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Review

Potential application of electronic nose technology in brewery

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The aroma of beer is important as a characteristic feature and for the quality of the product as well. Therefore, this fact is of interest to the brewers to evaluate the aroma of products, raw materials, and unfinished beer. This review describes the applications of electronic nose (machine olfaction) in brewery for beer quality assessment. The demand for electronic nose in the brewing industry is growing because the versatility and ease of operation of those instruments make them appropriate for fast and accurate analysis of beers or for monitoring quality in the brewery process especially in fermentation stage. Also, some considerations on the motivation for the development and use of electronic nose in brewery as well as future trends are discussed.

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Introduction

In brewery, a very complex mixture of constituents varying widely in nature and concentration levels is brewed from raw materials including water, yeast, malt, and hops and contains a broad range of different chemical components that may react and interact at all stages of the brewing process. Beers are known to be good sources of antioxidant compounds, such as volatile maltol and 2-furanmethanol (Wei, Mura & Shibamoto, 2001), polyphenols (Lugasi, 2003), and ferulic acid (Szwajgier, Pielecki, & Targonski, 2005 Beer has other valuable functions such as improving digestion, promoting a healthy heart, enhancing the potency of vitamin E and preventing scurvy by means of the possible mechanisms of stimulating gastrin, gastric acid, cholecystokinin and pancreatic enzyme secretion; reducing serum cholesterol, triglycerides, and lipid peroxides; and elevating high-density lipoprotein (HDL) cholesterol (healthy cholesterol) levels (Bagchi, Ray, Bagchi, Preuss, & Stohs, 2002). Beer was found to impair lymphokine-activated killer cell activity (Bounds, Betzing, Stewart, & Holcombe, 1994) and to have an antithrombotic effect (Moore & Pearson, 1986). Usual consumption of beer could lead to some favorable biochemical changes in the blood of patients with coronary artery disease (Gorinstein *et al.*, 1997) and also increases plasma antioxidant capacity (Gasowski *et al.*, 2004; Ghiselli *et al.*, 2000). In bibliography, this fact has been documented that moderate consumption of beer had counteracting effects on plasma antioxidant components, finally resulting in no significant effect on overall antioxidant status (van der Gaag, van den Berg, van den Berg, Schaafsma, & Hendriks, 2000).

More recently, a profound interest in establishing the most appropriate methods to assess and enhance the quality in brewing has increased (Iimure, *et al.*, 2010). These interests could be associated with new technological advances, the increasing interest in quality of consumer goods, the increasing of R&D laboratories in the brewery industry and the establishment of more regulations and standards for food in general and for beer in particular. All these conditions encourage the brewery to make more quality conscious and so, it also resulted in the steady growth of quality control.

The aroma of beer is composed of complex mixtures of many volatile organic compounds (VOC) with diverse sensory and chemical attributes. Subtle differences in the relative amounts of these compounds can often characterize the beer smell. However, not all the volatile compounds have a considerable contribution in sample aroma (Marti, Boque, Busto, & Guasch, 2005). The role of each compound is known as function of concentration as well as sensory threshold (the minimum concentration that can be perceived by the human nose). Odor activity value of any compounds is affected by the ratio between concentration and sensory threshold. When this value for a specified compound is more than 1, it will likely contribute to beer aroma (Mistry, Reineccius, & Olson, 1997).

Consumption of beer has been increasing trend in recent years, even in countries where alcoholic beverages are not habitual; therefore, there is a large demand for the fast and reliable methods to evaluate organoleptic characteristics such as the aroma and the flavor (Da Silva, Augusto, & Poppi, 2008). The flavor of a beer is characterized largely by its taste and smell, which is affected by about 700 volatile and non-volatile compounds (Pearce, Gardner, Friel, Bartlett, & Blair, 1993). The number of *key* volatiles is not indicated in literature but esters, sulfur, aldehyde, and hops volatiles are the most important among them. Beer flavor is conventionally detected through the combination of common analytical tools (e.g., gas chromatography) and organoleptic profiling panels known human sensory panels. These approaches are expensive and time consuming. In spite of organoleptic panels can also give a lot of information about the characteristics of the beer but this method has some drawbacks such as assessor fatigue and subjectivity. In addition, GC-MS and sensory panel evaluation cannot be used as on line in brewery. Currently, a very challenging problem in brewery is quality enhancement of beer, and, subsequently, much time and money are spent on the appropriate methods to achieve this goal. As highlighted above, the flavor of beer is one of the most determinant factors in its quality and generally has been evaluated by a human sense (Langstaff, Guinard, & Lewis, 1991a, 1991b; Langstaff & Lewis, 1993).

