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# Trevor Kletz's scholarly legacy: A co-citation analysis

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A R T I C L E I N F O

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A B S T R A C T

Dr. Kletz is one the pioneers in the process safety area, known widely for his work on inherent safety design and loss prevention. He worked 38 years in Imperial Chemical Industries, and became a fulltime researcher only after his retirement. He published more than 200 papers and 15 books during his retirement. The intellectual basis analysis presented in this article shows that he frequently cited his books in his articles, indicating that his industrial experience was very influential to his scholarly contributions. Lawley, H.G. was one of the researchers whose work had most influence on Kletz's research. Among Dr. Kletz's publications, the article '*What You Don't Have, Can't Leak*' has the highest impact, while his most influential book is '*Process plants: A handbook for inherently safer design*'. The references co-citation network is divided in two clearly connected components: his earlier work related to infra-red spectra, and his later work addressing process safety related topics, including inherent safety and hazard and accident analysis. Both his work and that of his followers is rooted in a similar intellectual basis within process safety research, in which particularly Dr. Kletz's earlier work forms an influential original body of knowledge rooted in his industrial experience. His career is a prime example of how process safety research has been strongly influenced by knowledge from industrial practice, illustrating that a continued strong connection between industry and academia can lead to very fruitful outcomes. It is hoped that the presented analysis can inspire especially young graduates with academic interests to first embark on an industrial career to gain industrial experience before aiming to contribute to academic process safety knowledge.

## 1. Introduction

Trevor Kletz (1922–2013) was one of the pioneers in the process safety area. He has spent his whole life to improve safety in high-risk industrial sectors. He was interested in chemistry when he was young, which led him later to study chemistry in Liverpool University, from which he obtained a BSc degree. After he graduated in 1944, he joined the research lab of Imperial Chemical Industries (ICI) in Billingham, UK, where he worked for 38 years until 1982 (Garside, 2006; Flavell-While, 2018). There, he dedicated 8 years to chemistry-focused research, worked 16 years in production management, and served the last 14 year as process safety adviser to the Petrochemicals Division (AIChE, 2020). After his retirement from ICI, he went to Loughborough University and he became a fellow of the Royal Academy of Engineering. This marks an important turning point in his career, as he started his second career as a consultant and prolific writer, commentator, and lecturer on all aspects of process safety (Public Relations Office, 2006). In 2003, he was appointed as adjunct professor at the Mary Kay O'Connor Process Safety Center at Texas A&M University. At that time, his PhD student Mahboobul Sam Mannan, another highly influential author in the process safety domain (Li et al., 2020; Wang et al., 2020), was director and professor in that center. During his research career, Dr. Kletz published over 10 books and more than 300 articles on process safety (MKOCPS Center, 2013), with topics including human error (Kletz, 1990, Kletz, 1993a), accident and disasters research (b, c, Kletz, 2001a, b, c), inherent safety (Kletz, 1978, Kletz, 1998a, Kletz and Amyotte, 2010), and methods such as HAZOP and HAZAN (Kletz, 2006a). He is perhaps most remembered as being the 'father of inherent safety', and for his contributions to HAZAN and HAZOP (Vaughen, 2012).

There are many articles and reviews published as a tribute to Dr.

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Kletz's contributions to the process safety domain. For example, in 2012, Paul Amyotte, Atsumi Miyake and Genserik Reniers co-edited a Special Issue '*Happy* 90th *Birthday, Professor Trevor Kletz*' (Volume 25, Issue 5, Pages 761–876) in *Journal of Loss Prevention in the Process Industries* to celebrate Dr. Kletz's 90th birthday. There are 17 articles published in this Special Issue, including a paper contributed by Dr. Kletz himself, entitled '*The history of process safety*' (Kletz, 2012). In the same year, *Process Safety and Environmental Protection* also opened a Special Issue '*Celebrating Trevor Dr. Kletz's* 90th *Birthday*', edited by David Edwards and Jai P. Gupta (Volume 90, Issue 5, Pages 341–450), in which 12 research articles were published. In addition, several book reviews (Galluzzo, 1988; Mooney, 1992; Grossel 2002, 2004) were published to introduce Dr. Kletz's works, which further spread his ideas regarding process safety.

The tributary editorials and research contributions in the above mentioned special issues focusing on Dr. Kletz's work mostly concern personal reflections on his work and career (Crowl, 2012; Gowland, 2012) or involve narrative reviews or perspectives of his work to reflect on its impact in the process safety domain (Gómez et al., 2012) (Mannan, 2012; Sanders, 2012).

In this article, a complementary approach is taken. Aiming to obtain high-level insights in the structure of his scientific work, a quantitative scientometric analysis is performed. In particular, through performing a co-citation analysis, insights in the intellectual basis (knowledge sources used) of Kletz's work and in the influence his work has had in the process safety research domain (Kletz's work as a knowledge source), are obtained. Similar scientometric analyses have been published about the research work of highly influential academics in various scientific domains, for instance Dr. Sam Mannan in process safety (Li et al., 2020), Dr. Eugene Garfield in scientometrics (Chen, 2018), and Dr. Keith Pavitt in science, technology, and innovation studies (Meyer et al., 2004). Of particular interest in the analysis in this article is how his industrial experience has influenced his scholarly contributions.

The remainder of this article is organized as follows. In Section 2, the data collection process and the methodology for analysis is outlined. Section 3 presents the results. First, the body of literature by Dr Kletz is quantitatively described in light of significant events in his career. Then, an overview of the intellectual basis of his work is presented, through a co-citation analysis. Finally, the cited references by his followers are analysed through a co-citation analysis, providing insights in the influence of Dr. Kletz's work in the process safety research community. Section 4 summarizes the main findings and concludes.

## 2. Data and methodology

### 2.1. Data collection

As mentioned in Section 1, Dr. Trevor Kletz has published more than 300 scientific articles during his research career. In order to obtain an as complete as possible set of these publications, with additional bibliographic information such as the references cited in these papers, the Web of Science Core Collections (WoSCC) was selected as a data source in this study. WoSCC has indexed almost all of the world's important scientific publications, including journal and conference papers ranging from the natural sciences to social science domains. The search strategy for obtaining Dr. Kletz's publications is represented below:

- Author: (Kletz T*)
- Timespan: 1900–2019
- Database: Web of Science Core Collection
- Indexes: SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH.
- Science Citation Index Expanded (SCI-EXPANDED): 1900-present
- Social Sciences Citation Index (SSCI): 1900-present
- Conference Proceedings Citation Index- Science (CPCI-S): 1990-present
- Conference Proceedings Citation Index- Social Science & Humanities (CPCI-SSH): 1990-present
- Data retrieval date: 03-29-2020

After a manual check of the resulting data set, performed by inspecting the titles and abstracts of the dataset retrieved from WoSCC using the above strategy, a total of 250 records are retained for further analysis. An overview of the dataset and the dataset of the citing articles, along with their references, is given in Fig. 1. There are 250 publications by Dr. Kletz's, which together include 996 references indexed in WoSCC, spanning a period from 1947 to 2012. His publications have received 588 citations in total, with 12 publications having received at least 12 citations in WoSCC, leading to an h-index of 12. After retrieving the papers by Dr. Kletz, the 'citations expand function' was used to download the data concerning the articles published by his followers, as available in WoSCC. This dataset of publications citing Dr. Kletz's work contains 469 documents, spanning a period from 1948 to 2020 (until March 29). Together, these contain 16,734 references, which can considered to be the knowledge base for the research activities by Dr. Kletz's followers. In Fig. 1, the references cited by Dr. Kletz and by his followers likely partially overlap, and in the latter by definition includes dataset 1. For simplicity of representation, these dependencies are not shown.

### 2.2. Methodology

Three research questions (RQs) are addressed in this article, see also Fig. 1:

RQ1. What is the evolution of the articles by Dr. Kletz in light of major events in his career?
RQ2. What are the main research clusters and research fronts apparent from the intellectual basis (references) of Dr. Kletz's work?
RQ3. What are the main research clusters and research fronts apparent from the intellectual basis (references) of the publications by Dr. Kletz's followers?

For RQ1, a simple graphical quantitative representation of the evolution of Dr. Kletz's research output is applied, supported by simple descriptive statistics and information obtained from the literature.

