terms. J Clean Prod 127, 72–83.
Gaviria-Marin, M., Merigo, J.M., Popa, S., 2018. Twenty years of the Journal of Knowledge Management: a bibliometric analysis. Journal of Knowledge Management 22 (8), 1655–1687.
Geoffrion, A.M., 1972. Generalized benders decomposition. J Optim Theory Appl 10 (4), 237–260.
Heck, J.L., Bremser, W.G., 1986. Six decades of The Accounting Review: a summary of author and institutional contributors. The Accounting Review 61, 735–744.
Hirsch, J.E., 2005. An index to quantify an individual's scientific research output. Proc. Natl. Acad. Sci. U.S.A. 102 (46), 16569–16572.
Kazemi, N., Modak, N.M., Govindan, K., 2018. A review of reverse logistics and closed loop supply chain management studies published in IJPR: a bibliometric and content analysis. International Journal of Production Research 1–24.
Kessler, M.M., 1963. Bibliographic coupling between scientific papers. American Documentation 14 (1), 10–25.
Kondili, E., Pantelides, C.C., Sargent, R.W.H., 1993. A general algorithm for short-term scheduling of batch operations—I. MILP formulation. Comput Chem Eng 17 (2), 211–227.
Laengle, S., Merigó, J.M., Miranda, J., Słowiński, R., Bomze, I., Borgonovo, E., Dyson, R.G., Oliveira, J.F., Teunter, R., 2017. Forty years of the European Journal of Operational Research: a bibliometric overview. Eur J Oper Res 262 (3), 803–816.
Laengle, S., Merigó, J.M., Modak, N.M., Yang, J.B., 2018a. Bibliometrics in operations research and management science: a university analysis. Ann Oper Res 1–45. doi:10.1007/s10479-018-3017-6.
Laengle, S., Modak, N.M., Merigó, J.M., De La Sotta, C., 2018b. Thirty years of the International Journal of Computer Integrated Manufacturing: a bibliometric analysis. International Journal of Computer Integrated Manufacturing 31 (12), 1247–1268.

Laengle, S., Modak, N.M., Merigo, J.M., Zurita, G., 2018c. Twenty-Five Years of Group Decision and Negotiation: a Bibliometric Overview. Group Decision and Negotiation 27 (4), 505–542.
Linton, J.D., 2004. Perspective: ranking Business Schools on the management of technology. Journal of Product Innovation Management 21, 416–430.
Martínez-López, F.J., Merigó, J.M., Valenzuela, L., Nicolás, C., 2018. Fifty years of the European Journal of Marketing: a bibliometric analysis. Eur J Mark 52, 439–468.
Mas-Tur, A., Modak, N.M., Merigó, J.M., Roig-Tierno, N., Geraci, M., Capecchi, V., 2018. Half a century of Quality & Quantity: a bibliometric review. Qual Quant 53 (2), 981–1020.
Merigó, J.M., Blanco-Mesa, F., Gil-Lafuente, A.M., Yager, R.R., 2017. Thirty years of the International Journal of Intelligent Systems: a bibliometric review. International Journal of Intelligent Systems 32, 526–554.
Merigó, J.M., Mas-Tur, A., Roig-Tierno, N., Ribeiro-Soriano, D., 2015. A bibliometric overview of the Journal of Business Research between 1973 and 2014. J Bus Res 68 (12), 2645–2653.
Merigó, J.M., Miranda, J., Modak, N.M., Boustras, G., de la Sotta, C., 2019a. Forty years of Safety Science: a bibliometric overview. Saf Sci 115, 66–88.
Merigó, J.M., Muller, C., Modak, N.M., Laengle, S., 2019b. Research in Production and Operations Management: a University-Based Bibliometric Analysis. Global Journal of Flexible Systems Management 20 (1), 1–29.
Merigó, J.M., Cancino, C.A., Coronado, F., Urbano, D., 2016. Academic research in innovation: a country analysis. Scientometrics 108 (2), 559–593.
Merigó, J.M., Pedrycz, W., Weber, R., de la Sotta, C., 2018. Fifty years of Information Sciences: a bibliometric overview. Inf Sci (Ny) 432, 245–268.
Merino, M.T.G., Do Carmo, M.L.P, Alvarez, M.V.S., 2006. 25 Years of technovation: characterisation and evolution of the journal. Technovation 26 (12), 1303–1316.
Modak, N.M., Merigó, J.M., Weber, R., Manzor, F., Ortuzar, J.D., 2019. Fifty years of Transportation Research journals: a bibliometric overview. Transportation Research Part A 120, 188–223.
Morari, M., Lee, J.H., 1999. Model predictive control: past, present and future. Comput Chem Eng 23 (4–5), 667–682.
Ramos-Rodríguez, A.R., Ruíz-Navarro, J., 2004. Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal, 1980–2000. Strategic Management Journal 25 (10), 981–1004.
Small, H., 1973. Co-citation in the scientific literature: a new measure of the relationship between two documents. Journal of the American Society for information Science 24 (4), 265–269.
Takama, N., Kuriyama, T., Shiroko, K., Umeda, T., 1980. Optimal water allocation in a petroleum refinery. Comput Chem Eng 4 (4), 251–258.
Valenzuela, L., Merigó, J.M., Johnston, W., Nicolás, C., Jaramillo, F., 2017. Thirty years of the Journal of Business & Industrial Marketing: a bibliometric analysis. Journal of Business & Industrial Marketing 32, 1–18.
Van Eck, N.J., Waltman, L., 2010. Software survey: vOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538.
Venkatasubramanian, V., Rengaswamy, R., Yin, K., Kavuri, S.N., 2003. A review of process fault detection and diagnosis: part I: quantitative model-based methods. Comput Chem Eng 27 (3), 293–311.
Wang, W., Laengle, S., Merigó, J.M., Yu, D., Herrera-Viedma, E., Cobo, M.J., Bouchon-Meunier, B., 2018. A bibliometric analysis of the first twenty-five years of the International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems. International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems 26, 169–193.
Weiss, M.A., Qiu, J., 2008. The Journal of Risk and Insurance: a 75-Year Historical Perspective. Journal of Risk and Insurance 75 (2), 253–274.
Yue, D., You, F., Snyder, S.W., 2014. Biomass-to-bioenergy and biofuel supply chain optimization: overview, key issues and challenges. Comput Chem Eng 66, 36–56.
Zhang, T., Sahinidis, N.V., Rosé, C.P., Amaran, S., Shuang, B., 2019. Forty years of Computers and Chemical Engineering: analysis of the field via text mining techniques. Comput Chem Eng 129, 106511.
Zhong, S., Geng, Y., Liu, W., Gao, C., Chen, W., 2016. A bibliometric review on natural resource accounting during 1995–2014. J Clean Prod 139, 122–132.