People have employed the human olfactory system to recognize the pattern of the chemical odors included in food. For instance, the quality control of beer may be characterized through the olfactory sense in brewery industries but much effort and time need to be spent in order to choose and train the expert panelists (Ghasemi-Varnamkhasti, Mohtasebi, Ahmadi *et al.*, 2009). Moreover, the human olfactory system is prone to fatigue, which will contribute to response lag and affect detection results. The subjectivity and low reproducibility of sensory evaluation have been pointed out as faults. To help solving these problems, an objective evaluation method using electronic nose (machine olfaction) has recently attracted particular attention (Ghasemi-Varnamkhasti, Mohtasebi, Siadat, & Balasubramanian, 2009). At the following sections, some aspects of such intelligent system and its applications in brewery for beer quality authentication are discussed.

Electronic nose

Electronic nose is the term most commonly used in the literature to refer to this type of instrument, although other terms are also used, such as machine olfaction, artificial nose, mechanical nose, odor-sensing system or electronic olfactometry. Gardner and Bartlett (1994) defined the electronic nose as an instrument which comprises an array of chemical sensors with partial specificity combined with an appropriate pattern recognition system for recognizing simple or complex odors. Even though the definition was appropriate at that time, nowadays it does not include all the electronic nose systems that are available on the market. At the end of the 1990s, a new type of electronic nose based on mass spectrometric (MS) was developed (Dittmann, Nitz, & Horner, 1998). Even though some researchers do not consider that the MS-based system is an electronic nose (Mielle, Marquis, & Latrasse, 2000), the purpose of this instrument, like the classical ones, is to discriminate and subsequently to classify samples according to their volatile composition in a fast and simple way.

Electronic nose technology tries to detect the fingerprint of volatile compounds present in the headspace of a food sample by means of an array of semi selective sensors. Benefits of electronic nose technology are known as preparation of relatively small amount of sample and the speed of analysis (Rock, Barsan, & Weimar, 2008). However, this screening tool employs sensors that are not very selective to particular kinds of compounds thus preventing any real identification or quantification of individual compounds present in a food sample (Reid, O'Donnell, & Downey, 2006).

Also, the electronic nose tries to imitate the structure of the human nose. In Fig. 1 the analogy between the human and the electronic nose is illustrated. The first step in both is the interaction between volatile compounds (usually a complex mixture) with the appropriate receptors: olfactory receptors in the biological nose and a sensor array in the case of the electronic nose. One odorant receptor is sensible to multiple odorants and one odorant is detected by multiple odorant receptors. The next step is the storage of the signal generated by the receptors in the brain or in a pattern recognition database (learning stage) and later the identification of one of the odor stored (classification stage). A portable electronic nose is illustrated in Fig. 2 in which different components have been shown.

The output of the electronic nose can be the identity of the odorant, an estimate of the concentration of the odorant, or the characteristic properties of the odor as might be perceived by a human. Each sensor included at the sensors array of the electronic nose has different sensitivity to the odorant. For example, a specified odorant may produce a high response in one sensor and lower responses in others.

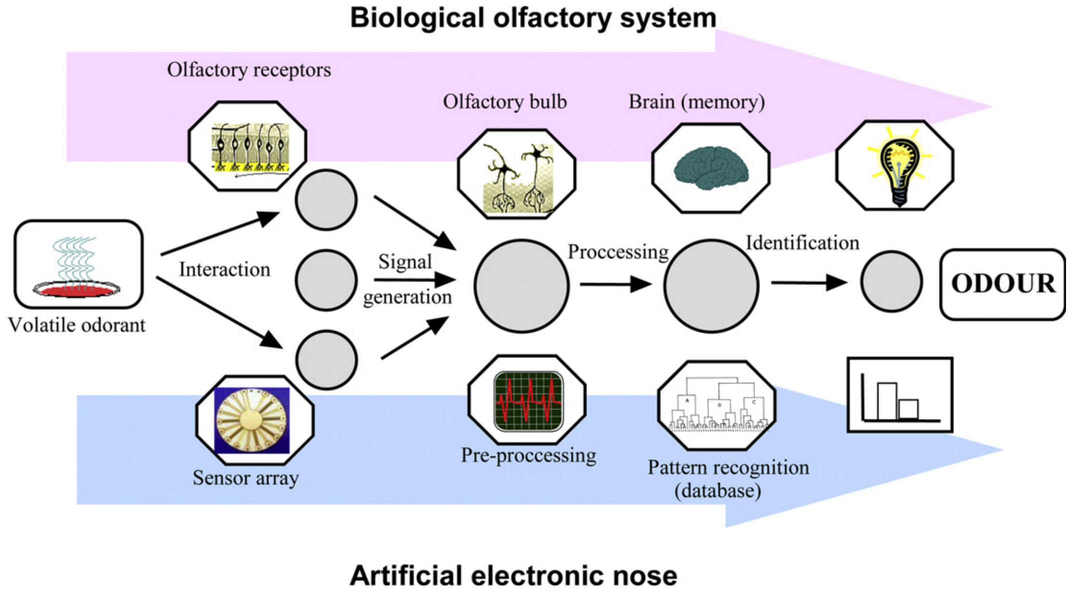

Fig. 1. Analogy between the biological and the electronic noses.