For RQ2 and RQ3, reference co-citation analysis is applied to map the structure of the body of knowledge created by Dr. Kletz and his followers. The concept of co-citation was first introduced by Small (1973) and Marshakova (1973) independently from one another in 1973, as a new method to measure the relationship between two documents. Two documents are co-cited if they both appear in the reference lists of a certain paper. The basic hypothesis underlying co-citation analysis is that the more two documents are co-cited (i.e. the more same references are included in these documents), the more similar these two documents are. Hence, highly co-cited documents can be considered to address similar research problems.

The latest version CiteSpace 5.6 R3 (Chen, 2020) is applied to construct and visualize the co-citation networks of Dr. Kletz's publications (RQ2) and that of the publications by his followers (RQ3). CiteSpace is developed by Chen (2006), and has been updated over more than 15 years. Over time, it has become one of the most applied bibliometrics mapping analysis tools, with thousands of scientific papers published using CiteSpace (Li and Chen, 2016). Compared to other bibliometrics mapping tools such as VOSviewer (van Eck and Waltman, 2010), BibExcel (Persson et al., 2009), or SCI2 (Light et al., 2014), CiteSpace is particularly suited for a temporal analysis of the co-citation network of a given set of publications. First, the publication years of the citing articles are divided into different time slices. Then, CiteSpace constructs the references co-citation network for each time slice. Finally, these time slice specific co-citation networks are merged into one network and a graphical clustering is applied to facilitate the visual

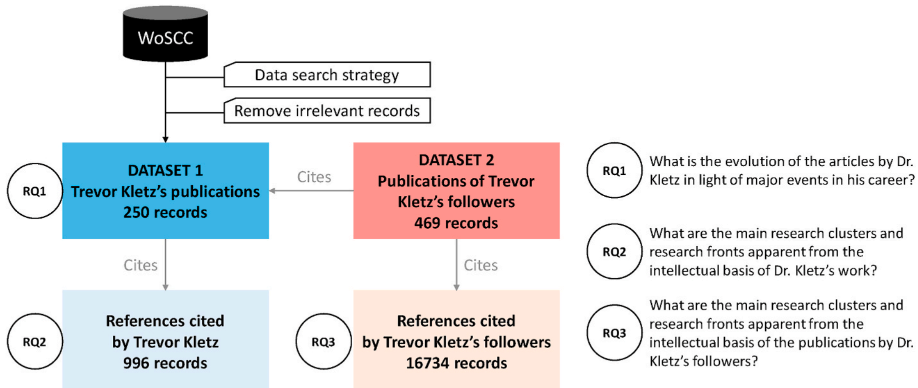


**Fig. 1.** Overview of datasets used for the scientometric analyses and associated research questions

interpretation of the results.

The conceptual model of co-citation analysis in CiteSpace is represented in Fig. 2 (Chen, 2006). Three sample citing articles are shown at the top of the figure, which together constitute the research front. The references of each of these citing articles are represented as black dots inside the bottom, and together can be regarded as the intellectual basis of the research domain. In the co-citation network cluster analysis, the co-citation links between two references are normalized using Cosine similarity methods (Chen et al., 2010) and the spectral clustering method is used to divide the references into different groups. To assess the quality of the clustering and the degree of separation between these, the Modularity Q (Newman, 2006) and Silhouette metrics (Rousseeuw, 1987) are calculated for the resulting network. The value of the Modularity Q ranges from 0 to 1, with larger values corresponding to better cluster quality. The Silhouette value ranges from −1 to 1, where the value 0.7 is commonly recommended as a threshold to separate clusters and to give these different interpretations (Chen et al., 2010). Furthermore, to facilitate interpretation of the results, the clusters were labelled with a noun phrase, which is extracted from the title of the citing articles using the log-likelihood ratio (LLR) algorithm (Dunning, 1993). In Fig. 2, the oval areas represent the clusters in the references co-citation network, where the small red rectangles are the terms extracted from the title of the citing articles, and used as labels of the co-citation clusters.

In the generated co-citation network, the node and label size are used to represent the number of citations of a reference, and the edges in the network encode the co-citation links between two references. The colour in the network provides information about the earliest year in which a co-citation between two references is detected. Each identified cluster in the co-citation network is furthermore shaded with a colour representing the average year of the references within a certain group. These visual markers are implemented in the visual representation of the co-citation network to facilitate interpretation of the research evolution.

## 3. Results

### 3.1. Evolution of articles authored by Dr. Kletz

There are in total 250 papers authored by Kletz retrieved from WoSCC, the annual trends of which are represented in Fig. 3. In this figure, the evolution of his publications is contextualized in light of key events in his career. The information used for this is based on (Public Relations Office, 2006; Loughborough University, 2007; Edwards, 2014).

After he graduated from Liverpool University in 1944, he joined ICI where he worked on chemistry research for 8 years (from 1944 to 1952). During this period, he published three co-authored articles (Kletz and Price, 1947; Ashdown and Kletz, 1948; Kletz and Sumner, 1948), of

