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A scientific approach with bibliometric analysis related to brick and tile drying: A review

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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

Extensive analyses of technological developments and technology foresight studies have been vital to help prepare possible scientific scenarios for the future. The primary purpose of this type of foresight study is to utilise methods and attempt to assess development trends in science and technology. This paper presents an approach to find out the various trends in scientific studies in the field of drying brick/tile that are occurring in the world. All documents used in this study were obtained from the Scopus database. To shed light on drying trends, both bibliometric and network analyses were conducted in this research. For the bibliometric analysis, the Scopus database was systematically searched to obtain a dataset in relation to the drying of brick/tile. The year range covered from 1980 to 2015. On the other hand, the patent data used in the study were taken from the Espacenet international patent database. The same keywords coupled with bibliometric analysis were used to find the relevant patent data. Some parameters were considered, such as the number of documents, authorship and ownership, patterns of international collaborations, address, and number of times cited. The collaboration networks with co-citation analysis for authors were also analysed in this study. Significant growth is observed in scientific production particularly in the period from 2000–2015. The countries that became evident as most productive on a scientific basis are the United States, Germany and China.

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1. Introduction

The term "drying" is commonly used to describe the process of thermally removing moisture from a solid product. It is often one of the most complex operations in a manufacturing process. The difficulties in theoretical analysis of the phenomena of simultaneous transport of heat, mass, and momentum constitute the main reason of underestimated process [1].

The efficient use of energy in the drying process and reduction in cost are immensely profitable for the industry. Therefore, recently, a considerable literature has grown up around the theme of drying in both industrial and academic contexts. Drying is inherently a cross and multidisciplinary field which has a very broad application area, such as food, agriculture and chemical industries, textile, building materials, and other applications. It requires optimal understanding of transport phenomenon and adequate knowledge of material science because the priority is not only to conserve energy but also to obtain better product quality during drying [2].

Developments in drying are driven in many ways, such as by [3]:

- presenting a new experimental approach for characterisation and quality control of desired dried product
- strengthening the technological aspects of existing equipment and putting emphasis on more effective design
- supporting an active collaboration among researchers from different disciplines
- using modern methods supported by computer tools and software which make transitions possible from the molecular pore to particles

Products must meet some specific requirements after the drying process such as being free flowing or dust free, specified particle size distribution, solubility or active component preservation. Hence, the selection of the right drying process and dryer design has an undeniable importance on the quality, size, shape and moisture content of final product and cost price [4].

Due to the above mentioned importance, drying has been an important part of research since the 1980s. Most of the studies generally have focused on two components; "drying theory" which deals with the analysis of the transport phenomenon and "drying equipment" which aims to design, manufacture and optimise dryers based on drying theory [5]. Professor Arun S. Mujumdar is one of the leading researchers popularly known as "Drying Guru" who led to the increasing interest in this subject with over 575 journal publications, 9 e-books, 3 authored books, 60+ edited books, and 120+ book chapters [6]. The latest book by Professor Mujumdar is a comprehensive source called "Modern Drying Technology" which has provided a significant contribution to the researchers.

A considerable amount of literature has been published in the field of drying process. In particular, scientific and technological research institutions in many countries have been trying to constitute a road map with the reports published in certain periods for researchers and global companies that work on drying systems. In contrast to these studies, there is much less information about the drying of porous medium, especially related to brick/tile drying. Therefore, this is the first study that aims to make an original contribution to the literature and fill in the gap in the relevant area by using bibliometric analysis technique on brick/tile drying. Indeed, the bibliometric analysis offers a big potential and promotes their use for better understanding of this type of reviews.

2. Basic drying theory

The most common, important and expensive step of industrial applications is the drying process. For instance, this process is used in the following fields: agricultural and chemical industry, food preservation, drying of building materials, etc. Basically, the drying phenomenon can be defined as simultaneous heat, mass and momentum transfer resulting in the removal of water from the products to reduce the moisture content (Fig. 1).

The drying process takes place in two basic mechanisms; the migration of moisture from the interior of a product to the surface, and the evaporation of moisture from the heated surface to the surrounding air. These transport mechanisms of moisture are closely related to several external factors such as temperature, the type and nature of the exposed surface, humidity, pressure and the flow velocity [7–9]. Investigations on drying phenomenon due to its complexity, are still a major area of interest for many researchers around the world. The central motivation in most of these research projects is to determine the effects of external factors on the drying process, since the understanding of the drying process in detail is necessary for the process design with scientific principles, preserving the quality of the product and energy optimisation [10–13].

Despite the increase in the number of studies and technological developments, drying process is an exclusive area to be studied in detail and extensively by researchers. Continued efforts are needed to make drying process more understandable on the grounds that non-linear physical phenomenon and to simplify dryer design, control and product quality. The integration of the knowledge of basic thermodynamics and transport phenomenon into the description of phase equilibria and drying kinetics is among the current challenges for the research [14,15].

A number of researchers have presented review articles on the topic of drying in the past decades. Hall [16] published an article to present the list of literature on drying and related topics from the period 1982–2006. These articles including the word "review", were prime sources of these listings. In the same vein, several attempts have been made to highlight the current state and future trends related to drying [17–21]. A great development has been made in computer software and hardware over the past 30 years, which obviously broaden the application of computers to drying technologies. Since then, calculations have become feasible with one, two, or three independent state variables (i.e., temperature, moisture content) in one, two, and three dimensions thanks to developments in computer technology along with the advantages of applied mathematics in engineering applications [22]. Numerous studies have attempted to explain the computational modelling and software that can be used in the drying process [23–34].

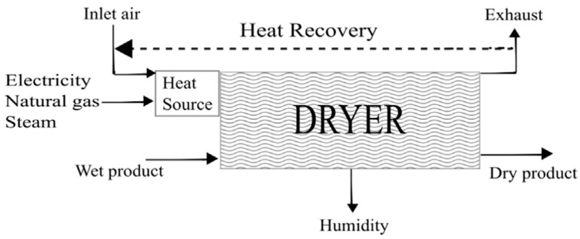


Fig. 1. Basic drying system.

In a large longitudinal study, Chauhan et al. [34] investigated the role of software such as Ansys, Fluent, Fortran and Matlab in drying process to provide useful information to researchers. Some researchers (e.g. Peishi and Pei, 1989; Haghi, 2011; Zhang Z, 1999) have attempted to design a mathematical model for drying process which takes all the major internal moisture transfer mechanisms and the properties of the material into consideration [35–37]. In contrast to research, which reports a general perspective related to drying process, energy and exergy analysis of drying systems were considered by the researchers [38–41].

Studies conducted in recent years have focused on speeding up the drying process due to certain factors, such as increasing energy costs and usage the limited time interval in some countries. In fast drying, the maximum use of existing air by increasing circulation in the dryer specifically for convection drying is one of the most popular applications in these studies.

In view of all that has been mentioned so far, most of the papers from the past to the present have tended to focus on understanding why the drying phenomena has become so dominant in our life. Extensive analyses of technological developments and technology foresight studies have been vital to help prepare possible scientific scenarios for the future. These types of foresight studies are used to assess developments in science and technology. The purposes of these foresight studies can be listed as follows [42,43];

- determining emerging trends in the world and their reflections at the national level
- determining the main axis of science and technology policy by taking socio-economic impacts into consideration
- determining priorities

2.1. Classification of drying methods

Drying methods have been classified and diversified according to the specific requirements of each product. The process occurs in many different forms and uses various kinds of equipment depending on these requirements.

As can be seen from Table 1, the drying methods can be handled basically in two subheadings, which are called batch and continuous according to the operation mode. Although continuous processing is more technological and usable, batch dryers are widely used especially when quality control or health considerations are factors, such as in the pharmaceutical and food industries. Batch drying is a chemical operation (easy to work and versatile in use) and generally preferred whenever a number of materials are to be dried in the same unit, or whenever the drying schedule is long and complex and in which batch equipment is located upstream and downstream e.g. brick, wood etc. The major disadvantage of batch drying is that the process does not have a steady state and this handicap causes continuous change in the operating conditions [44]. On the other hand, continuous drying requires less labour, fuel and space. It ensures a more uniformly dried product at a lower unit cost than a batch dryer of the same capacity. The drying process takes many forms depending on the product's specific requirements and uses various kinds of equipment. Predominantly, drying

Table 1
Classification of drying methods [4].

Criteria	Classification
Mode of operation	Batch Continuous
Heat input-type	Convection, conduction, radiation, dielectric Intermittent or continuous Adiabatic or non-adiabatic
State of material in dryer	Stationary Moving, agitated, dispersed
Operating pressure	Vacuum Atmospheric
Drying medium (convection)	Air Superheated steam Flue gases
Drying temperature	Below boiling temperature Above boiling temperature Below freezing point
Relative motion between drying medium and drying solids	Co-current Counter current Mixed flow
Number of stages	Single Multistage
Residence time	Short (1 min) Medium (1–60 min) Long (60 min)

operation consists of two basic methods: adiabatic and non-adiabatic. The heat of vaporisation is provided by the sensible heat in contact with the product to be dried during the adiabatic processes. By contrast, in non-adiabatic processes, evaporation heat is provided by radiant heat or by heat transferred through walls in contact with the product to be dried [1].

Heating during the drying process can be examined under four headings: conductive, convective, radiative and dielectric. In conductive heating, heat transfer takes place if there is a temperature gradient in a solid material and required heat is obtained from a heat source like an electric heater. Typically, direct contact occurs between the heat source and the target tissues. The heated air is circulated into the drying area using a blower or fan and used to facilitate the drying process which involves evaporating. The term convection is adopted for transferring heat energy from the air to solid, liquid, or gas. The heat obtained by cooling the gas stream is used to evaporate moisture. The step of removing the evaporated moisture also utilises gas stream as a carrier. This process enables the molecules of the hot fluid to transfer heat continuously toward the volumes of the colder fluid. Physical contact with the desired product to be dried is not necessary in radiative heating. The underlying principle of radiant heating is radiant energy is transferred from an emitting heat source to an object without physical contact. This feature of radiant heating provides a superior advantage when physical contact gives damage to the product or when the product must be heated while in motion. In addition to that, radiation heating system eliminates the need for long pre-heat cycles. There are relatively few historical studies in the area of heat transfer mechanisms [45–50].