What is important is that the pattern of response across the sensors is diverse for different odorants. This distinguishability allows the system to recognize an unknown odor from the pattern of sensor responses. A unique response profile to the spectrum of odorants under test is produced by each sensor included at the array. The pattern of response across all sensors in the array is used to identify and/or characterize the odor by pattern recognition methods. These methods are required for the qualitative analysis of different compounds present in foods like beers and multicomponent analysis methods are required for the quantitative determination of one or more compounds in the product. Pattern recognition techniques are employed for analyzing the responses created by sensor array. The advantage of these methods is the characterization capability of complex mixtures without identification of individual components (Peris & Escuder-Gilabert, 2009).

Pattern recognition is a decision vector used for species classification based on a series of data obtained on those species. In general, a data matrix is formed from the patterns for a number of species and then a decision vector which divides the pattern into an assigned binary classification is computed based on normal experiments. Subsequently, classification of unknown patterns is fulfilled. The success rate of pattern

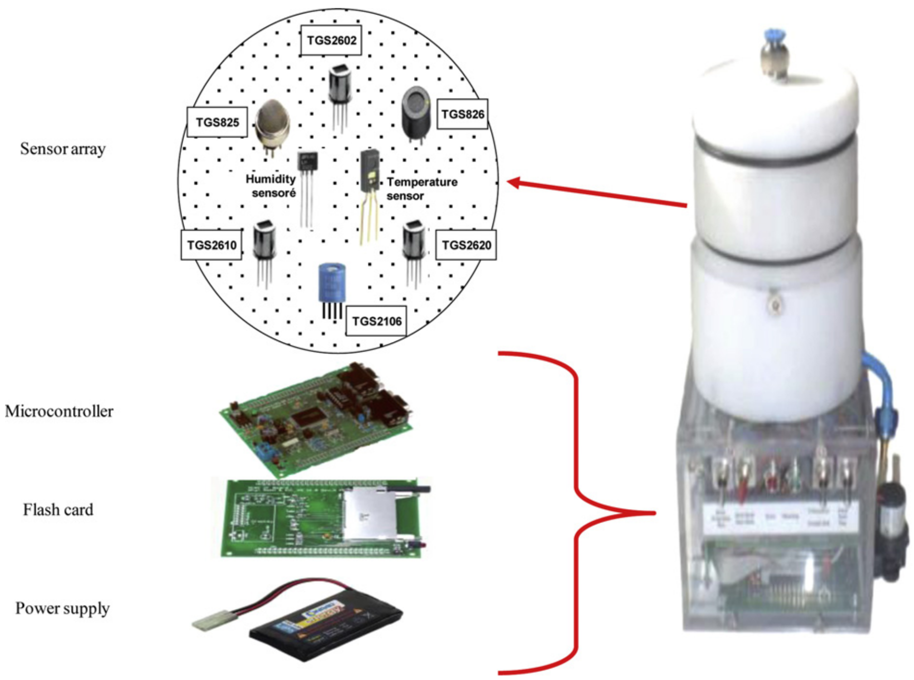

Fig. 2. Portable electronic nose (Fuchs, Strobel, Siadat, & Lumbreras, 2008).