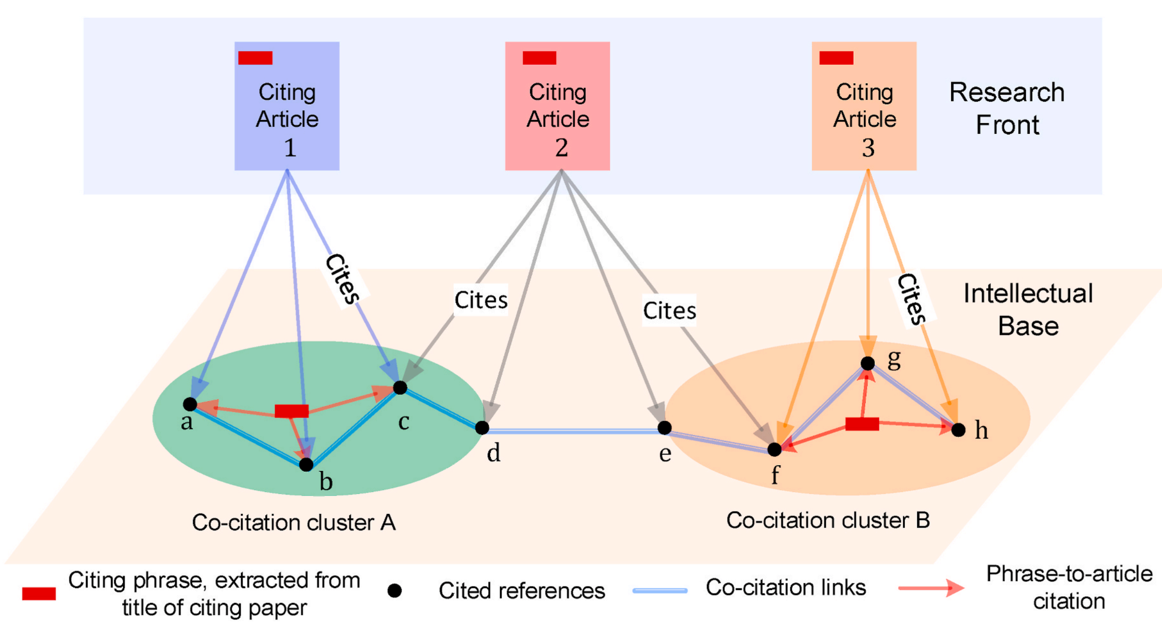


**Fig. 2.** Conceptual representation of the co-citation analysis method implemented in CiteSpace, based on Chen (2006)

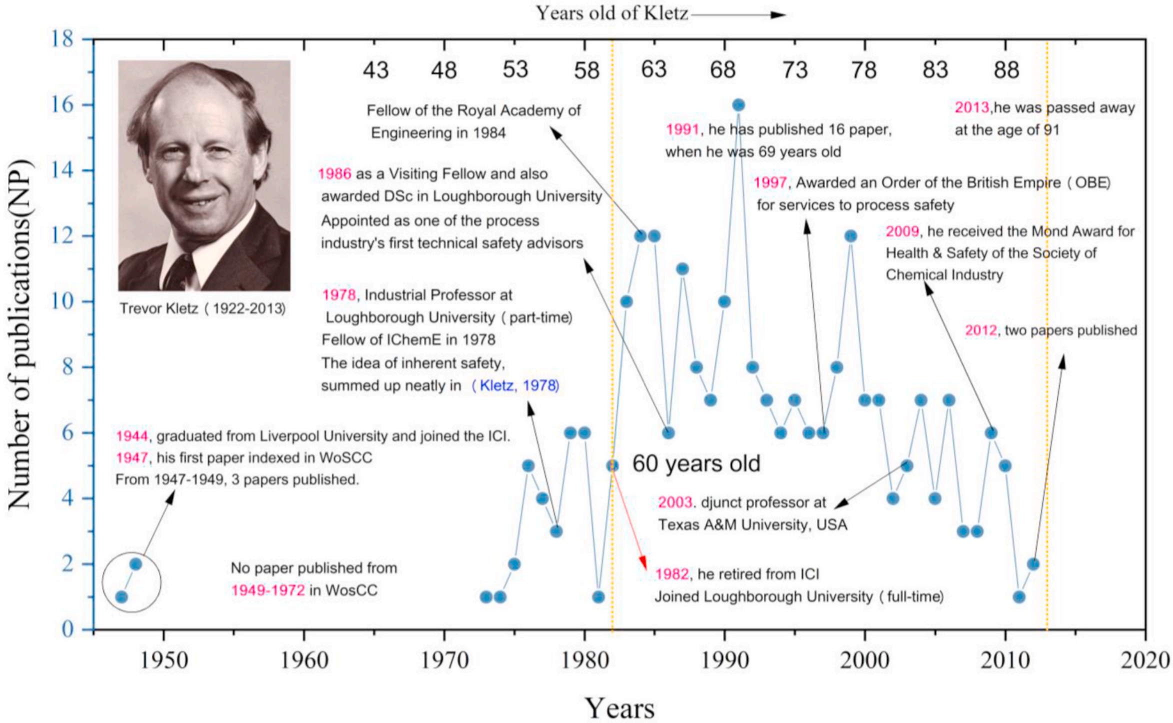


**Fig. 3.** Evolution trend of Dr. Kletz's published research articles in context of key events in his career

which two are related to Infra-Red Spectra. He did not publish any paper during the period 1950–1972, which largely corresponds to the time he worked in production management in ICI (1952–1968, i.e. 16 years).

From 1969 to 1982 (14 years), he served as process safety adviser to the Petrochemicals Division for 14 years. Having spent a long time in the front line of process safety practise, he became very knowledgeable in process safety practise, and his interest in academia was rekindled. During his time as a process safety adviser, his publications increased rapidly from 1973 to 1980. In this time period, he first proposed the idea of inherent safety in his paper '*What You Don't Have, Can't Leak*' (Kletz, 1978). He was also appointed as a part-time professor in Loughborough University. It can be said that his long experience in ICI led him to become a highly productive and prominent process safety researcher.

After his retirement from ICI, he started his second career as a full-

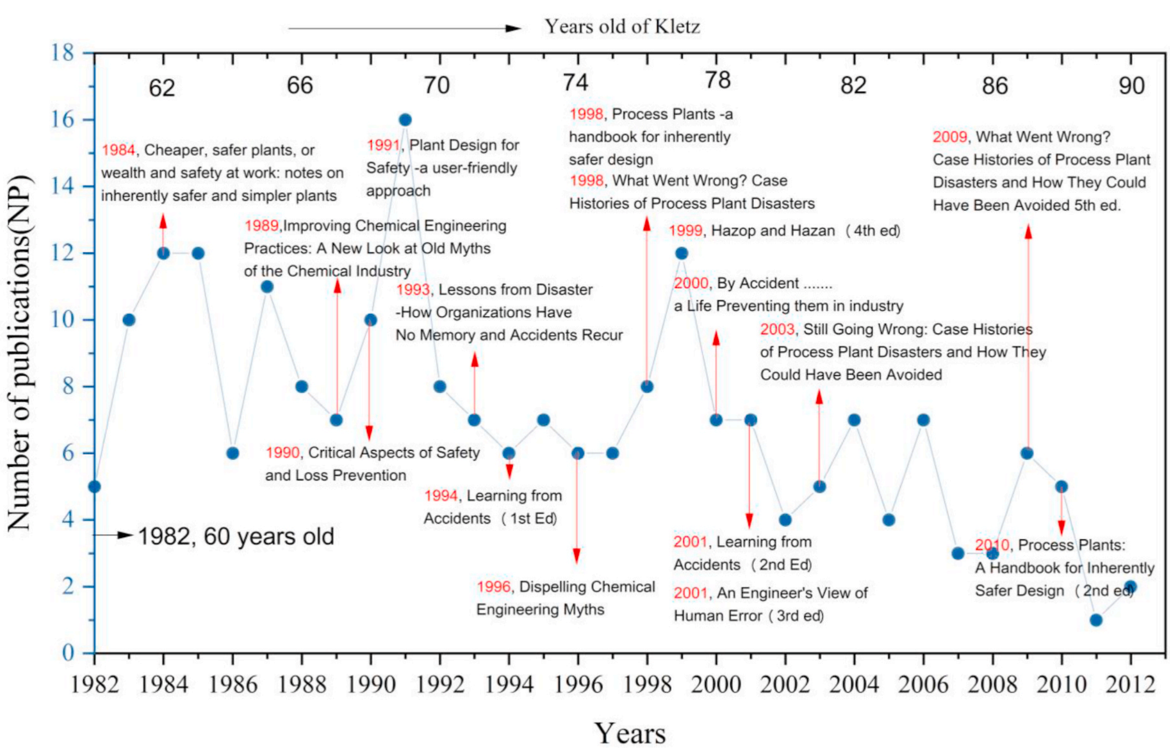


**Fig. 4.** Publication trend of Dr. Kletz's books, summarized from (Vaughen, 2012)

time scholar in process safety area. As represented in Fig. 3, almost all of his scientific papers are published after 1982 (213 articles, accounting for 85.2%). In 1991, when he was 69 years old, his publications reached the peak of his outputs, amounting to 16 papers published in that year. Thereafter, his outputs decreased rapidly until 2012, after which he did not publish anymore. Even in 2012, at the age of 90, he published two articles (Kletz, 2012; Vaughen and Kletz, 2012).

Fig. 4 shows the books authored by Kletz from 1984 to 2010, summarized based on (Vaughen, 2012). Clearly, Dr. Kletz was not only highly productive in publishing scientific papers, but also was very prolific in writing books.

Most scholars perform very little research after their retirement, and usually publish only a few articles or books during their emeritate. However, as the current analysis shows, Dr. Kletz has a truly exceptional career as a scholar. He gained a lot of practical experience from industry until he retired, and then very successfully embarked on a second career in process safety research. This shows Dr. Kletz's passion for process safety, as he truly devoted his life to it. His career also is a great example of how a career based in industrial practice can be a very solid basis for becoming a highly influential academic.

### 3.2. *Clusters and research fronts in the intellectual basis of Dr. Kletz's work*

The references cited in Dr. Kletz's publications, especially the highly frequently appearing ones can be regarded as the intellectual basis of his research. As found in Section 2.1, there are in total 996 references cited in his work. In this section, the reference co-citation network analysis is applied to show the intellectual structure underlying his work.

To construct a clear reference co-citation network, the top-50 ranked citing papers in terms of citations received are selected as the dataset to create the reference co-citation network. This leads to a set of 752 references selected from the data sample, to which 4404 co-citation links are associated. The largest connected component of the reference co-citation network of Dr. Kletz' s publications includes 614 references and is shown in Fig. 5. The references with more than 5 citations are listed in Table 1 and highlighted in Fig. 5. Among these references in Table 1, there are 10 references authored by Dr. Kletz, with other authors being Lawley H.G., Lees F.P., and Gibson S.B. The timespan of the references ranges from 1974 to 2003, with 8 out of the 14 cited references in Table 1 published before 1990. This shows that Dr. Kletz in his research relies heavily from insights obtained from industrial practice. It

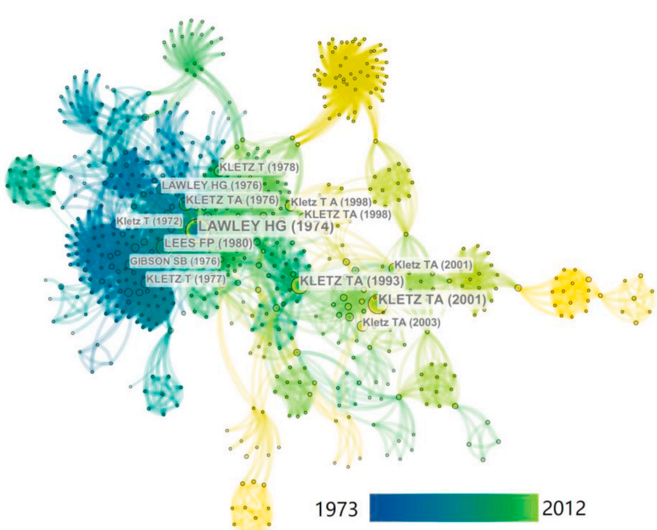


**Fig. 5.** Reference co-citation network and clusters of Dr. Kletz's publications, references cited more than 5 times by Dr. Kletz

also indicates that most of the work influencing his thinking dates from the early period in the development of process safety research, in which significant research volumes only became published from the 1990s onwards (, Li et al., 2020).