Research related to dielectric drying methods with microwave and radio frequency energy started in the 1940s [51]. Dielectric heating is described as the process in which a high-frequency alternating electric field, radio wave or microwave electromagnetic radiation heats a dielectric material. In contrast to convective heating with steam and hot-air, or even radiation heating in general, dielectric heating produces heat directly inside the exposed material. Dielectric heating is a technology widely used for the removal of moisture from the product that is to be dried. It possesses a number of advantages such as shorter processing time, uniform heating, less energy required flexible control, and shortened production line lengths. In radio frequency heating, the applied frequency is between 1.3×10^7 and 2.45×10^9 Hz, while in microwave heating the frequency is between 9.15×10^8 and 2.45×10^9 Hz [10]. As these properties come to the fore, dielectric heating has drawn much attention from both the research community and industry over the past decades [1,52–55].

Drying is the most energy intensive process of the major industrial process and constitutes nearly 15% of all industrial energy usage [4,56]. Therefore, the relationship between intermittent and continuous drying on energy efficiency and product quality has been widely investigated [57–60]. Overall, these results indicate that intermittent drying is more energy efficient than continuous drying. In addition to that the quality degradation and damages caused by heat can be minimised by applying intermittent drying. Intermittent drying can be operationalized by means of controlling the supply of thermal energy achieved by altering the air-flow rate, air temperature, humidity, or operating pressure. Hence, the mode of energy input may vary from product to product. One of the most important factors to be taken into account in the selection of a suitable dryer is the state of the product. A separate classification and selection can be made depending on whether the product to be dried is moving or stationary.

The pressure surrounding the product sample also significantly affects the drying rate. The atmospheric pressure is 760 mm of mercury (also expressed as 1 atm) and pure water boils at 100 °C at sea level. However, it should be noted that decreasing the atmospheric pressure should decrease the boiling point as well. Under vacuum conditions (reduced pressure), water boils at a lower temperature. The reduced boiling point at low pressure yields significant practical applications in the field of vacuum evaporation, especially for the drying of temperature sensitive products. Vacuum drying is operated on materials to be dried in a reduced pressure environment and this causes the heat to drop; this is needed for rapid drying. The vacuum drying process is advantageous with regards to productivity, quality and energy consumption [61,62]. Besides, there are various ways of classifying drying methods, such as based on drying medium, drying temperature, relative motion between drying medium and drying solids, number of stage and residence time. Detailed information of these methods can be found in the studies conducted by Mujumdar and Strumillo [1,63].

2.2. Description of various dryer types

The selection of the dryer is often the most complicated stage in the system design and involves an interaction between technical and economic factors. In the technical literature, it can be seen that there are 400 dryer types. Nevertheless, only about 50 types are in various stages of development and commonly found in practice. In the scope of the present study, the dryer types are examined and brief information about each one is given based on the classification in the study performed by Mujumdar [1] entitled “Handbook of Industrial Drying”. As previously discussed, studies carried out by Prof. Mujumdar have an immeasurable value in the field of drying because they fill the gaps in the industry related to both drying method and dryer selection. Also, they are a source of reference for researchers.

2.2.1. Indirect dryers

Drying systems are typically grouped into two primary categories based on how the energy is transferred from the heat source to the product in the process: direct and indirect. In direct drying (contact), a warm or hot gas stream (usually air or an inert gas) is applied directly to the product and the operation is typically continuous. In contrast, indirect drying is a batch (or continuous) operation in which the product is contained in a sealed vessel and heated by a hot fluid that circulates through a jacket around the vessel. The predominant method of heat transfer in indirect drying is conduction [64,65]. An indirect dryer requires a lower gas flow rate than a dryer with direct contact, and it also increases energy efficiency while bringing down the gas-handling equipment's size and costs. In addition to that, higher product quality can be attained in indirect drying process due to the fact that the flows into and out of the dryer are moderately small. While indirect drying is a feasible option, the most indirect drying methods are less economically efficient than the direct dryers. Indirect dryers are used worldwide in order to dry various products in many industries including food (e.g., potato flakes, baby food, buttermilk powder), chemical (e.g., carbon black, colloidal clay), and different sorts of sludge (e.g., pulp mill sludge, metal oxide sludge) [1]. The selection of a proper indirect dryer requires detailed knowledge about the material to be dried. The selection of specific indirect dryers is described in the literature [13].

Types of indirect dryers

1. *Batch tray dryers*: Batch tray dryers are used for drying small quantity products, and are used for a wide range of sectors such as the food or chemical industry. These dryers have some disadvantages. For instance, they necessitate a great deal of labour to load and unload the product and also the drying times are quite long. Several attempts have been made to analyse batch tray dryers by using Computational Fluid Dynamic (CFD) software [66–70].
2. *Indirect contact rotary dryers*: Typically, indirect rotary dryers are an alternative option when direct rotary dryers are unsuitable. They are used for processes where the process must remain isolated or the particle size is fine. In the indirect dryer, it is more suited to fine and dusty materials, as it cannot handle liquids or slurries or adhesive solids. Although indirect rotary dryers can supply a limited heat transfer area, they allow sensitive control of the processing environment [71,72]. The steam tube dryer is the most observed type of indirect-contact rotary dryers.
3. *Rotating batch vacuum dryers*: Rotary batch vacuum dryers provide the opportunity for drying heat sensitive materials at well below the boiling point of water, thus eliminating the problem linked with very long drying periods. The dryer operation is normally carried out in vacuum and it is a clean, simple and very effective method of drying wet cake, powder and even the slurry. One of the rotating batch vacuum dryers is called “double cone dryer” [73].
4. *Agitated dryers*: Agitated dryers have higher drying rates per unit heating area when compared with non-agitated systems, such as ovens and tray dryers. Continuous renewal of solids in contact with the dryer's heated surfaces is the main reason for this situation. Besides, the agitation shows a positive effect in terms of uniformity of the product. In contrast to these advantages, energy costs and production rates increase due to long drying times [74]. Agitated dryers can be of two types: horizontal and vertical type dryers. Schematic diagrams of indirect dryers can be seen in Fig. 2.

2.2.2. Rotary dryers

The rotary dryer is known as the workhorse of industrial dryers; it is intended to decrease or minimalize the liquid moisture content of the product. Combining flexibility with reliability, it is a totally efficient technology for drying a full range (and sizes) of materials. These dryers work with the direct heating principle, as heat is transferred to the material via convection. Some of the unique features of rotary dryers are efficient drying of materials, high thermal efficiency, and the design which permits highest

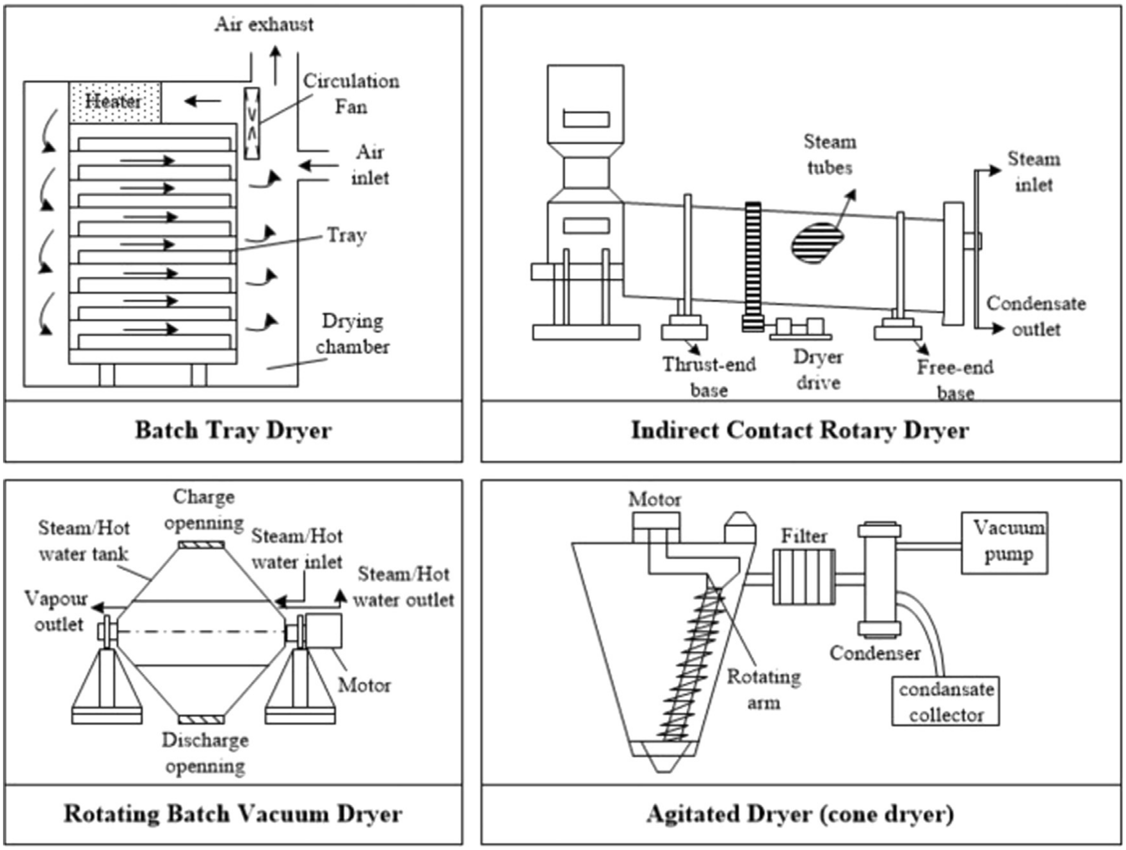


Fig. 2. Schematic diagrams of indirect dryers [1].

possible drying temperatures, suited to the most arduous applications, etc. On the negative side, they require high capital and maintenance costs according to the material being dried. Fragile materials and low production rates are not convenient for this type dryer [75,76]. Rotary dryers are categorised as direct, indirect–direct, indirect, and special types. This classification hinges upon the method of heat transfer. More recent attention has focused on the modelling and simulation of rotary dryers [77–79].