recognition techniques can be improved or simplified by proper pretreatment of the data like feature selection (Adams, 1995). Feature selection determines and selects those features present in the analytical data, which may be far critical to calibration. Also, feature extraction changes the dimensionality of the data and particularly is the combination of the main variables to provide new and better ones. Pattern recognition methods are classified into supervised and non supervised methods even if a combination of both can be considered. The major unsupervised technique is principal component analysis (PCA) while artificial neural network (ANN) is the well known supervised approach. It can be stated that PCA is a linear feature extraction technique which reduces dimensionality of the data with a minimum loss of information. In PCA, an axis is projected throughout a multidimensional data set that captures most of the variance (Massart *et al.*, 1997). This is to some extent like a regression line through a swarm of points. Each sample is then projected perpendicularly down onto this axis. This captures much of the sense of the data on the single new one-dimensional axis, or principal component (PC), where the location of each sample along the new axis (its PC score) is known. Also, a second axis is constructed that accounts for maximum remaining variance; this axis is orthogonal (perpendicular in the multidimensional space) to the first PC axis. This limitation has the effect of assuring that the PCs are completely uncorrelated and thus represent entirely different properties of the samples. Additional PCs are then extracted, each orthogonal to all previously extracted, until there are as many PCs as original measurements. On the other hand, artificial neural network approach is known a mathematical model that share among themselves the characteristics that their main algorithmic features are to some extent inspired to some issues of the functioning of the human brain. While the idea of emulating the real neural activity was a major aim of the first network models, nowadays this part is mostly left aside and neural networks are employed more a mathematical than a biological model (Marini, 2009). There are so many of pattern recognition methods used for electronic noses data processing and increasing advances are in this sense. However, a full discussion about data analysis for e-nose systems is out of the aim of this review. For this purpose, the reader is referred to these reviews compiled by Jurs, Bakken, and McClelland (2000), Siebert (2001), and Scott, James, and Ali (2007). Also, a comprehensive detail about pattern recognition methods could be found in the books of *Statistics and Chemometrics for Analytical Chemistry* (Miller & Miller, 2000), *Chemometrics—Data Analysis for the Laboratory and Chemical Plant* (Brereton, 2006) and *Applied Chemometrics for Scientists* (Brereton, 2007), and *Chemometrics—Statistics and Computer Application in Analytical Chemistry* (Otto, 2007).

Applications of electronic noses to the brewery industry

Electronic noses have emerged as a potential alternative to conventional volatile analyzers and many studies have shown the benefits and impact of electronic nose employment in monitoring the quality of food products (Ampuero & Bosset, 2003; Berna, 2010; Schaller, Bosset, & Escher, 1998). During the last years, many attempts have been reported about using the electronic nose in brewing as follow below. Electronic noses could be used for on line monitoring in some of the beer production stages in brewery as shown in Fig. 3.

These stages consisted of a) incubating and extracting malted, ground up cereal grains (usually barley) with warm water. Sometimes the ground malt is mixed with other starchy materials and/or enzymes, b) the solution obtained is then boiled with hops or hop preparations, c) The boiled solution is clarified and cooled, d) The cooled liquid is fermented by added yeast. Usually the beer is clarified, packaged and served while effervescent with escaping carbon dioxide. Comprehensive explanation and the relevant considerations in brewery for beer production is out of the aim of this paper, so the reader is referred to the literature for more study (Bamforth, 2006; Briggs, Booulton, Brookes, & Stevens, 2004). Since the research on electronic nose to beer quality monitoring is in early stages, so there are many challenges to see the satisfactory applications of such systems in brewery. As follows, recent studies have shown a promising future through the development of new advanced tools to enhance the electronic nose performance in such a way potential application of electronic noses has been of profound interest to the brewers.

There are some challenges for application of electronic nose in brewery. The sample preparation of beer has some considerations. Beer degassing, known as decarbonation, is necessary prior to application of electronic noses to the beers under consideration. Many degassing methods have been documented in the literature, including placing a sample container in an ultrasonic bath, applying manual or mechanical shaking, pouring beer back and forth between vessels, helium sparging, and filtering, either by gravity or through the application of vacuum (Constant & Collier, 1993; Siebert & Lynn, 2007). Another challenge is eliminating the influence of water and ethanol on the sensor signals. The presence of water and ethanol in the beer headspace could cause strong interferences in the response of resistive sensors and mask the responses from other low concentration volatile components. Ethanol and water mask other volatile compounds since the concentration among these compounds are very different (several orders of magnitude in some cases). In case of ethanol the problem becomes worse because many sensors used in electronic nose are designed to detect ethanol. This could cause that an e-nose discriminate among several samples due to a difference in the ethanol content instead of different aroma. This effect could be minimized by means of using preconcentration methods, calibration techniques and using more specific sensors (Cozzolino, Cynkar, Dambergs, & Smith, 2010; Cynkar, Dambergs, Smith, & Cozzolino, 2010; Lozano, Arroyo, Santos, Cabellos, & Horrillo, 2008;