In the highly cited references list, the most prevalent topics concern hazards, accidents, and industrial losses. These highly-cited references have a significant influence in his research. The most cited reference in Dr. Kletz's work was published in 1974, authored by Lawley H.G. The core topic of that article focuses on 'hazard analysis' and 'HAZOP', and is referenced in (Kletz, 1997), where he states that "*The first publication on HAZOP in the open literature was a paper by Herbert Lawley presented at the 1973 AICHE Loss Prevention Symposium*". The second most cited paper authored by Lawley H.G. is entitled '*Size up plant hazards this way*', published in *Hydrocarbon Processing* (Lawley, 1976). In the list of Table 1, other influential authors to Dr. Kletz's work include Lees F.P. and Gibson S.B. This shows that Dr. Kletz is a true process safety pioneer as he contributed to the process safety domain on the shoulder of a few scholars (i.e. Lawley H.G., Gibson S.B., and Lees F.P.), creating a large body of knowledge based on his own insights. His large reliance on his own work could also be seen as a weakness, as current research developments in process safety research shows the value of the diversity in conceptual and theoretical contributions to the development of a domain (Li et al., 2020).

In the remainder of the highly cited publications in Dr. Kletz's research contributions, there are seven books authored by Dr. Kletz. These give a systematic introduction to past accidents and losses, and put forward new insights to advance the understanding of the nature of errors and accidents. Here, it is noteworthy that his work continues to be relevant even long after he passed away. This is evident from the recent publication of a new (sixth) edition of his book "What went wrong?", in which co-author Paul Amyotte builds further on Dr. Kletz's legacy to provide insights in process plant disasters and how they can be avoided (Kletz T and Amyotte P 2019).

The reference co-citation network is clustered by the Modularity method, and a cluster label is selected from the citing publications as generated by the LLR algorithm, as outlined in Section 2.2. The clustering result of the Modularity Q equals 0.7755, which represents a high quality cluster.

In total, there are 80 clusters identified from the co-citation network, where many groups include only very few publications and are not connected to the largest connect network. The largest connect network includes 614 members, accounting for 84% of the extracted references. Hence, in this Section, only the largest connected network component is clustered and discussed. The clusters of the reference co-citation analysis are shown in Fig. 6, where clusters are filled with the mean publication year of the cluster members. Clusters indicated with a shade closer to yellow are more recent. The clusters members with more than 50 citations are listed in Table 2, and the references inside the clusters which received at least 2 citations are shown in Fig. 6. As show in those, the mean year and co-citation links of the clusters #a, #e and #d are earlier than other clusters. This indicates that Dr. Kletz's research associated with those knowledge bases stems from earlier years. For example, his research in protecting pressure-vessels from fire, hazard analysis review, Human Performance Improvement (HPI), and HAZOP olefin plant safety predates work on loss prevention, human factors, and accident investigation, which he engaged in more in the 1980s and 1990s.

In this context, it is noteworthy that the work by Lawley (1974) appears to be the earliest document influencing Dr. Kletz's thinking in a significant manner. Nevertheless, it is worth pointing out that Dr. Kletz noted in his own reflections on the origins and history on loss prevention, that events such as the first American Institute of Chemical Engineers annual loss prevention symposium in 1967 and the first European conference of loss prevention in Newcastle in 1971 were very influential to establishing a collaborative community of process safety practitioners and experts, with articles such as (Kletz, 1971) on hazard analysis, (Stewart, 1971) on high integrity protective systems, and (Bell, 1971) on

**Table 1**
References cited by Dr. Kletz more than 5 times

| No. | First author | Year | Sources title | SC | Title phrase | Note | Reference |
|---|---|---|---|---|---|---|---|
| 1 | Lawley H.G. | 1974 | Chem Eng Prog | 18 | hazard analysis | | Lawley (1974) |
| 2 | Kletz T. | 2001 | Learning Accidents | 14 | learning accidents | ■ | (Kletz, 2001c) |
| 3 | Kletz T. | 1993 | Lessons Disaster Org | 12 | lessons from disaster | ■ | (Kletz, 1993b) |
| 4 | Lees F.P. | 1980 | Loss Prevention | 10 | loss prevention | ■ | Lees (1980) |
| 5 | Kletz T. | 1976 | Chem Eng Prog | 9 | plant modification | | (Kletz, 1976c) |
| 6 | Kletz T. | 1998 | What Went Wrong | 7 | went wrong | ■ | (Kletz, 1998b) |
| 7 | Kletz T. | 1978 | Chem Ind | 7 | leak | | Kletz (1978) |
| 8 | Kletz T. | 2003 | Still Going Wrong | 7 | going wrong | ■ | (Kletz, 2003b) |
| 9 | Kletz T. | 2001 | Eng View Human Error | 7 | human error | ■ | (Kletz, 2001b) |
| 10 | Lawley H.G. | 1976 | Hydrocarb Process | 7 | plant hazards | | Lawley (1976) |
| 11 | Kletz T. | 1977 | Hydrocarb Process | 7 | plant design | | (Kletz, 1977a) |
| 12 | Kletz T. | 1998 | Process Plants Hdb I | 7 | inherently Safer Design | ■ | (Kletz, 1998a) |
| 13 | Kletz T. | 1972 | Loss Prevention | 6 | protective systems | | Kletz (1972) |
| 14 | Gibson S.B. | 1976 | Chem Eng Prog | 6 | hazard analysis | | Gibson (1976) |