2.2.3. Fluidized bed dryers

The last three decades have seen a growing trend towards to fluidized bed dryers due to their superior features provided in the drying process. Fluidized bed dryers are suitable for a wide range of processes, especially for powders, granules, agglomerates, and pellets with an average particle size between 50 microns and 5 mm. The important potential advantages of using fluidized bed technology in drying application are good contact between hot air and particles to be dried which causes rapid drying considerably without undermining heat sensitive materials, uniform and controllable temperature with high thermal efficiency in the bed, facility in operation and maintenance of the dryer, and adaptability to automation. On the other hand, fluidized bed technology also involves many unwanted characteristics that lower fluidisation quality, cause high pressure drop, and create the possibility of non-uniform moisture content in the product. According to studies in the literature, the performance of the fluidized bed dryer could not be reliably predicted owing to the lack of sound mathematical models. Fluidized drying of solids can be batchwise or continuous [80]. Generally, batch processes are used for small scale and heat sensitive materials. The topic of fluidized bed dryer simulation has received considerable critical attention [81–84].

2.2.4. Drum dryers

Nowadays, the cylindrical shape drum dryers have begun to be used for drying a large range of products, from baby food to chemicals. The drum dryer has a particular place among other dryer types due to its features which are suitable for situations that, when using other dryers, give poor or unsatisfactory results. Unlike other types of dryers the drum dryer can dry highly-sticky products and/or highly viscous media. The drum dryer turns continuously and it is heated from the inside. After application of the desired product to be dried on the outside of drum as a thin film, the drying starts immediately. Thermal results are better than other methods due to the absence of any losses occurring in the hot air outlet. In addition to that, stable quality products can be obtained in a short period of time in drum type dryers. Cleaning and making a change of application is easy. Despite this, the high capital cost of the machined drums and the possibility of heat damage to sensitive products have increased the tendency towards spray drying [85]. Drum dryers are grouped under four categories: an atmospheric type and vacuum type according to operating pressures, double drum and single drum.

2.2.5. Industrial spray dryers

The spray drying process has become widely used in industry through increased efforts in recent years to better understand of the basic principles and to develop applications. A spray dryer, as its name suggests, utilises a spray for drying. In order to acquire free flowing dry powder with a controlled average particle size, spray dryers combine a heated gas with an atomised liquid stream in a drying chamber. The surface area per unit generated by atomisation of the liquid feed is the unique quality of a spray dryer. The spray drying process takes form according to the composition of the product to be dried. Some products may not have such an easy drying process in comparison with others. The spray dryer

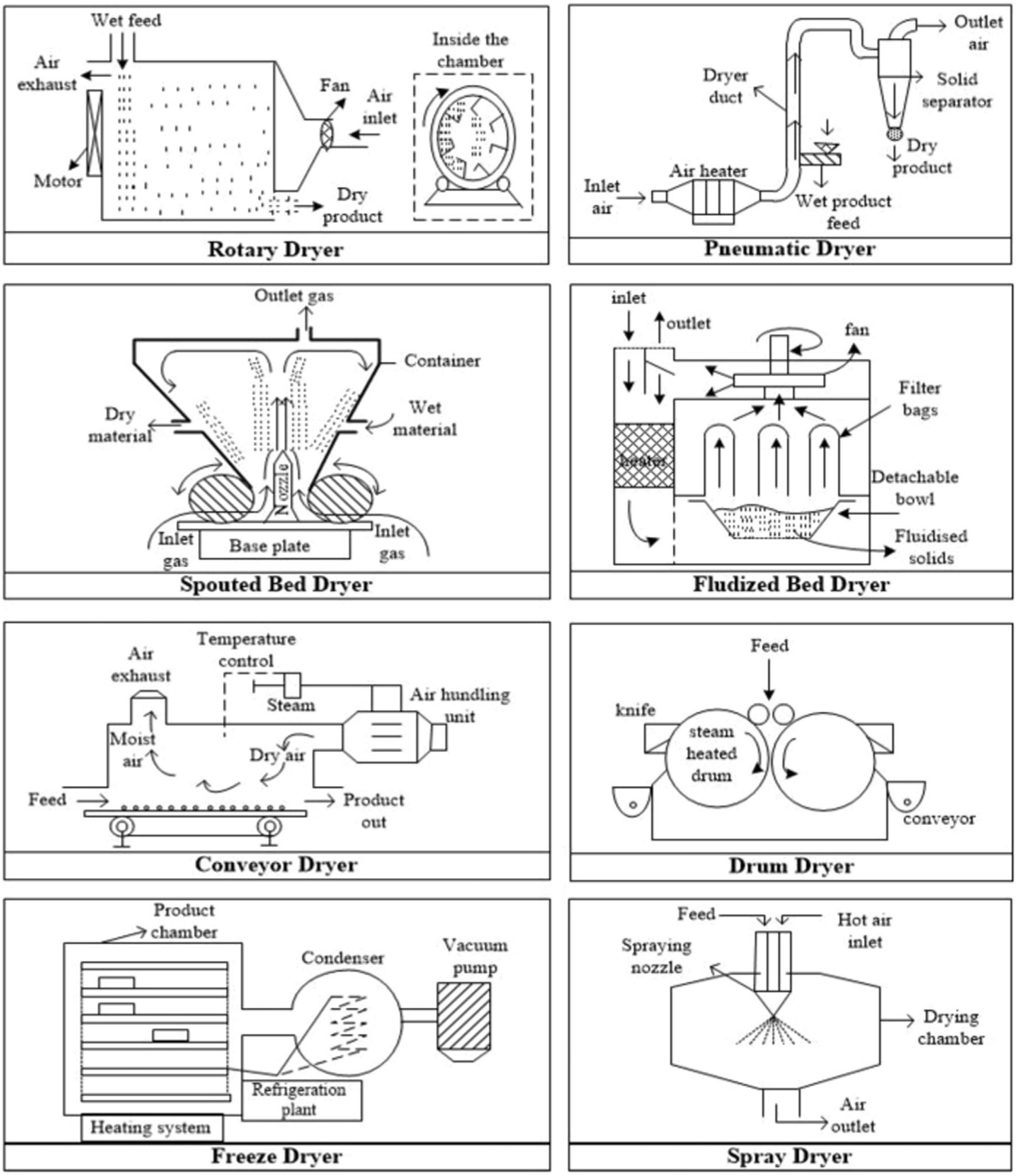


Fig. 3. Simplified diagram of dryers.

technology is optimum in certain circumstances. This includes when the outcomes must conform to quality standards such as particle size distribution, residual moisture content, bulk density and particle morphology [1].

2.2.6. Freeze dryers

Freeze drying is widely utilised for the drying of heat sensitive materials in the pharmaceutical and diagnostic industries [86,87]. The main idea behind freeze drying is to entirely remove water from material while completely leaving the basic structure and composition of the material in a way that the foods or products could endure. Moreover, it is easier to reposit the products at room temperature. The freeze dryer has several design parameters involving freezing temperature and time at freezing stage, cooling rate, target product temperature, chamber pressure, and dryer capacity at primary drying stage, and heating rate and chamber pressure at secondary drying steps [1].

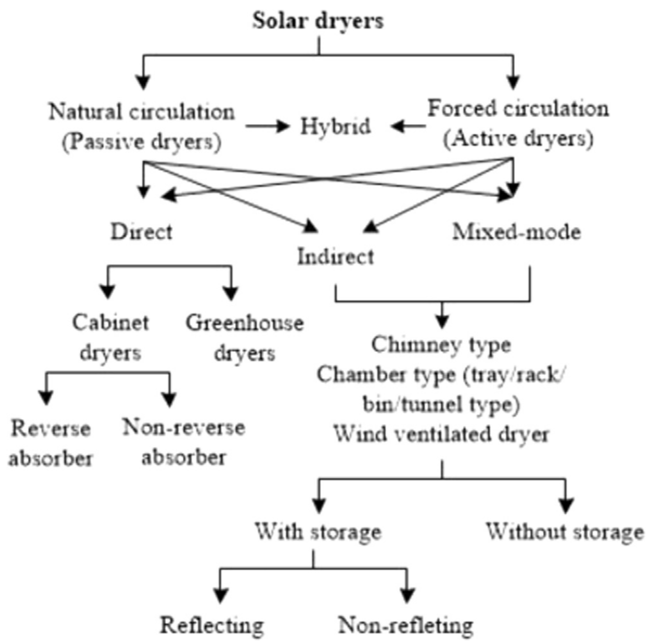
2.2.7. Spouted bed dryers

There is an immense interaction between the solid and gas phase in spouted beds dryers where effective heat and mass transfer is obligatory. Spouted bed dryers are favourable for operations using heat sensitive materials because their good heat transfer, specifically in particles which have a wide distribution, particles which are small and light or lastly very large, strongly non-spherical, particles with rough or adhesive surfaces [88,89]. It provides higher drying rates and hence shorter drying times as a result of continuous particle air contact.

2.2.8. Impingement dryers

Impingement dryers are typically utilised in numerous industrial drying operations, such as drying of paper, films, foils,

Table 2
Classification of solar dryers and drying modes [98].



nonwovens and fabric. The drying medium of impingement drying is air [90,91].

2.2.9. Pneumatic and flash dryers

Flash dryers, also called “pneumatic dryers”, are the most affordable dryers for drying different products, such as powders, granules, crystals, and wet products when short residence times are tenable. In a flash dryer, the product is only in contact with the gas stream for a very short time, usually less than three seconds. Therefore, it is perfectly suitable for extracting free moisture from the surface of the material being dried. Low thermal efficiency is the main limitation in the flash drying concept [92].

2.2.10. Conveyor dryer

Conveyor dryer theoretically, has a simple working principle: the product is transmitted to the dryer through conveyors. After that, the hot air is forced through the bed of product. Although it is generally defined as a conveyor in a box with hot air, in reality, the conveyor dryer is one of the most widely available multi directional dryers. Generally, the conveyor dryer is the best choice for drying particulate material within the range from 1- to 50-mm diameter.