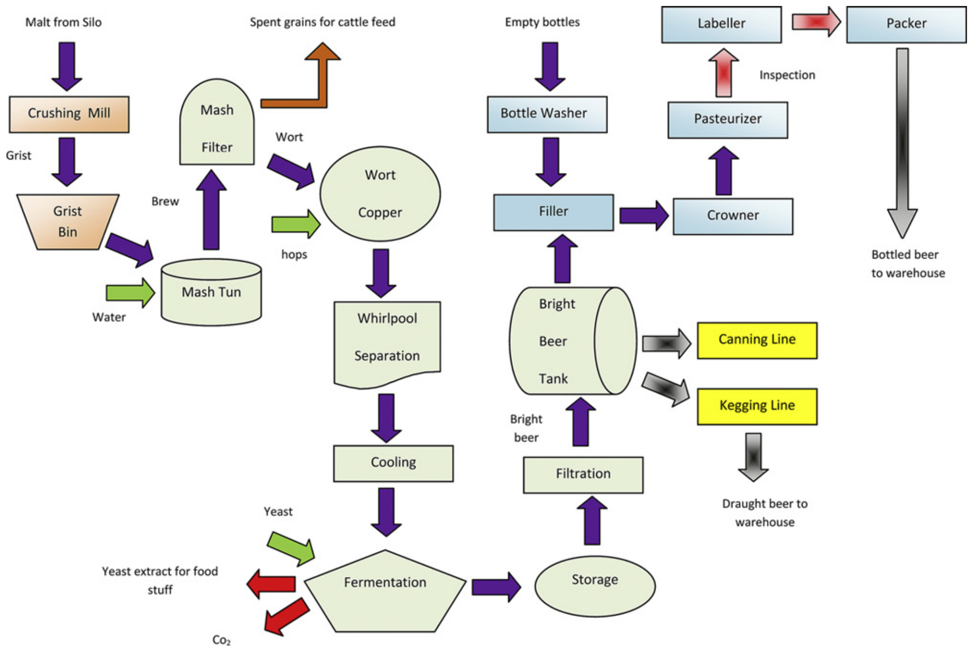

Fig. 3. Beer production process in industrial brewery (Anonymous, 2010).

Lozano, Santos, & Horrillo, 2008; Santos *et al*., 2010). As a consequence, it is not possible to discriminate beers by analyzing directly the headspace of the beers. The headspace of beers should be pretreated to remove or diminish the presence of these two main components in the volatile mixture (Villanueva *et al*., 2006). Instead of the latter method (removing the ethanol and water), the signals could be considered regarding a reference (water and ethanol). This method has been reported in literature for the product in which ethanol and water could be limiting factor to pattern recognition (Lozano *et al*., 2007).

Ragazzo-Sanchez, Chalier, Chevalier, and Ghommidh (2006) demonstrated the influence of ethanol concentration on the aroma detection by use of a standard electronic nose and by the DAENS (De-Alcoholization and Electronic Nose System). They took into account the relations between the variations of activity coefficients and volatility of some aroma compounds. Based on the report, headspace de-alcoholization strongly enhanced the aroma sensing capability of a metal oxide semiconductor based electronic nose but sensor signals were under influence of initial alcohol content, because ethanol diminished the volatility of aroma compounds. Gas chromatographic quantified this effect in the 0–12% (v/v) ethanol concentration range. They suggested that when no headspace pretreatment can be considered, experimental procedures should be revisited to keep away from wrong discriminations.

As mentioned earlier, a major problem for the gas sensors included is their sensitivity to humidity. Water vapor influences measurements by electronic noses and the researchers working on these instruments have focused on this issue. It is worth mentioning that electronic noses consisting of conductive polymers are more sensitive to differences in moisture in samples than other gas sensors. The use of non gas sensor systems such as mass spectrometric (MS) coupled with chemometrics can replace those now widely used. With reviewing the works conducted on alcoholic beverage, this fact is found that MS-based electronic noses have showed more satisfactory capabilities from point of view of speed, selectivity and sensitivity than gas sensor-based electronic noses because of masking ethanol effect. To solve this problem in the case of gas sensors, sample handling systems, such as dynamics headspace and Solid Phase Microextraction (SPME) other than the classical static headspace sampling approaches have attracted much attention to reduce the ethanol and water content and augment the concentration of the other volatile compounds accordingly. As a consequence, the speed and simplicity are compromised (Peris & Escuder-Gilabert, 2009). Speed of such systems is important in brewery to beer authentication. Removing ethanol and water present in beer headspace could save time in purging time of electronic nose that this leads to performance acceleration of such systems in brewery. Simplicity is crucial from utilization and cost view points.

SPME can be employed to inject the volatiles in the sensor array chamber. In these methods, certain adsorbent resins are used that show low affinity towards water or ethanol (this is very attractive for those brewing industries which produce mainly alcoholic beers), while are able to efficiently retain and concentrate other volatiles present in beer. The volatiles can be released afterward by applying a temperature program to the trap. This has demonstrated to be able to concentrate volatiles efficiently. However, the capability of eliminating water and ethanol is the most advantage of SPME. This specification is more interesting for the beverage (Dziadas & Jelen, 2010). Other merits of SPME consisted of the extraction is fast and simple and can be done without solvents, and detection limits can reach parts per trillion (ppt) levels for certain compounds. This means SPME coupled with electronic nose could be successfully used in brewery. SPME could increase or enhance the discrimination capability of the electronic nose. Also, since the detection limit of some volatiles responsible for off flavor in beer is low (ppt), so the employment of SPME coupled with the electronic nose for monitoring the beer quality to prevent off flavor in aging stage in brewery line is more feasible. This capability is far helpful in fermentation stage.