**Notes:** SC = self-citations, number of times cited by the papers from 251 publications | ■ Book.

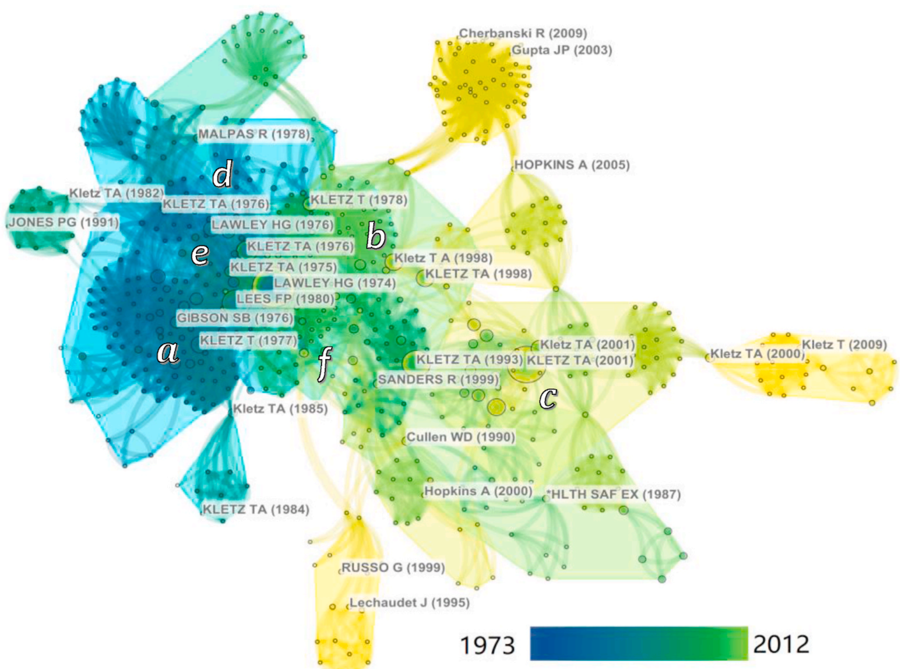


**Fig. 6.** Reference co-citation network and clusters of Dr. Kletz's publications, top 2 cited references labelled

**Table 2**
Cluster information of clusters at least with 50 members

| ID | Size | Silhouette | Mean year | LLR Title terms | Selected citing papers |
|---|---|---|---|---|---|
| *a* | 91 | 0.919 | 1972 | Pressure-Vessel; Fire; Hazard Analysis | (Kletz, 1977a; Kletz, 1982a) |
| *b* | 77 | 0.815 | 1985 | Loss Prevention; HPI; Lesson | (Kletz (1999)) |
| *c* | 67 | 0.809 | 1995 | Human Factor; Accident Investigation | (Kletz, 2001a, b) |
| *d* | 60 | 0.846 | 1977 | Olefin Plant Safety; Preventing Catastrophic Accident | (Kletz, 1976b; Barker et al., 1977, Kletz, 1996) |
| *e* | 52 | 0.856 | 1979 | HPI; Lesson; Hazop | (Kletz, 1976c, Kletz, 1982a, Kletz, 1985, Kletz, 1997) |
| *f* | 51 | 0.868 | 1993 | Loss Prevention Case-Histories; HPI; Olefin Plant Safety | (Kletz, 1976c, Kletz, 1995) |

loss prevention in nitroglycerine manufacturing examples of the topics addresses in such early community building efforts. Discussions in such symposia were very influential to Dr. Kletz's thinking as well, and his influence on contemporary authors is evident for instance from the work by (Houston, 1971), who acknowledges discussions with Dr. Kletz in his contribution covering early ideas related to HAZOP, fault trees, and inherently safe design. This article also highlights the importance of the work at various divisions of ICI, where Dr. Kletz was then working, as an important source for collaborative process safety developments, highlighting the importance of practical industrial experience in advancing process safety scholarship.

### 3.3. *Clusters and research fronts in the intellectual basis of the work of Dr. Kletz's followers*

As shown in Section 2.1, 467 citing papers of Dr. Kletz's publications are downloaded from the WoSCC. The reference co-citation network of Dr. Kletz's followers is shown in Fig. 7, in which references with more than 15 citations are displayed. More detailed information about these is given in Table 3. From the co-citation network and the highly cited references, it is evident that the landmark papers the co-citation network of the intellectual basis of his followers are almost all authored by Dr. Kletz. Highly influential topics from Dr. Kletz's publications are related to inherently safer design, loss prevention, hazard analysis, and infra-red spectra.

The most highly cited paper, with 58 local citations, is his influential article entitled "*What you don't have, can't leak*" (Kletz, 1978). This is a foundational article presenting the concept of 'inherent safety' based on lessons from the Flixborough disaster. Many researchers have referenced this paper and taken ideas from it, marking it as a highly influential contributor to the process safety community. Among these, the article by Faisal Khan and Paul Amyotte entitled '*How to make inherent safety practice a reality*' has the highest impact, with 90 citations in WoSCC. Khan cited the paper as '*This, in part, led Trevor Kletz of ICI to suggest inherent safety as an explicit, identifiable component of process safety*' (Kletz and Amyotte, 2019; Khan and Amyotte, 2003).

In contrast to the co-citation analysis of Dr. Kletz's papers shown in Section 3.2, his followers more frequently cited his journal articles than his books. Nevertheless, his book entitled *'Process plants: A handbook for inherently safer design*' also has a high influence among his followers, and is influential to spreading the ideas related to inherent safety. Apart from Dr. Kletz's publications the work by Edwards and Lawrence (1993) on inherent safety, by Lawley (1974) on hazard analysis and by Gupta and Edwards (2002) on inherently safer design are also highly impactful publications for Dr. Kletz's followers.

The clustered reference co-citation network of the research citing Dr. Kletz' work is shown in Fig. 8, with detailed information of the co-citation clusters listed in Table 4. The modularity of the network is 0.8277, indicating a high quality of the clustering results. Two clearly separated components are identified, with the cited references from the smaller network on the right hand side having been published earlier than the larger network on the left hand side. The reference clusters on the left side hand point to Dr. Kletz's main body of research focusing on process safety. Key clusters here concern inherent safety, hazard and safety evaluation, and accident investigation and analysis. This reflects the more recent research of his followers addressing these topics. The clusters on the right hand side is are associated with his earlier research on infra-red spectra, which corresponds to the earlier research of his followers. The selected key articles by his followers are listed in the last column of Table 4. The mean year of publication of the references cited by his followers confirms the evolution of the research dynamics as earlier described.

**Table 3**
References cited by Trevor Dr. Kletz's followers

| No. | First author | Year | Sources title | Citations | Title phrase | Reference |
|---|---|---|---|---|---|---|
| 1 | Kletz T. | 1978 | Chem Ind | 56 | leak | Kletz (1978) |
| 2 | Kletz T. | 1997 | Reliab Eng Syst Safe | 31 | hazop | Kletz (1997) |
| 3 | Kletz T. | 2003 | Process Saf Environ | 29 | inherently safer design | (Kletz, 2003a) |
| 4 | Ashdown A. | 1948 | J Chem Soc | 19 | infra-red spectra | Ashdown and Kletz (1948) |
| 5 | Kletz T. | 1999 | Process Saf Environ | 19 | Loss Prevention | Kletz (1999) |
| 6 | Kletz T. | 1947 | J Chem Soc | 18 | infra-red spectra | Kletz and Price (1947) |
| 7 | Edwards D.W. | 1993 | Process Saf Environ | 18 | inherent safety | Edwards and Lawrence (1993) |
| 8 | Kletz T. | 2010 | Process Plants | 17 | inherently safer design | Kletz and Amyotte (2010) |
| 9 | Lawley H. G. | 1974 | Chem Eng Prog | 17 | hazard analysis | Lawley (1974) |
| 10 | Gupta J.P. | 2002 | Process Saf Environ | 16 | Inherently Safer Design | Gupta and Edwards (2002) |

## 4. Conclusions

In this article, a literature analysis is performed of the work by one of the most famous process safety pioneers, Dr. Trevor Kletz. By providing insights in his career and the evolution of his research focus areas, the aim is to help the process safety community, especially the early career researchers understand and appreciate the work by one of the fathers of the process safety domain. It is hoped that this can inspire young and aspiring academics, while also highlighting the importance of a strong connection between industrial practice and scientific work.

The analysis clearly shows that Dr. Kletz's career can be divided into two stages. The first stage spans the period 1944–1982, during which he worked for ICI. After his retirement, in the period 1982–2013, he

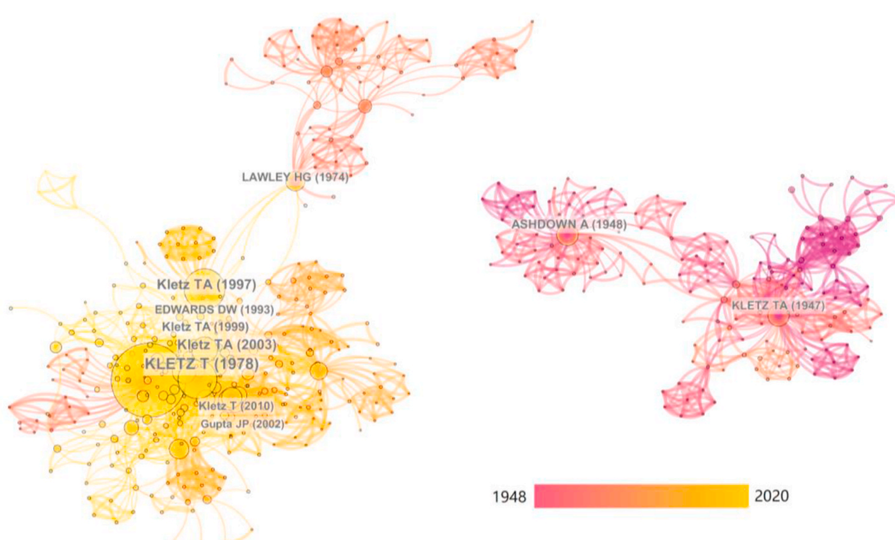


**Fig. 7.** Reference co-citation network of the publications of Dr. Kletz's followers, indicating record with more than 15 citations