2.2.11. Infrared dryer

Infrared (IR) drying has been a popular technique in recent years. The method of supplying heat to the product for drying is infrared radiation. Infrared (IR) drying provides significant advantages over conventional drying, such as time and energy savings, high product quality, clean working environment, and precise control and monitoring of process parameters. IR dryers are small units with very high heat flux, which makes them easy to retrofit on existing machines [93–95].

2.2.12. Superheated steam dryers

Superheated steam drying is an environmentally friendly and energy saving process that uses super steam heated beyond its boiling point. This method is based upon the vaporisation of water in the product through contact with superheated steam. The superheated steam allows good heat transfer to the product that needs to be dried. In general, superheated steam drying should be considered under the following conditions: when the energy cost, or product quality is very high or when there is a risk of fire and explosion [96]. Fig. 3 presents the working principle of various dryer types.

2.2.13. Solar dryers

Solar dryers produce higher temperatures, lower relative humidity, and lower product moisture content and reduced spoilage during the drying process in contrast with natural “open drying”. In addition, they take less space and time, and they are inexpensive compared to artificial mechanical drying methods. Low capital and operating costs are the primary advantages of solar dryers, as well as the fact that they require little expertise. The basic handicaps of solar drying method are listed as follows: risk of contamination, theft or damage by birds, rats or insects; slow or intermittent drying and no protection from rain or dew which allows mould to grow, possibly resulting in a relatively high final moisture content; low and variable quality of products because of over- or under-drying; large areas of land needed for the shallow layers of food; high demand for physical labour as the crop must be turned, and moved in case of rain; direct exposure to sunlight which reduces the quality (colour and vitamin content) of some fruits and vegetables. Furthermore, as sun drying depends on uncontrollable factors, product quality cannot be standardized [97]. Table 2 shows a systematic classification of current solar dryers for agricultural products, hinged on the design of system components and mode of utilisation of solar energy.

Comprehensive overviews of constructional and working details of different types of solar dryers used for the drying of various commodities such as agricultural, food, herbal, and medicinal products have been presented by many researchers [99–103].

3. Drying in porous media

A porous medium can be defined as any medium having a matrix and a void space. In a porous medium, any fluid flows through a very complex network of pores and capillaries. Due to this complexity, drying of porous media has been a focal point for many studies. Prat [104] highlights that drying is one of the more energy intensive processes in the industrial field, such as in the fields of food, textile, soils, minerals, rocks, wood, ceramic powders and building materials, etc. One of the first serious discussions and analysis of the drying of porous material based on the theories for simultaneous heat and mass transfer was introduced during the 1960s by Luikov [105]. Resent research is mainly based on the work of Whitaker [106], who applied volume averaging to the transport equations for continua in an attempt to obtain a general theory that would model the drying of porous media. Crucially, much more information has become available on heat and mass transport phenomenon during the past 30 years [107–111]. Two-dimensional coupled heat and mass transfer was modelled by Boukadida et al. [112]. Kowalski et al. [113] presented the coupled heat and mass transfer model based on thermodynamics. Another model for the moisture transport in porous media was provided by Carmeliet et al. [114], Chen and Shi [115], and Kallel et al. [116]. There is always the need to have good values for the process parameters, such as diffusion coefficient to determine the transport of heat and moisture in porous media. Much research has been dedicated to obtain these values [117–119]. Table 3.

Classification of the drying process in the porous material can be achieved in various ways. First, this can be dependent on the product type such as bricks, wood or granular, or on the product

Table 3
Some of the papers on drying of porous media.

Sr. no.	Researchers	Year	Remarks
1	Shokouhmand et al. [120]	2012	A novel method for numerical simulation of drying a porous media was proposed
2	Belleghem et al. [121]	2012	Newly developed model was used to simulate the convective drying of a sample of ceramic brick
3	Koptyug [122]	2012	Reviewed the use of MRI techniques to study drying and sorption processes of porous materials
4	Vorhauer et al. [123]	2013	Isothermal and non-isothermal drying experiments were conducted with imposed constant temperature gradients in a two-dimensional square pore network
5	Khalfaoui et al. [124]	2013	The work was focused on the coupling of the thermal (temperature distribution), hygroscopic (moisture, humidity), and mechanical (strains and stresses) aspects shown during the drying process of a saturated porous medium
6	Kowalski and Banaszak [125]	2013	The thermo-hydro mechanical model of drying of the fluid-saturated porous materials that is suitable for a mathematical description of these phenomena as well as the acoustic emission technique for their experimental detection were presented
7	Kowalski et al. [126]	2013	Numerical simulations of optimal control during the convective drying of saturated capillary-porous materials were presented.
8	Yuejin et al. [127]	2014	The pore network model was presented to describe the slow isothermal drying process of porous media
9	Cai et al. [128]	2014	The convective drying kinetics of porous medium was investigated numerically
10	Yiotis et al. [129]	2015	A pore network model was identified experimentally for the evaporative drying of macroporous media
11	Shokri et al. [130]	2015	A snapshot of the range of issues and contemporary understanding of drying porous media was provided

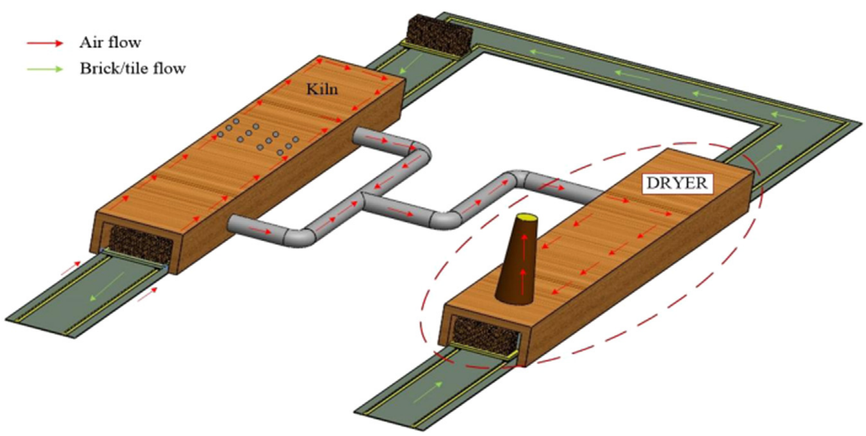


Fig. 4. Schematic illustration of brick/tile production line.

geometry including sheets-paper, textiles and fibrous materials. Second, materials might be classified being hydroscopic, meaning they contain either bound or free water, or non-hydroscopic. The drying process can be classified according to the technology used to remove the liquid. Convective drying in air is the most common drying process [131,132]. Others include microwave drying, radiative drying or infrared radiation, supercritical drying, contact drying, freeze drying, or a combination of these and possibly others. The type of equipment used is another aspect of the classification of the drying process. Some of the more typical possibilities include the following: flash, drum, press and fluidized bed dryers [133].

3.1. Fundamental principles of brick/tile drying

Brick and tile manufacturing consists of different processes which have a remarkable impact on the quality of products, such as raw material preparation from soil, moulding, drying and firing. The published literature reveals that drying is one of the most significant stages for energy cost and product quality.

The drying process makes the brick and tile ready for firing by slowly and uniformly reducing moisture content from the soft “green” brick [134-136]. As can be seen from Fig. 4, green bricks/tiles are moved in the tunnel or chamber dryers on cars for drying. Heat from the hot flue gases coming out of the kiln is utilised for the drying of bricks/tiles. The cars loaded with dried green bricks/tiles are pushed into kiln. The flue gases from the drying tunnel are released into atmosphere through a chimney. Drying does not only refer to the removal of the moisture but also to the protection of the physical structure and appearance as an important part of the drying process. Drying is basically formed by the principles of transport of heat and mass. When heat is applied to a moist solid from the external environment (such as air and hot gases) until it reaches a certain temperature, moisture evaporates from the region near the solid surface first. Drying is a diffusional process in which the transfer of moisture to the surrounding medium takes place by the evaporation of surface moisture, and as soon as some of the surface moisture vapours, more moisture is transported from interior of the solid to its surface. A number of authors have reported analyses of diffusional process [137-140]. The transport of heat and mass within the moist solid occurs by a variety of mechanisms depending upon the nature and type of the solid.

The drying conditions are important in relation to both deformations during the process and the final quality of the product. For instance, if this heat and mass transport does not occur under the suitable external and internal conditions like atmospheric temperature, air flow rate, relative humidity, soil characteristics and brick moulding type, it causes damage to the final product [141]. In many circumstances, the drying process leads to the loss of product and sometimes the damage occurring as a result of drying might be observed after burning [142]. Hence, the detailed analysis of the simultaneous heat and mass transfer mechanisms during drying is important for providing information which results in a final product of good quality with minimal waste. There are a relatively large number of numerical studies in the area of heat and mass transfer in the brick/tile drying process [143-150].

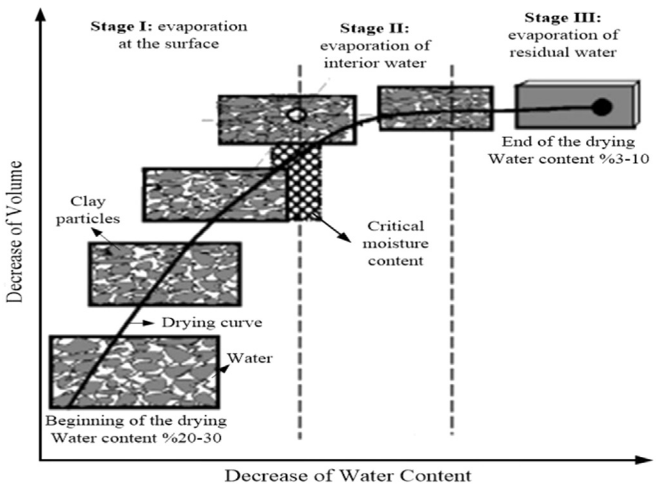


Fig. 5. Schematic illustration of drying process.