The first study on beer products was reported by Pearce *et al*. (1993). A sensor array up to 12 conducting polymers was included in the instrument to beer brand characterization. The system showed the capability of identification among three brands. After this work, the contribution of some compounds affecting on the beer flavor was studied. Tomlinson, Ormrod, and Sharpe (1995) studied the possibility for combination of AromaScan A20S into their production process. The researchers investigated various beers (four lager and five ale brands) as well as their raw materials (hop, leaf and malt). Signal changes caused by introducing diacetyl, phenolic and metallic off-taints to a lager beer were also assessed. The data obtained were treated with multidimensional analysis. Identification was found between the two beer brands. Lower signal intensity was for diacetyl and metallic off-taints while the more one was found for phenolic off-taint. For the raw materials, both clear differences and discrimination power within one group of material were concluded. This work showed that off flavor of beer could be detected by electronic nose. Off flavor detection could be an interesting criterion in fermentation stage of brewing. This study showed a promising outlook in the brewery industry.

Complex mixture of volatile constituents varying in chemical structures and concentration levels creates the beer flavor which is a key factor to beer quality evaluation. Sikorska *et al*. (2007) reported the application of a system for analysis of beer flavors. This system had a headspace sampler and a mass-spectral detector. The aim of this study was to get the fingerprints of the volatile compounds in beers to find the discrimination among different beer samples for recognition among brands and storage conditions. So, an electronic nose consisting of a TurboMatrix HS-40 Headspace Sampler and a TurboMass Mass Spectrometer and controlled by TMSOFT NT chemometric software was employed to analyze the volatile compounds present in beer headspace. They believed that the headspace sampling technique renders solvent free extraction of volatiles from a liquid mixture and saves time as well as omits error producing steps required in GC-sample preparation techniques like purge and trap or solvent extraction. Twenty repetitions for each beer sample were analyzed by use of an electronic nose equipped with the sample of 2 mL aliquots sealed in headspace vials. The carrier gas was Helium. Full mass spectra of the beer headspace constituents were considered to chemometric analysis. The mass spectra analysis resulted in not only beer brands discrimination but also detection of beer aging and photodegradation. The chemometrics used in this work were unsupervised PCA modeling and the discrimination task was performed by use of kNN, LDA, and D-PLS methods. The authors reported that the fresh beers could be recognized from the others with an acceptable accuracy. So, beers aged in different conditions were confidently distinguished from fresh ones. Misclassification for aged beers were sometimes observed in different conditions; the influence of time (3 weeks) or the presence of light in storage conditions on beer changes was more significant compared to the aging temperature variations (4 °C vs 22 °C).

Tao, Lei, and Teng (2008) employed Probabilistic Neural Networks (PNN) for alcoholic beer discrimination in terms of brands and storage conditions. They used MOS-based electronic nose. The method that they used for sampling was dynamic headspace sampling. An array of three gas sensors in the electronic nose system was employed. The results of the experiments were promising and this technique showed a good classification and generalization capacity. The electronic nose with the universal pattern recognition could separate one category of all the samples directly. Their system has some merits over others such as shorter training time, simpler training methods, and higher accuracy.

As reported in bibliography, the hops, the female inflorescences of the hop plant (*Humulus lupulus* L.), are used in the brewing industries to create bitter taste and aroma to the beer. Their flowers aroma and bouquet derive from their essential oils that represent among 0.5–3% of the dry weight of the cone. Around 300 different chemical components characterize these oils (Peacock & Deinze, 1981). However, because of volatilization in elaboration process in brewery, only small shares of them exist in the beer. The hop experiences a continuous process of deterioration after the crop caused by oxidative processes when exposed to ambient air. For the brewing industry, therefore, an early alarm of oxidative processes is a crucial factor influencing in final beer quality. The hops essential oils are presently analyzed by means of gas chromatography (GC) coupled to mass spectroscopy (Lermusieau, Bulens, & Colli, 2001) although these methods are expensive and time consuming. The use of electronic noses is an attractive option to overcome these objections. Lamagna, Reich, Rodriguez, and Scoccola (2004) used a prototype of an electronic nose, based on an array of six undoped and doped SnO_2 gas sensors made by the rheotaxial growth and thermal oxidation (RGTO) technique, for the analysis of hop in beers. They addressed two main requirements from the local brewing industry to evaluate the hop's quality in aging processes and to discriminate among various similar types of pellets. They studied aging process through three different alternatives to extract the feature from the sensors signals. Also, two chemometrics methods such as principle component analysis and Self Organizing Map (SOM) were included in their work. They verified the methods used and then concluded that it is possible to relate the aging of the hops with increasing distance from the fresh aroma locus in a two dimensional plane and there exist this capability to introduce a "cut-off" for inappropriate hops as a fast and cost effective method in brewery. Their study showed a perspective to implement a simple and cheap electronic nose for application in brewery industry for hop's quality assessment.