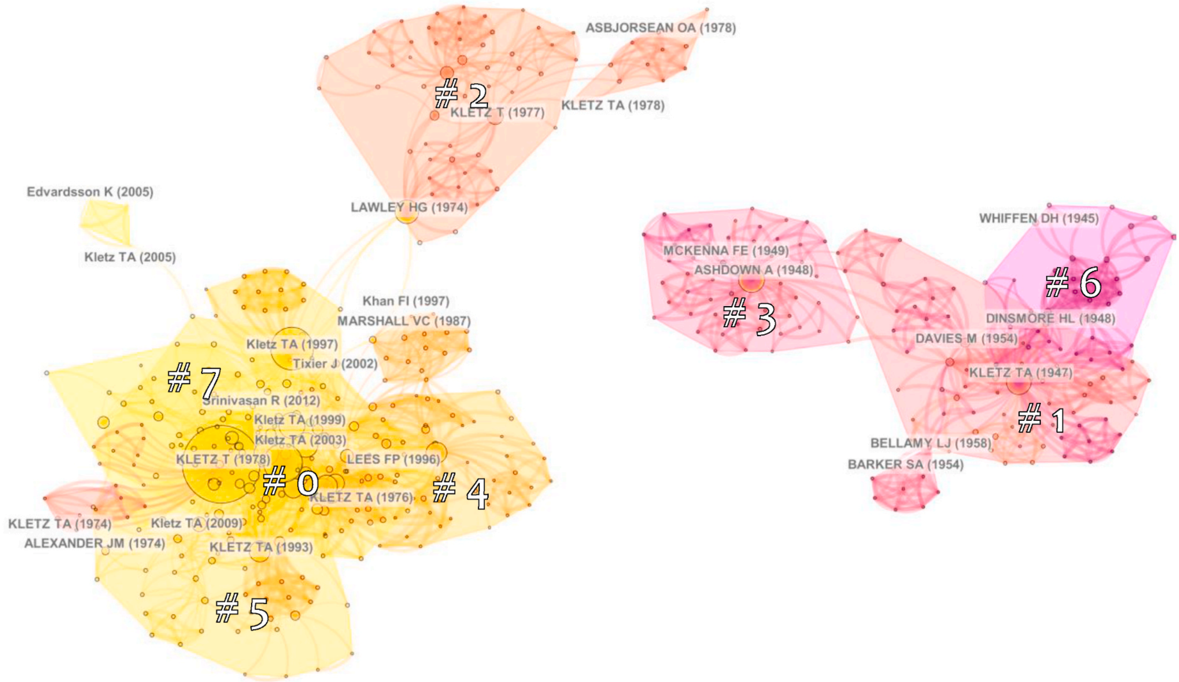


**Fig. 8.** Reference co-citation network and clusters of the work by Dr. Kletz's followers, references cited more than 15 times by his followers were labelled

**Table 4**
Information of main clusters of in the co-citation network of the work by Dr. Kletz's followers, clusters with at least 40 members shown

| ID | Size | Silhouette | Mean year | LLR | Selected citing papers |
|---|---|---|---|---|---|
| 0 | 104 | 0.74 | 2003 | inherent safety; fuzzy logic-based inherent safety index; inherent safety practice; inherent safety index | (Gentile et al., 2003; Khan and Amyotte, 2003; Srinivasan and Natarajan 2012) |
| 1 | 67 | 0.896 | 1955 | n-terminal group; infrared spectra; amino acid | (Ramachandran et al., 1955; Srivasta, 1970; Ansari and Srivastava, 1971) |
| 2 | 53 | 0.985 | 1977 | fault tree synthesis; designing safety; ethylene plant | (Barnwell, 1978; Martinsolis et al., 1982; Lovati, 1983) |
| 3 | 52 | 0.984 | 1948 | carboxylic acid derivative; addition compound; infrared absorption spectra | (Bender, 1953; Campbell et al., 1967; Lehenaff, 1968) |
| 4 | 49 | 0.89 | 1991 | weighted hazard index; comprehensive hazard identification; safety evaluation | (Kletz, 1999, Khan and Abbasi, 2001, Khan et al., 2001, Pekalski et al., 2005) |
| 5 | 49 | 0.898 | 2000 | accident investigation; risk metrics; occupational safety | (Kletz, 2002a, b, Johansen and Rausand, 2014, Sousa et al., 2014) |
| 6 | 41 | 0.955 | 1944 | aplikace infracervene spektroskopie; ultrarotspektroskopie als analytisches hilfsmittel | (Luttke, 1951; Pliva, 1951) |
| 7 | 40 | 0.812 | 2004 | risk management; process safety; aspen hysy; safety analysis automation | (Janosovsky et al., 2015; Khan et al., 2015; Mannan et al., 2015) |

endeavoured into his second career as a researcher, writer, and lecturer on process safety and loss prevention. Dr. Kletz was not only a knowledgeable employee in the process industry, but became one of the leading pioneers in the process safety research community. Bridging industry and academia, he disseminated much of his knowledge to the process industries, while producing very influential scholarly contributions, mostly rooted in industrial practice and based on actual needs.

As a process safety scholar, he was highly productive even at an older age. He authored a very high number of articles, with 250 articles downloaded from WoSCC. He published 37 papers during his career in ICI, which accounts for 14.8%. Following his retirement from ICI, he worked for different universities and institutions, and published 213 papers, accounting for 85.2%. Unlike other scholars, Dr. Kletz started his full-time academic research career after he was retired at the age 60. Apart from producing a high number of articles, he also published more than 15 books as a scholar.

The reference co-citations network and research clusters of Dr. Kletz show the intellectual basis and structure and evolution of his research. The highly cited references within his research body are almost all from his own publications, where especially the books he published on process safety and loss prevention are a very important intellectual basis. Other pioneers, for example Lawley H.G. and Gibson S.B. related to hazard analysis, are also highly cited in his research. The clusters in the reference network associated with his work shows that his research is closely connected, with a focus on process safety related topics, including pressure vessels, loss and accident prevention, and olefin plant safety.

In order to obtain insights in the impacts on his followers, a total of 469 papers of his followers were collected from WoSCC. The most highly cited publications cited by his followers are almost all Dr. Kletz's research papers, for example the highly impactful article '*What you don't have, can't leak*', which can be considered the original source of the 'inherent safety' concept. The clustered reference co-citation network of the work by his followers shows that the largest connected network primarily focuses on inherent safety, hazard analysis, accident investigation, and risk management for process safety. The second largest reference co-citation network of the work of his followers relates to his earlier studies on infra-red spectra. Comparing Dr. Kletz's reference co-citation network to that of the work of his followers, it is interesting that both research bodies of knowledge are based on Dr. Kletz's process safety research, especially related to inherent safety and loss prevention. However, while Dr. Kletz very frequently cited his own books, his followers more frequently cited his scientific articles.

As shown through the various analyses, Dr. Kletz's impressive academic contributions are very strongly rooted in his industrial experience. This is evident mostly because he relied heavily on his books as knowledge base for his articles. These books were based on his own experience from industry, and insights developed through discussions with other process safety pioneers in intellectual exchanges at early process safety symposia. It is hoped that Dr. Kletz's example of academic work rooted in industrial experience can inspire young graduates, also aspiring academics, to pursue a career in industry to understand the practices of process safety and the ongoing challenges. The example of Dr. Kletz's impressive career clearly shows that a strong industrial basis, as well as a strong ongoing connection between industry and academia, can lead to a very fruitful scholarly body of work, which furthermore impacts industrial environments to this date.