Thermally removing the moisture can be attained by either mechanical heating (dryer) or atmospheric drying (exposure to sun rays). Although atmospheric drying is much more preferred in many countries, the use of different types of mechanical dryers is increasing day by day due to their remarkable advantages.

The three stages of the drying process are illustrated in Fig. 5. At the beginning of stage I, the wet bricks and tiles have a moisture content 20–30%. Hence, as much moisture as possible must be removed before the firing process in order to prevent cracking. In this stage, a significant proportion of the total water within the brick and tile surface is transferred as vapour to the environment. At the same time, the water diffuses by capillary action from the interior to the surface. For optimal drying, this process should be done slowly, because if the heat transfer takes place quickly, it becomes impossible for the moisture inside to escape and as a result of this some cracking may occur. Therefore, the solution of this problem requires experience and knowledge of conditions like the flux and temperature of air at the surface.

The moisture content is crucial at the second stage due to the water level in the clay reaching the critical point. The critical moisture content (CMC) is an important parameter for determining the coefficient of sensitivity of clays to drying. It must be determined experimentally. Several attempts have been made to describe the relationship between critical moisture content and drying rate [151,152]. In the case of brick, Perry et al. [153] reported a value of 14.0% for a sample with a thickness of 1.6 cm. At the third stage, the drying rate can be increased by providing the maximum amount of heat to reach the minimum moisture content (approximately 3–10%). A thorough consideration of the drying kinetics of materials is advantageous for understanding the effect of environmental conditions on the moisture content of porous materials. Therefore, numerous studies have attempted to explain the drying kinetics of porous materials by using many moisture transfer models in the literature [154–157].

Together these studies provide important insights into the drying process. In addition to this, some scientific studies fill a gap in the literature related to brick and tile drying. Shokouhmand et al. [158] proposed an innovative method for an accurate simulation and design of a chamber dryer used in the brick industry. In this method, they solved two-dimensional coupled mass and heat transfer equations using a finite difference method. As a result, the heat transfer coefficient for a chamber brick dryer was obtained. Murugesan et al. [159] studied conjugate drying along with drying induced stresses of a two-dimensional rectangular brick of aspect ratio 2, using two-dimensional Navier Stokes equations. The results indicate maximum stress occurring at the regions closer to the leading edge. García et al. [160] performed mechanical and thermal characterisation of fired brick walls made using traditional handcraft. Xu and Shao [161] proposed a dry processing technique for tile production and also compared semi-dry processing, dry processing and wet processing techniques. Experimental results showed that high energy consumption and high production cost were solved by dry processing technique. In his dissertation study, Akal [162] performed a series of experiments to investigate the drying characteristics of brick on reproduction channel. The experimental results showed that the process of drying was rapid at the beginning but then it gradually slowed down. In 2014, Ozen [163] published a thesis study entitled "Experimental investigation of convective drying of green bricks in a laboratory scale tunnel dryer". The aim of this study was to investigate the drying behaviour of green brick, which has different clay contents. In the experiments performed in a laboratory scale tunnel dryer, different air temperatures and air velocities were applied on green bricks to determine the drying kinetics. The results indicated that drying process is affected by drying air temperature and green brick clay content.

3.2. Classification of brick/tile dryer types

Drying is an important step that requires sufficient knowledge and mastery of the subject to create an efficient process and quality products. Generally, two types of dryers are used. Tunnel dryers are one of the most efficient dryers which can be employed for drying different kinds of bricks and tiles with various dimensions and used to move the brick and tile through humidity controlled zones while preventing cracking (Fig. 6). Wagons loaded with bricks and tiles are carried on rails through a one-way tunnel and continue their way through changing temperature zones. In order to accelerate the process, external sources of fan-circulated hot air are directed to the dryer. The heat exchange fully takes place between the air and brick/tile. The number of circulating fans inside the dryer is defined according the capacity requirements of the dryer. Tunnel type dryers are widely used in industry because of the important advantages that they have possess, such as high efficiency, energy saving charactristics, easy maintenance, homogeneous and very sensitive drying, and short drying cycles [164–169].

It is widely common to see automatic chamber dryers in Europe. The extruded bricks/tiles are automatically placed in rows on two parallel bars. The principle behind automatic chamber dryers is that air is blown from below the drying charge through the bricks or tiles. An inclined floor, ceiling and correct spacing of the bottom and upper grades are necessary for equal air flow over the entire chamber. A significant analysis and discussion on the optimisation of tunnel and chamber type dryers was presented by Vellhuis and JDeniswn [170]. The optimisation procedure followed was a combination of experiments and simulations with DrySim software.

The terms related to energy, such as consumption, efficiency, etc. have become an important starting point for research in recent years. Particularly, new ideas in brick/tile drying methods and dryer design are required due to rising energy costs, the negative effects of fossil fuels on the environment. The new ideas and practices developed for this purpose should consider several points of view; methodological, technological, socioeconomic, organisational, ecological. In a study conducted by Mancuhan and Küçükada [168], it was reported that the energy requirement varies between 2040 and 3510 kJ/kg for brick based on the type of the fuels used. Detailed information about energy and exergy values of different type of dryers can be found in the review performed by Aghbashlo et al. [39].

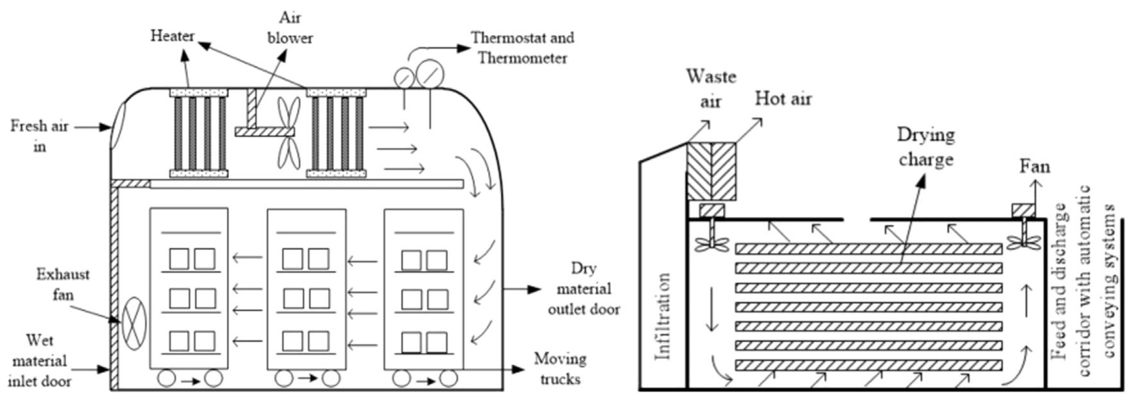


Fig. 6. Simplified diagram of tunnel and channel type dryers.

4. A brief overview on bibliometric analysis

Quantitative analysis, statistics related to publications and frequency distributions are important parts of science policy in many countries. This type of scientific performance study can be used as an important reference to reveal trends and to enhance the research activity in research topics for both developing and mature disciplines [171].

Bibliometric analysis has been a commonly used methodology in recent years. The main goal of bibliometric analysis is to measure science and technology performance both on a national and international basis within a given field or body of literature. The methodology used contains data from a variety of disciplines such as life sciences, physical sciences, social sciences, and health sciences. Bibliometric analyses play a more serious role particularly when traditional literature reviews are inadequate in terms of to draw a roadmap [172]. The Zipf, Bradford, and Lotka laws are the main pillars of bibliometric analysis [173].

- Zipf's law of word occurrence: Zipf's Law is a prediction method about the frequency distribution of words within a text.
- Bradford's law of scatter: Bradford's Law serves as a general guideline to librarians in determining the number of core journals in any given field.
- Lotka's law of scientific productivity: Lotka's Law describes the frequency of publication by authors in a given field.

There are two main process steps in bibliometric analysis; performance analysis and science mapping [174]. The starting point of performance analysis (data retrieval, pre-processing, network extraction, normalisation) is to characterize bibliometric variables according to authors, year, the source of publication, type of document, citations, country and institutions, etc. At the second step (mapping, analysis and visualisation), the way that fields, disciplines, individual papers or authors, and specialities are related to one another in a scientific research field is determined [175]. There are a number of different ways to form a science map; co-citation and co-word analysis [176,177]. ISI Web of Science, Scopus (access is limited to subscribers) and Google Scholar (free access) are commonly used sources for retrieving bibliometric data. At the same time, there are some general software tools that can be utilised for processing of data and science mapping, such as citespace, bibexcel, publish or perish, ucinet, pajek, vosviwer and science of science (Sci^2) [178]. Each of them has certain advantages and limitations which may influence a study.

4.1. Research questions

This study was carried out to find the various trends in scientific studies in the field of brick and tile drying in the world. For this purpose, all documents used in this study were accessed from the Scopus database. To shed light on trends, both bibliometric analysis and a historical review were conducted in this research.

In our research, we attempted to answer the following main questions:

- *What is the number of publications on drying?*
- *What is the number of publications and patents on drying of brick/tile?*
- *What are the types of publications?*
- *What are the leading journals?*
- *What are the leading keywords?*
- *What are the distributions of publications according to countries?*
- *What are the leading organisations?*
- *What are the relations among publication areas?*
- *Who are the leading authors?*

The study comprises a wide array of scientific publications on the field of brick/tile drying to provide some insight into how this research area has developed, what kind of events have become more/less influential, and which authors and journals are the most referenced within the field.

4.2. Method

As the first step of the bibliometric analysis, the Scopus database was systematically searched to obtain a dataset for all the published documents relating to the drying of bricks and tiles. Scopus is a bibliographic search field, founded in 2004 by Elsevier, which indexes citations for scientific publications. Scopus delivers the most flexible overview of the world's research output in the fields of science. The dataset collected from the Scopus database can be used without the necessity of separating the different sections in order to analyse the evolution of the research field. This feature is one of the reasons to prefer the Scopus database. The year range covered from 1980 to 2015. Although the methods proposed in this paper should apply equally well to any field of research, we focus our discussion on a research regarding brick and tile drying technologies. This field was chosen as it encompasses many highly active subfields and it is an example of diverse research fields used in conjunction with new purposes.