According to the literature, Kojima, Araki, Kaneda, and Takashio (2005) investigated the description of beer aroma with a fingerprint mass spectrometry (FMS) type electronic nose for quality control in brewing line. Ten Japanese commercial pilsner beer brands were selected and an experimental protocol was aimed in such a way that each sample was incubated in a vial, and the headspace was directly transferred to the FMS-type electronic nose. According to the findings reported, the aroma of the beers could be discriminated by the ratio of higher alcohols to esters, which has key role in beer aroma balance. The authors expected that this new electronic nose could characterize beer aromas and this apparatus could be employed for marketing strategies development in brewery sector. Furthermore, this system could recognize dimethyl sulfide (DMS) added to beers. A good correlation was observed between the intensity of a characteristic ion from a DMS-added beer and the DMS concentration. Similar work was previously reported by Yang, Yang, and Wang (2000).

In early stages of electronic nose development, the main problem of e-nose and this type of machine was to detect small differences among food products, for example due to different processing conditions, or factors such as another ingredient, storage. Nowadays, by development in sensor fabrication and sampling techniques combined with advanced computational methods, these problems are going to be solved. One of these deep concerns in brewery for beer quality control is off flavor detection. An unexpected off flavor in alcoholized beverages like beer is always a critical problem in brewery marketing and the governing commercial rules is that alcoholic beverages and particularly beers have to be free of defect. Detection of off flavor may involve detection of presence of one or several compounds normally absent in beer such as 1-octen-3ol which brings mushroom odor, or the presence of normal flavor components in excessive concentrations such as diacetyl (2,3 butanedione) producing a buttery flavor, which leads to be produced if valine levels are low in the wort in brewing line. Ragazzo-Sanchez, Chalier, Chevalier-Lucia, Calderon-Santoyo, and Ghommidh (2009) studied the application feasibility of an electronic nose, including eighteen metal oxide semiconductor gas sensors (MOS) disposed in three controlled temperature chambers, in combination with the dehydration and dealcoholization technique not also for detection of different off flavors in beers but also for assessment of the influence of some changes in the aroma profiles and ethanol content. Leave-one-out method was considered as a discrimination tool which finally showed high accuracy in sample classification. Both principal component analysis (PCA) and discriminant factorial analysis (DFA) showed clearly visualizing the differences among the different samples and independently their ethanol content, consequently a good classification was fulfilled. As given at the report of these authors, discrimination capability between a given beer and a tainted beer of the same brand were more than between two different brands. In fact, recognition of tainted beer from the reference beer was more precise. These results are in close agreement with the previous findings of these researchers (Ragazzo-Sanchez, Chalier, Chevalier, Calderon-Santoyo, & Ghommidh, 2008).

Pornpanomchai and Suthamsmai (2008) aimed a research for classification of beer smell. The brands consisted of Asahi, Chang, Cheer, Samiguel, Singha, Kloster, Heineken, Leo, Tiger and Tai present in Thailand market. They used a MOS-based electronic nose including 10 gas sensors with high sensitivity to several different smells that could classify many trademarks of beer. Pattern recognition was employed to classify the patterns obtained based on knowledge or statistical information extracted from the patterns. They used two types of decision making: neural network and rule base. Rule base was used for classification of unknown sample and neural network was used to check the types of beer studied. This network consisted of 25 input nodes, 28 hidden nodes, and 10 output nodes. Experimental protocol was aimed as: at first, they poured the warmed beer of 40 mL (sample) into the beaker and they considered poured water at the same level into another beaker as a reference. When the system was running, two beakers equipped with the heater were required to make all samples and references at 25 °C all the time. Based on the results, they concluded that an electronic nose combined with a neural network technique has a potential application for classification of beer brands in Thai markets.