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## References

AIChE, 2020. Dr. Trevor Kletz.. Retrieved 03-10, 2020, from. https://www.aiche.org/bio/dr-trevor-kletz.
Ansari, B.J., Srivastava, S.L., 1971. Electronic absorption spectra of 2,4-dichlorophenols and 2,5-dichlorophenols in vapour phase. Indian J. Pure Appl. Phys. 9 (10), 820.
Ashdown, A., Kletz, T.A., 1948. The infra-red spectra of mixtures of aldehydes and alcohols. J. Chem. Soc. 1454–1456.
Barker, G.F., Kletz, T.A., Knight, H.A., 1977. Olefin plant safety during last 15 years. Chem. Eng. Prog. 73 (9), 64–68.
Barnwell, J., 1978. Designing safety into an ethylene plant. Chem. Eng. Prog. 74 (10), 66–72.
Bell, N.A.R., 1971. Loss prevention in the manufacture of nitroglycerine. Major loss prevention in the process industries. I. Chem E. Symposium Series 34, 50–53.
Bender, M.L., 1953. Intermediates in the reactions of carboxylic acid derivatives .2. Infrared absorption spectra as evidence for the formation of addition compounds of carboxylic acid derivatives. J. Am. Chem. Soc. 75 (23), 5986–5990.
Campbell, N., Craig, J.T., Delahunt, K.W., 1967. 9-Substituted fluorene derivatives. Chem. Ind. (32), 1361–&.
Chen, C., 2006. CiteSpace II: detecting and visualizing emerging trends and transient patterns in scientific literature. J. Am. Soc. Inf. Sci. Technol. 57 (3), 359–377.
Chen, C., 2018. Eugene Garfield's scholarly impact: a scientometric review. Scientometrics 114 (2), 489–516.
Chen, C., 2020. CiteSpace 5.6 R3. Retrieved 03-12, 2020, from. https://sourceforge.net/projects/citespace/files/.
Chen, C., Ibekwe-Sanjuan, F., Hou, J., 2010. The structure and dynamics of cocitation clusters: a multiple-perspective cocitation analysis. J. Assoc. Inf. Sci. Technol. 61 (7), 1386–1409.
Crowl, D.A., 2012. Trevor Kletz, friend and mentor. J. Loss Prev. Process. Ind. 25 (5), 766–767.
Dunning, T., 1993. Accurate methods for the statistics of surprise and coincidence. Comput. Ling. 19 (1), 61–74.
Edwards, David, 2014. Trevor Kletz Obituary. Retrieved 03-12, 2020, from. https://www.theguardian.com/education/2014/jan/07/trevor-kletz-obituary.
Edwards, D.W., Lawrence, D., 1993. Assessing the inherent safety of chemical process routes: is there a relation between plant costs and inherent safety? Process Saf. Environ. Protect.: Trans. Inst. Chem. Eng., Part B 71 (4), 252–258.
Flavell-While, Claudia, 2018. Trevor Kletz, the Father of Inherent Safety, Explains His Remarkable Career. Retrieved 03-12, 2020, from. https://www.thechemicalengineer.com/features/cewctw-trevor-kletz-a-lifetime-spent-saving-lives/.
Galluzzo, M., 1988. "What went wrong? Case histories of process plant disasters: by Trevor A. Kletz; published by Gulf Publishing Company, Houston, 1985; xix + 204 pp.; price, £47.00. Chem. Eng. J. 37 (2), 134.
Garside, J., 2006. Tribute to Trevor Kletz. Process Saf. Environ. Protect. 84 (3), 157.
Gentile, M., Rogers, W.J., Mannan, M.S., 2003. Development of a fuzzy logic-based inherent safety index. Process Saf. Environ. Protect. 81 (B6), 444–456.
Gibson, S.B., 1976. Risk criteria in hazard analysis. Chem. Eng. Prog. 72 (2), 59.
Gómez, G., Rodríguez, S., Cadena, J., Muñoz, F., 2012. Kletz's legacy for developing countries: simple systems based on inherently safer design. J. Loss Prev. Process. Ind. 25 (5), 843–847.
Gowland, R., 2012. A journey into process safety with Trevor Kletz. J. Loss Prev. Process. Ind. 25 (5), 768–769.
Grossel, S.S., 2002. Learning from accidents, 3rd edition: Trevor Kletz; Gulf professional publishing, Oxford, UK and Boston, MA, pp. 345, price £40. J. Loss Prev. Process. Ind. 15 (3), 250–251.
Grossel, S.S., 2004. Still going wrong!—case histories of process plant disasters and how they could have been avoided: Trevor Kletz; Gulf Professional Publishing, Burlington, MA and Oxford, UK, 2003, 230 pages, US$ 49.95. J. Loss Prev. Process. Ind. 17 (4), 323–324.
Gupta, J.P., Edwards, D.W., 2002. Inherently safer design—present and future. Process Saf. Environ. Protect. 80 (3), 115–125.
Houston, D.E.L., 1971. New approaches to the safety problem. Major loss prevention in the process industries. I. Chem E. Symposium Series 34, 210–216.
Janosovsky, J., Labovsky, J., Jelemensky, L., Kalenda, P., Prague, J. Lubojacky, 2015. Aspen hysys modelling in safety analysis automation. In: Proceedings of the 3rd International Conference on Chemical Technology. Czech Soc Industrial Chemistry, pp. 500–507.
Johansen, I.L., Rausand, M., 2014. Foundations and choice of risk metrics. Saf. Sci. 62, 386–399.
Khan, F.I., Abbasi, S.A., 2001. Risk analysis of a typical chemical industry using ORA procedure. J. Loss Prev. Process. Ind. 14 (1), 43–59.
Khan, F.I., Amyotte, P.R., 2003. How to make inherent safety practice a reality. Can. J. Chem. Eng. 81 (1), 2–16.
Khan, F.I., Husain, T., Abbasi, S.A., 2001. Safety weighted hazard index (SWeHI) - a new, user-friendly tool for swift yet comprehensive hazard identification and safety evaluation in chemical process industries. Process Saf. Environ. Protect. 79 (B2), 65–80.
Khan, F.I., Rathnayaka, S., Ahmed, S., 2015. Methods and models in process safety and risk management: past, present and future. Process Saf. Environ. Protect. 98, 116–147.
Kletz, T.A., 1971. Hazard analysis – a quantitative approach to safety. Major loss prevention in the process industries. I. Chem E. Symposium Series 34, 75–81.
Kletz, T.A., 1972. Specifying and designing protective systems. Loss Prevent. 6, 15.
Kletz, T.A., 1976b. Preventing catastrophic accidents. Chem. Eng. 83 (8), 124–128.
Kletz, T.A., 1976c. Three-pronged approach to plant modification. Chem. Eng. Prog. 72 (11), 48–55.
Kletz, T.A., 1977a. Evaluate risk in plant design. Hydrocarb. Process. 56 (5), 297–324.
Kletz, T.A., 1978. What you don't have, can't leak. Chem. Ind. 287–292.
Kletz, T.A., 1982a. Hazard analysis - a review of criteria. Reliab. Eng. Syst. Saf. 3 (4), 325–338.
Kletz, T.A., 1985. Eliminating potential process hazards. Chem. Eng. 92 (7), 48–68.
Kletz, T., 1990. Ether, Protoplasm and Human Error, vol. 479. Chemical Engineer-London, pp. 19–20.
Kletz, T.A., 1993a. Computer control—living with human error. Reliab. Eng. Syst. Saf. 39 (3), 257–261.
Kletz, T.A., 1993b. Lessons from Disaster – How Organisations Have No Memory and Accidents Recur. Institution of Chemical Engineers, Rugby, UK.
Kletz, T.A., 1993c. Organizations have No memory when it comes to safety. Hydrocarb. Process. 72 (6), 88.
Kletz, T.A., 1995. Some loss prevention case-histories. Process Saf. Prog. 14 (4), 271–275.
Kletz, T.A., 1996. Inherently safer design: the growth of an idea. Process Saf. Prog. 15 (1), 5–8.
Kletz, T.A., 1997. Hazop—past and future. Reliab. Eng. Syst. Saf. 55 (3), 263–266.
Kletz, T.A., 1998a. Process Plants: a Handbook for Inherently Safer Design. Taylor and Francis, Philadelphia, PA, USA.
Kletz, T.A., 1998b. What Went Wrong?, fourth ed. Gulf Publishing, Houston, TX.
Kletz, T.A., 1999. The origins and history of loss prevention. Process Saf. Environ. Protect. 77 (3), 109–116.
Kletz, T.A., 2001a. Accident Investigation - Missed Opportunities. Rugby, Inst Chemical Engineers.
Kletz, T.A., 2001b. An Engineer's View of Human Error, third ed. Institution of Chemical Engineers.
Kletz, T.A., 2001c. Learning from Accidents. Butterworth-Heinemann, Oxford, UK.
Kletz, T.A., 2002a. Accident Investigation - Missed Opportunities. Godalming. Springer-Verlag London Ltd.
Kletz, T.A., 2002b. Accident investigation - missed opportunities. Process Saf. Environ. Protect. 80 (B1), 3–8.
Kletz, T.A., 2003a. Inherently safer design—its scope and future. Process Saf. Environ. Protect. 81 (6), 401–405.
Kletz, T.A., 2003b. Still Going Wrong!: Case Histories of Process Plant Disasters and How They Could Have Been Avoided. Gulf Professional, Boston, MA.
Kletz, T.A., 2006a. HAZOP and HAZAN, fourth ed. IChemE, Rugby, UK.
Kletz, T.A., 2006b. Introduction and editorial - special issue - human factors and management. Process Saf. Environ. Protect. 84 (B3), 159–163.
Kletz, T., 2012. The history of process safety. J. Loss Prev. Process. Ind. 25 (5), 763–765.
Kletz, T.A., Amyotte, P., 2010. Process Plants: A Handbook for Inherently Safer Design. CRC Press.
Kletz, T., Amyotte, P., 2019. What Went Wrong? Case Histories of Process Plant Disasters and How They Could Have Been Avoided, sixth ed. Butterworth-Heinemann.