The data used in the study were obtained from the Scopus database by using the descriptive keywords “drying” and “drying brick/tile”. The subject area was limited to physical sciences, and engineering and energy were selected as research areas in the search. Bearing these factors in mind, various analyses were performed for research mapping and forecasting.

The bibliometric fields including the cited references for each article were exported. The bibliometric information was analysed through the use of Bibexcel software which was developed by Professor Olle Persson at Umeå University, Sweden. The first step was to convert the Scopus file into Bibexcel Dialog format. Bibexcel is a great tool to carry out bibliometric analysis and in citation studies in particular. After making the necessary limitations, some parameters were obtained, such as the number and type of documents, the number of times cited, country and journal information of selected studies. The connections were also investigated in in a co-citation analysis. After that, CiteSpace software was used for bibliometric network visualisations.

5. Trends in scientific studies for brick and tile drying

The aim of this study was to identify the trends in the world and to present a roadmap related to scientific studies conducted on brick and tile drying. For this reason, the answers were sought to the following questions:

1-What is the number of publications on drying between 1980 and 2015 cited in Scopus database?

In the study conducted over the Scopus database, 32,438 scientific studies with the keyword "drying" were identified in the engineering and energy research areas between 1980 and 2015. A gradual increase in scientific production was observed from the '80s up to 2000; however, a steep rise occurred after 2000. 2009 of these studies (6.19%) occurred in 2015, 2552 (7.86%) in 2014, 2362 (7.28%) in 2013, 2167 (6.68%) in 2012. The remaining parts of these studies (23,348-71.97%) were published between the years 1980 to 2011. The number of publications grew by 40.5% between 2000 and 2015. The distribution of these studies between 1980 and 2015 is shown in the graphical form in Fig. 7.

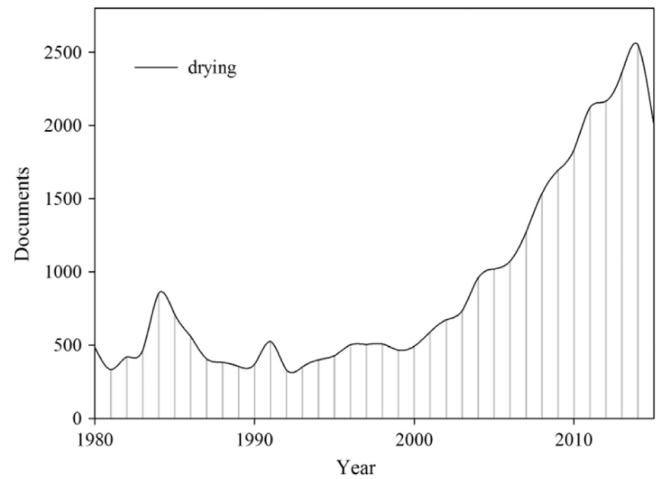


Fig. 7. Number of publications on drying in the Scopus database.

2-What is the number of publications and patents on drying of brick/tile between 1980 and 2015 cited in Scopus database?

In the same manner, the study results were obtained with the keyword "drying of brick" and "drying of tile" in the Scopus database, 349 scientific studies related to brick and 171 scientific studies related to tile were published by researchers in the engineering and energy research fields between 1980 and 2015. As can be seen in Fig. 8, 371 publications (71.34%) were published after 2000 in total. 2014 was the most productive year for drying of brick and tile with the publication of 28 and 13, respectively. The "Espacanet" international patent database was used in order to analyse the patent studies done on the drying of brick and tile. According the scanned results, 25 patent studies related to the drying of brick and 55 patent studies related to the drying of tile were found. It is apparent that there is not a direct correlation between the number of patents and scientific publications when the number of patents and publications were analysed in terms of years. It was realized that many researchers focused on raw material synthesis and dryer design when patents were individually analysed. In the manufacturing sector of brick and tile, which were was the first manufactured building materials in history, Turkey continues its activities with approximately 350 factories and takes its place among countries that have a say in the world. However, few writers have been able to draw on any structured research into the drying of brick and tile in Turkey.

3-*What are the types of publications*?

As depicted in Fig. 9, the majority of publications regarding the drying of brick were made as article (249-71.3%) in 349 studies. It was followed by 65 conference papers (18.6%) and 16 reviews (4.6%). In the same manner, the majority of publications surrounding the drying of tile were in the form of articles (128-74.9%) in 171 studies. It can be deduced from the analysis of document type that the researchers preferred to disseminate their study results mostly in national/international journals or in conferences. Researchers have preferred mostly the English (462) and German (171) languages in order to share their study results.

4-Which are the leading journals that directly (by publication) contribute to the brick/tile drying literature?

This study shows that Ziegelindustrie International/Brick and Tile Industry International is one of the most comprehensive sources of brick/tile research. Ziegelindustrie International/Brick and Tile Industry International is the leading international trade journal for the entire heavy clay industry published by Bauverlag BV Gmbh in Germany. The journal on an average has published 4,6 research papers per year related to the drying of brick and tile. Fig. 10.

5-Which are the leading keywords used in the literature?

To be able to analyse the content of 520 publications in the area of brick/tile drying, a network map was designed for the most often used words in the studies by browsing "keywords" (Fig. 11). As a result of the analyses, the most preferred key words were drying (188), brick (155), brickmaking (108), tile (78) and kilns (60). Fig. 11 shows the distribution of keywords according to years. Fig. 11 also illustrates the frequency of usage in accordance with years. The most used keywords were brick, drying and brickmaking in 1980s. Especially since the 2000s, new keywords have begun to take place in studies such as sintering, mechanical properties, shrinkage, etc. depending on technological developments.

6-What are the distributions of publications according to countries?

The geographic distribution of scientific production for both the drying of bricks and the drying of tile between the years 1980–2015 is given in Fig. 12. The country with highest scientific output throughout the whole period studied was Germany, with 79 studies (15.19%). After Germany, the countries found to have the highest output are China, the United States, and the Netherlands in the field of brick drying; they are United States, Spain, and Brazil in the field of tile drying. Fig. 12 also shows the collaborations among the countries which can help us to identify to the global trends. When viewed from the perspective of countries, the United States of America (USA) is the dominant country engaged in joint publications with other countries according to an analysis of global trends in science. The UK and Spain are second in terms of their share of the world's scientific research papers related brick and tile drying written in English. China has been pushed into third place, with Germany, Japan, Canada and France following behind.

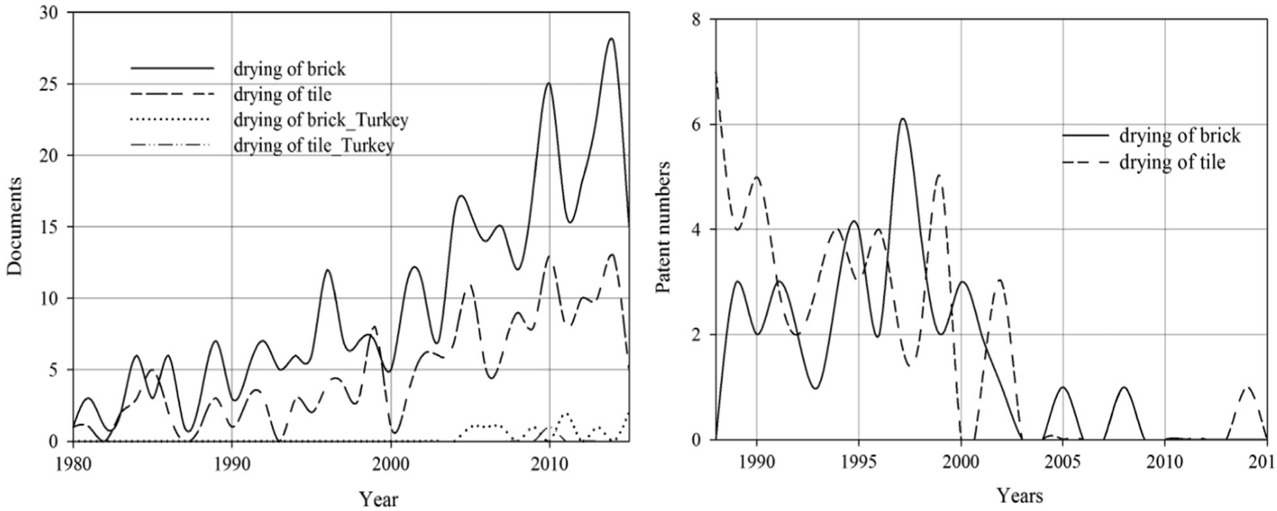
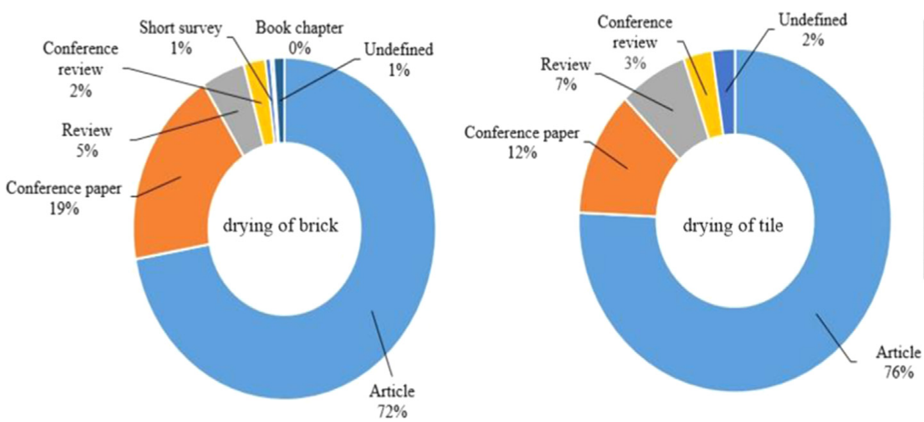
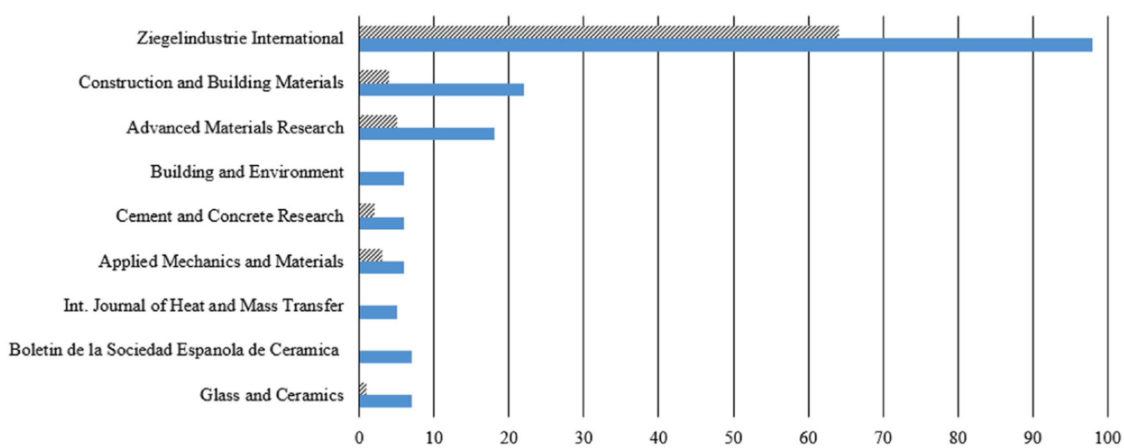