Recently, non alcoholic beers had been of interest to brewers since it can offer several opportunities that can be exploited by marketers. This is true especially in a context where more strict regulations are likely to ban or restrict alcoholic products from classical usage situations. Some profits for the non alcoholic beers are: a) no limitation for sale by hours and by places of consumption; b) no warning on labels for sensitive consumer subgroups such as pregnant women; c) health benefits of beer can be promoted (Porretta & Donadini, 2008). In spite of these advantages, that should make a non alcoholic beer more attractive to consumers, marketers have to consider that non alcoholic beers have been criticized because they have a different flavor profile in comparison to regular beers. General flavor in non alcoholic beer is suggested to be quite poor and mild because of a very low intensity of most of the descriptors typically associated with beer, and to a meticulous lack of complexity and balance which can be partially associated with the absence of alcohol (Porretta & Donadini, 2008). Up to now, no independent research has been published on the quality evaluation of non alcoholic beer by electronic nose, which is probably due to the complexity of the matrix and the variety of the components present therein as well as low level of consumption of this kind of beer encourage the researcher to focus more on alcoholic beers. However, because of increasing trend in consumption of non alcoholic beer in recent years, the quality enhancement of such beer has been of great interest to the brewers. So, quality evaluation of non alcoholic beer has a high potential to be studied by electronic nose since the information obtained on flavor could give an insight into process control in non alcoholic beer production. So, a brewer can check the non alcoholic beer production line that whether flavor attributes of the non alcoholic beer processed are within the categories considered or not. Also, non alcoholic beer production manager decide about the items contributing to the beer flavor quality.

Conclusions and future trends

Electronic noses have been used in a variety of applications and could help to overcome problems in many fields including beer quality assurance in brewery. The demand for electronic nose in brewery is growing because the versatility and ease of operation of those instruments make them suitable for quick and accurate analysis of beers or for monitoring quality in the production process. This review paper dealt with the most important applications of electronic noses in beer quality evaluation. This technology is still being developed but the advantages are already obvious. Strengths of the electronic nose include high sensitivity and correlation with data from human sensory panels for several applications. It might have other advantages regarding mobility, price, and ease of use. Therefore, electronic nose has the potential to enter our daily life far away from well-equipped chemical laboratories and skilled specialists (Che Harun, Covington, & Gardner, 2009; Gardner, Tan, Covington, & Pearce, 2007; Gardner & Taylor, 2009). Sensor-based electronic noses today generally suffer from significant weaknesses that limit their widespread application. Their sensing ability is heavily affected by environmental factors: general drift due to temperature, humidity and background noise, sensor variations and sensor poisoning. These challenges, in addition to often wanting to detect very low concentrations (below ppm) of the odor in air (Ryan *et al*., 2004; Young, Buttner, Linnell, & Ramesham, 2003), make the design of an electronic nose difficult even with expensive auto samplers and the supply of clean air. Faced with this challenge, novel devices are being designed to tackle these issues and improve detection thresholds and classification success rates; examples include combining an electronic nose array with a gas chromatography column or mass spectrometer. These analytical instruments are large and expensive and place significant limitations on the way in which their application and potential market. Regardless of these concerns, the future for the electronic nose appears to be promising as it can fulfill niche analyses. This is because research and development activities are continuing in many laboratories around the world. Even the early instruments have performed well for some applications and it is believed that the newer prototypes will advance the field further. Some of these exciting developments include the artificial olfactory microsystem (e-mucosa). This is a new type of electronic nose that mimics nasal chromatograph effect and has richer information content and so will enable a higher level of discrimination than existing electronic nose systems (Che Harun *et al*., 2009; Gardner & Taylor, 2009). These systems should be considered for research to assess the capability of application in brewery.

Integration and combination of some analytical instruments and methods with electronic nose could be very interesting to full monitoring quality of beer (McKellar *et al*., 2002). Such integrated system could complement traditional chemical and sensory approaches to the beer quality control in processing line in brewery. For instance, SPME could be combined with electronic nose in brewery industry. This extraction technique is fast, precise, and simple and can be done without solvents, and detection limits can reach even by parts per trillion (ppt) levels for certain compounds. In Recent years, combination of electronic tongue with electronic nose has been reported in the literature (Apetrei *et al*., 2010). This could be applied in brewery as well because monitoring the odor and the taste of the beer could achieve more successful monitoring to the brewers.

At the end, it is suggested that on line sensors play a key role in the automation of beer in brewery. In near future when the basic issues of the gas sensors have been solved, we will see more online gas sensors implemented in the brewing industry. For each application, however, technical problems have to be solved for on line implementation (Ghasemi-Varnamkhasti, Mohtasebi, & Siadat, 2010). One interesting vision for the future would be to have a fully automated platform of different kind of sensors to monitor the essential information required for the characterizing of quality of the raw material, process or product. Taste and gas sensors would make up a vital part of such a multisensor system. This may be realized in brewery in the close future.

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