Kletz, T.A., Price, W.C., 1947. The infra-red spectra of solid and liquid alkylphenols. J. Chem. Soc. (MAY), 644–648.

Kletz, T.A., Sumner, A., 1948. Note on the intensity of the double-bond valence vibration in octenes. J. Chem. Soc. (SEP), 1456–1457.

Lawley, H.G., 1974. Operability studies and hazard analysis. Chem. Eng. Prog. 70 (4), 45–56.

Lawley, H.G., 1976. Size up plant hazards this way. Hydrocarb. Process. 55 (4), 247–258.

Lees, F.P., 1980. Loss Prevention in the Process Industries, first ed., 2 volumes. Butterworths, London, UK.

Lehenaff, P., 1968. Methods of study and properties of hydrates hemiacetals and hemithioacetals deriving from aldehydes and ketones. Bull. Soc. Chim. Fr. 11, 4687–+.

Li, J., Chen, C., 2016. CiteSpace:Text Mining and Visualization in Scientific Literature, 2 Edition. Capital University of Economics and Business Press, Beijing.

Li, J., Goerlandt, F., Reniers, G., 2020. Mapping process safety: a retrospective scientometric analysis of three process safety related journals (1999-2018). J. Loss Prev. Process. Ind. 65, 104141. https://doi.org/10.1016/j.jlp.2020.104141 (in press).

Li, J., Goerlandt, F., Reniers, G., Zhang, B., 2020. Sam Mannan and his scientific publications: a life in process safety research. J. Loss Prev. Process. Ind. https://doi.org/10.1016/j.jlp.2020.104140 (in press).

Light, R.P., Polley, D.E., Borner, K., 2014. Open data and open code for big science of science studies. Scientometrics 101 (2), 1535–1551.

Loughborough University, 2007. Trevor Kletz. Retrieved 03-02, 2020, from. https://web.archive.org/web/20070717201508/http://www.lboro.ac.uk/departments/cg/staff/cgtk.html.

Lovati, A., 1983. Is it possible to agree on acceptance levels of risk from relevant accidents connected with industrial-activity. Chim. Industria 65 (7–8), 497–500.

Luttke, W., 1951. Ultrarotspektroskopie als analytisches hilfsmittel. Angew. Chem. 63 (17–1), 402–411.

Mannan, M.S., 2012. Trevor Kletz's impact on process safety and a plea for good science – an academic and research perspective. Process Saf. Environ. Protect. 90 (5), 343–348.

Mannan, M.S., Sachdeva, S., Chen, H., Reyes-Valdes, O., Liu, Y., Laboureur, D.M., 2015. Trends and challenges in process safety. AIChE J. 61 (11), 3558–3569.

Marshakova, I.V., 1973. System of Document Connections Based on References, (In Russian)." Nauchno-Tekhnicheskaya Informatsiya Seriya 2-informatsionnye Protsessy I Sistemy, pp. 3–8, 6.

Martinsolis, G.A., Andow, P.K., Lees, F.P., 1982. fault tree synthesis for design and real-time applications. Trans. Inst. Chem. Eng. 60 (1), 14–25.

Meyer, M., Pereira, T.S., Persson, O., Granstrand, O., 2004. The scientometric world of Keith Pavitt: a tribute to his contributions to research policy and patent analysis. Res. Pol. 33 (9), 1405–1417.

MKOCPS Center, 2013. Trevor Kletz. Retrieved 03-05, 2020, from. http://psc.tamu.edu/trevor-kletz.

Mooney, D.G., 1992. Plant design for safety: a user friendly approach: by T. Kletz. Taylor & Francis, London, 161 pp., £28.00. Chem. Eng. Sci. 47 (8), 2129.

Newman, M.E.J., 2006. Modularity and community structure in networks. Proc. Natl. Acad. Sci. Unit. States Am. 103 (23), 8577–8582.

Pekalski, A.A., Zevenbergen, J.F., Lemkowitz, S.M., Pasman, H.J., 2005. A review of explosion prevention and protection systems suitable as ultimate layer of protection in chemical process installations. Process Saf. Environ. Protect. 83 (B1), 1–17.

Persson, O., Danell, R., S.J.W., 2009. How to Use Bibexcel for Various Types of Bibliometric Analysis. Celebrating Scholarly Communication Studies: A Festschrift for Olle Persson at His 60th Birthday, pp. 9–24.

Pliva, J., 1951. Infracervena spektroskopie A Jeji pouziti V organicke chemii .2. Aplikace infracervene spektroskopie. Chem. Listy 45 (3–4), 160–170.

Public Relations Office, L.U., 2006. Honorary Degree Orations, Professor Trevor Kletz. Retrieved 03-11, 2020, from. https://www.lboro.ac.uk/service/publicity/degree_days/2006/Summer/Kletz.html.

Ramachandran, L.K., Epp, A., McConnell, W.B., 1955. Infrared spectra of 3-phenyl-2-thiohydantoins of amino acids and their application to identification of N-terminal groups in peptides. Anal. Chem. 27 (11), 1734–1737.

Rousseeuw, P.J., 1987. Silhouettes: a graphical aid to the interpretation and validation of cluster analysis. J. Comput. Appl. Math. 20, 53–65.

Sanders, R.E., 2012. Tanks A Lot – Trevor: for enduring process safety contributions. J. Loss Prev. Process. Ind. 25 (5), 775–779.

Small, H., 1973. Co-citation in the scientific literature: a new measure of the relationship between two documents. J. Am. Soc. Inf. Sci. 24 (4), 265–269.

Sousa, V., Almeida, N.M., Dias, L.A., 2014. Risk-based management of occupational safety and health in the construction industry - Part 1: background knowledge. Saf. Sci. 66, 75–86.

Srinivasan, R., Natarajan, S., 2012. Developments in inherent safety: a review of the progress during 2001-2011 and opportunities ahead. Process Saf. Environ. Protect. 90 (5), 389–403.

Srivasta, Sl, 1970. Vibrational spectra of 2,3-dichlorophenols, 2,4-dichlorophenols and 2,5-dichlorophenols. Indian J. Pure Appl. Phys. 8 (4), 237–&.

Stewart, R.M., 1971. High integrity protective systems. Major loss prevention in the process industries. I. Chem E. Symposium Series 34, 99–104.

van Eck, N.J., Waltman, L., 2010. Software survey: VOSviewer, a computer program for bibliometric mapping. Scientometrics 84 (2), 523–538.

Vaughen, B.K., 2012. A tribute to Trevor Kletz: what we are doing and why we are doing it. J. Loss Prev. Process. Ind. 25 (5), 770–774.

Vaughen, B.K., Kletz, T.A., 2012. Continuing our process safety management journey. Process Saf. Prog. 31 (4), 337–342.

Wang, Q., Edwards, D., Gupta, J., Vechot, L., Dr, M., 2020. Sam mannan - process safety pioneer. Process Saf. Environ. Protect. 137, 366–367.