Fig. 8. Number of publications and patents on drying brick/tile between 1980 and 2015.



language	number of documents
English	462
German	172
Spanish	14
Russian	5
Chinese	3
French	3
Japanese	3
Polish	3
Czech	1

Fig. 9. Distribution of publications according to document type.

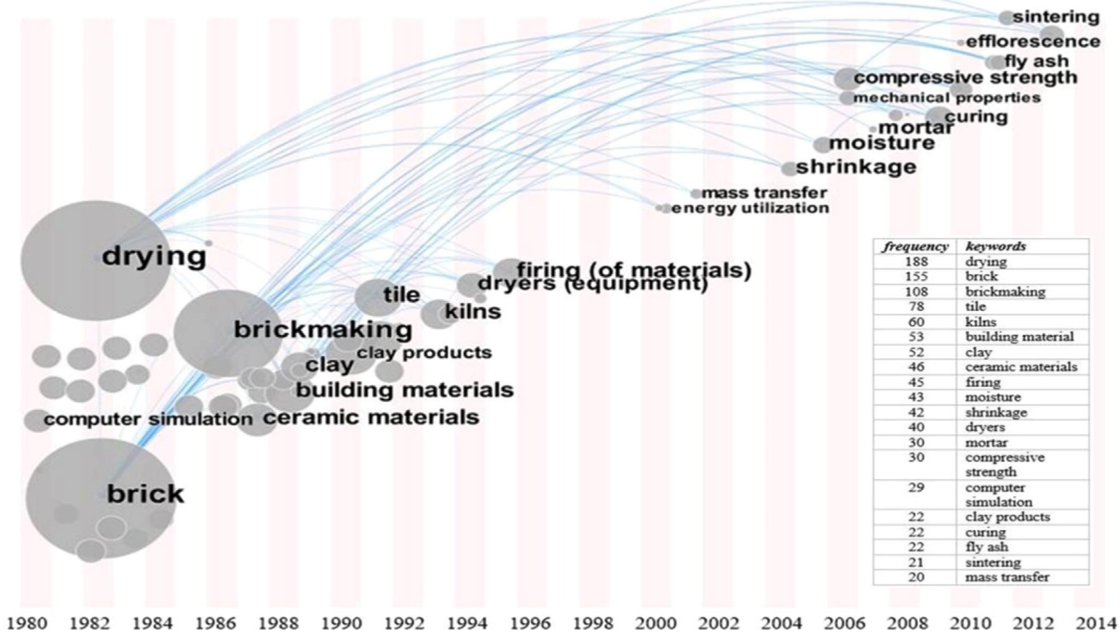


	Glass and Ceramics	Boletin de la Sociedad Espanola de Ceramica	Int. Journal of Heat and Mass Transfer	Applied Mechanics and Materials	Cement and Concrete Research	Building and Environment	Advanced Materials Research	Construction and Building Materials	Ziegelindustrie International
drying of tile	1	0	0	3	2	0	5	4	64
drying of brick	7	7	5	6	6	6	18	22	98

Fig. 10. Distribution of leading journals.

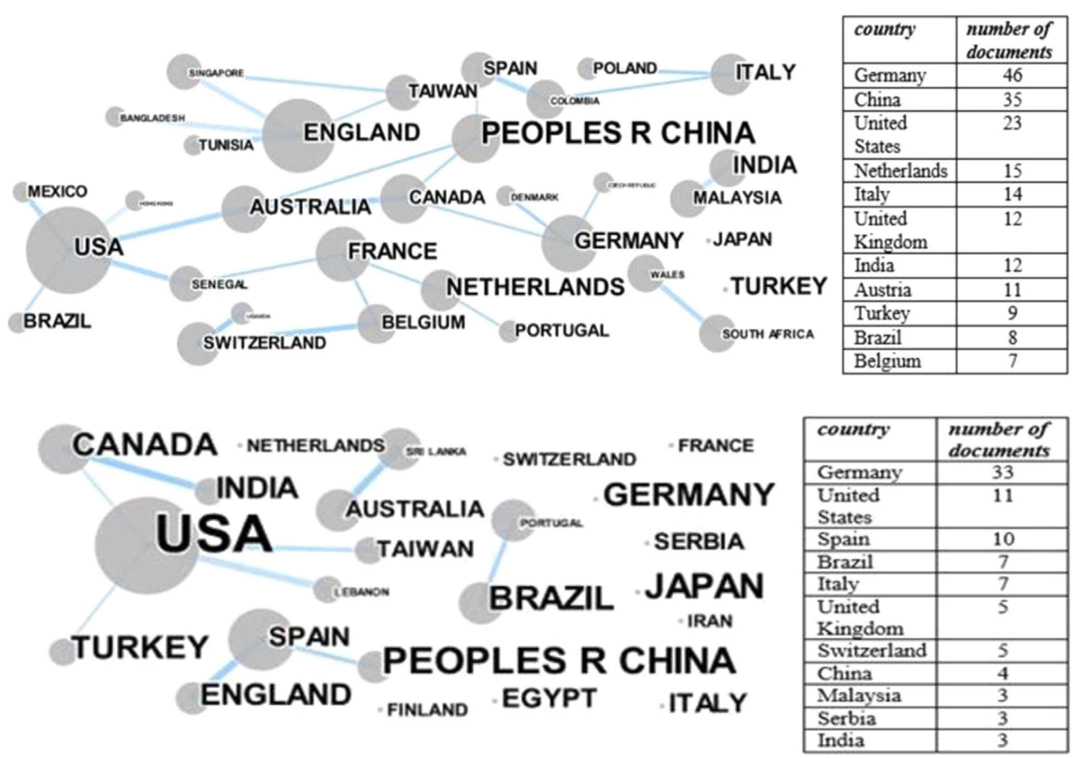
7-Which are the leading organisations that directly (by publication) contribute to the literature?

As can be seen in Fig. 13, the most prominent institutions in the world carrying out research on the drying of brick/tile are Eindhoven University of Technology (Netherlands), National Taiwan University (Taiwan), University Paris-Est (France), Hong Kong Polytechnic University (Hong Kong), Shizuoka University (Japan), Pennsylvania State University (USA) and Bristol University (UK).



frequency	*keywords*
188	drying
155	brick
108	brickmaking
78	tile
60	kilns
53	building material
52	clay
46	ceramic materials
45	firing
43	moisture
42	shrinkage
40	dryers
30	mortar
30	compressive strength
29	computer simulation
22	clay products
22	curing
22	fly ash
21	sintering
20	mass transfer

Fig. 11. The network map of keyword analysis.



country	*number of documents*
Germany	46
China	35
United States	23
Netherlands	15
Italy	14
United Kingdom	12
India	12
Austria	11
Turkey	9
Brazil	8
Belgium	7

country	*number of documents*
Germany	33
United States	11
Spain	10
Brazil	7
Italy	7
United Kingdom	5
Switzerland	5
China	4
Malaysia	3
Serbia	3
India	3

Fig. 12. Distribution of publication numbers according to country (a) brick (b) tile.

In the local context, Gazi University and Afyon Kocatepe University are the most prolific institutions in terms of brick/tile drying studies. Fig. 13 also demonstrates that most of the studies have been carried out at universities since 1980. Moreover, firms such as TNO Science and Industry, Terada Seisakusho Co. and BNFL Magnox in countries like the Netherlands, Japan and the UK, conducted R&D studies in corporation with universities.

8-What are the relations among publication areas?

When the results obtained from the Scopus database were evaluated, it was determined that a major part of these publications (500) were published in the field of engineering. In Fig. 14, which shows the relationships between research areas, revealed that there is a strong connection among engineering, chemistry and material science.

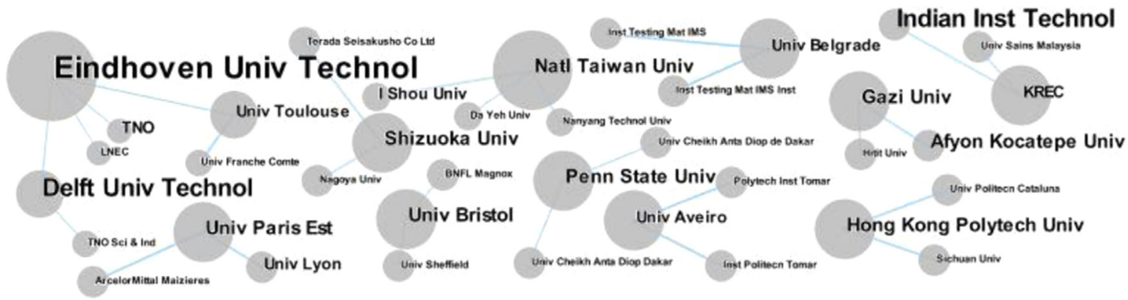


Fig. 13. Featured institutions in publications.

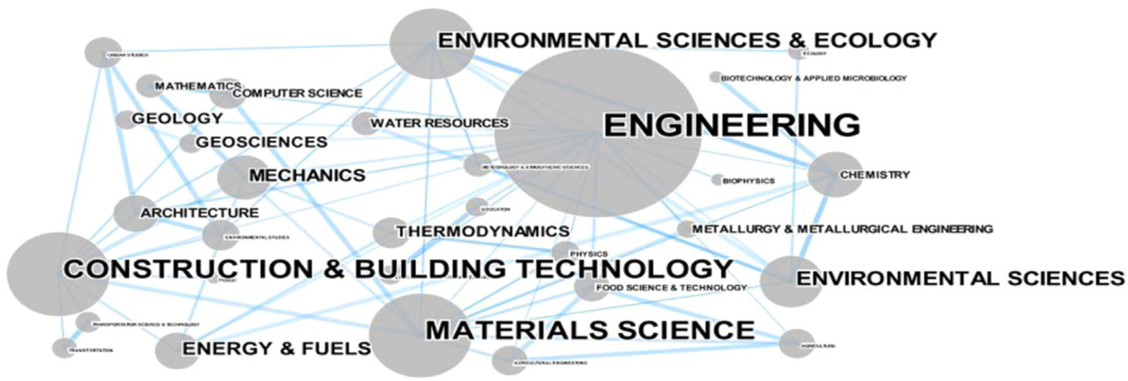


Fig. 14. Distribution of publications according to research area.

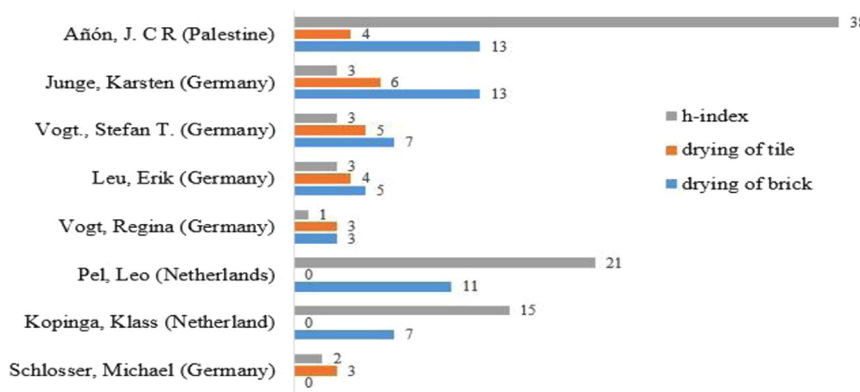


Fig. 15. The number of author' documents and h-index.

9-Who are the leading authors that directly (by publication) contribute to the drying of brick and tile literature?

The leading authors that directly contributed to the literature, their citations and h-index are shown in Fig. 15. When the authors were analysed with regard to the number of publication and citation, it was observed that German authors came into prominence on brick and tile drying. The majority of the studies acquired from the Scopus database were written by multiple authors. Only 166 publications were written by a single author. On the other hand, 354 publications were written by two or more authors. These results show that the researchers placed emphasis on teamwork rather than on individualism in the studies on the drying of brick/tile. As can be seen in the graph below, the h-index is a specific method used to measure the combined academic impact and productivity of a scientist or scholar. The use of qualitative and quantitative attributes is regarded as one of the advantages of the h-index. Anon, J. CR (Palestine), Pel, Leo (Netherlands), and Kopinga, Klass (Nertherlands) were the scientists whose h-index was the highest with values of 38, 21 and 15, respectively.

10-Author Co-citation network analysis

There are different types of methods to form a science map, for instance the most popular ones are co-citation and co-word analysis. In the present study co-citation analysis was used in order to provide a way of exploring the interpretation of the results. Since author co-citation analysis (ACA) was introduced in 1981 by White and Griffith [179], it has gained great popularity in the study of scientific and technological structure. Over the 34 years under analysis, it was observed that the number of international collaborations in science and technology among different countries has increased. The increase in papers co-signed by authors from different countries is one indicator of this process.

In Fig. 16, the authors and their interrelationship form a network graph. The name of the most prominent author in the interrelated topic is used for the labelling of each network. In this graph, several authors are interrelated, where the volume of the

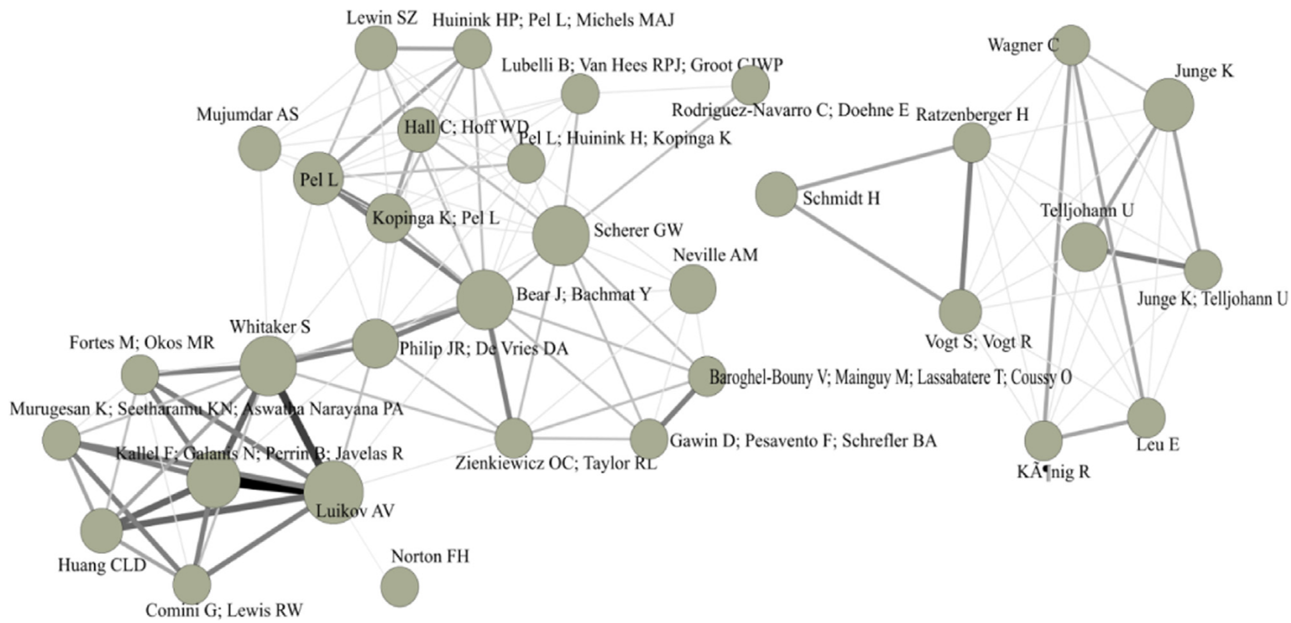


Fig. 16. The co-citation analysis network.

Table 4
Year-wise authorship pattern.

Authorship	Year							Total	Percentage
	1980–1985	1986–1990	1991–1995	1996–2000	2001–2005	2006–2010	2011–2015		
Single	8	17	24	27	45	21	24	166	31.92%
Joint	18	10	14	31	47	106	128	354	68.08%
Total	26	27	38	58	92	127	152	520	100%

spheres is proportional to the number of citations, when two references are co-cited, there is a link and the thickness of the link between two spheres is proportional to the relationship between the citations. The map shows three well-defined clusters: at the top left corner, the authors in this group, especially Whitaker S, Luikov AV, Galanis N, Kallel F, Galanis N, Javelas R and Perrin B were ranked as the most often co-cited authors. A second cluster is at the middle region of the map and it is formed by: Kopinga K, Pel L, Bear J, Bachmat Y, Scherer GW. In this case Bear J and Bachmat Y are the most productive authors. The third cluster is located at the right zone of the map, where Telljohann U is the most productive author.

Table 4, below shows that out of 495 articles single authors contributed 166 (33.53%) articles while the remaining 354 (66.47%) articles were contributed by joint authors.

6. Conclusion

Although the technical studies conducted in recent years show a rapid increase in terms of understanding of the drying process, the current situation and the design of more efficient systems, the studies in the academic field have lagged behind this acceleration. One of the most important factors causing this situation is the difficulties in combining the basic thermodynamic knowledge and transport phenomena in describing the drying process. Therefore, it has a critical importance to attempt more research in addressing the issue of these challenges. Starting from this point of view, the main purpose of the present study is to gain a new perspective about the latest developments and future trends of researchers, particularly in the area of brick/tile drying. This article covers many of the research articles, reviews, conference papers, and book chapters in the literature covering drying published in the last 25 years.

As a result of the study, general assessments are presented below.

- In the research on drying, effective transfer of knowledge between industry and academia plays a critical role in the development of modern tools and methods.
- There is a need for more active collaboration of researchers from different disciplines to be persistent in commercial applications as well as scientific studies.
- The use of analysis methods supported by computer software has been widely preferred by researchers in recent years for the design of systems with regard to suitable drying method, simulation and control.

Returning to the hypothesis posed at the beginning of this study, it is now possible to state that to measure science and technology performance both on national and international basis is possible with bibliometric and network analysis. This study provides a framework and serves as a base for future studies into the identification of influential authors, journals, works and subjects in the field of drying publication published between 1980 and 2015, using a highly selective dataset of the field.

Based on the analysis, the following remarkable conclusions are presented:

- 349 scientific studies related to brick and 171 scientific studies related to tile were published by researchers according to the Scopus dataset.
- Significant growth is observed in scientific production particularly in the period 2000–2015.
- The largest number of contributions come from multiple authors, with 354 (68.08%).
- The highest number of publications is in the field of engineering.
- The largest number of contributions come from Germany, with 79 publications.
- The study showed that the highest number of contributions were from universities.

The findings from this study make several contributions to the current literature. Considerably more work needs to be done to identify worldwide the trends related to brick/tile drying or other topics.

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