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Viewpoint

Electronic nose and electronic mucosa as innovative instruments for real-time monitoring of food dryers

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A crucial aspect of drysing process is monitoring of product moisture content, nutritional value, and sensorial characteristics. This viewpoint paper considers the challenges and the opportunities in application of electronic nose and electronic mucosa as innovative instruments in drying technology in order to improve the final food quality. Electronic nose is reliable and easy to use tool in actual drying conditions. Nonetheless, the electronic mucosa, imitates nasal chromatograph effect, can provide more useful information leading to higher level of recognition than the existing electronic nose systems. Perspectives and potential employment of such tools are discussed as well.

Background

Drying is a process widely used by the food industries to hinder the growth of microorganisms, to guarantee the microbial stability, to make easy the handling of product, and to assure the expected shelf-life of product (Aghbashlo, Kianmehr, & Arabhosseini, 2008; Aghbashlo, Mobli, Rafiee, & Madadlou, 2013). Unfortunately, this process might occasionally lead to low quality dried foods with unpleasant sensorial properties worth mentioning due to unwanted physiochemical changes caused by inappropriate drying conditions. Furthermore, the importance of food organoleptic characteristics as first quality indicator for consumers encourage the food technologists to highlight the better preserving and improving the foodstuffs original composition, nutritional value, and functional properties during drying process. The aroma volatilization and off-odors production are the major reasons for the food deterioration during drying process, and, these reactions might alter the sensorial quality, nutritional value, and functional properties, influencing negatively on the consumer preference. Thus, the original aroma of dried product should be sufficiently kept to maintain its functionality and marketability.

Although the sensorial properties of dried products such as aroma is the key element for real-time process monitoring and consequently dryers controlling and monitoring, real-time, fast, reliable, accurate, and cost-effective aroma profiling techniques are lacking. Conventionally, aroma measurement of foodstuffs underlying different unit operations was tremendously challenging and was generally confined to off-line, time-consuming, and less efficient laboratory testing approaches. These techniques were usually based on randomly collected samples, which limited their use for real-time monitoring and accurate in-process closed-loop control. On the other hand, drying process is relatively complex, dynamic, non-linear, uncertain, and unforeseeable operation because of concurrent heat and mass transfer, fast moisture evaporation, case-hardening, and intensive chemical and biochemical reactions (Aghbashlo, Mobli, Rafiee, & Madadlou, 2012). This complexity becomes even more in the case of food drying pronounced due to product heterogeneity, anisotropicity, and non-uniformity (Nazghelichi, Aghbashlo, Kianmehr, & Omid, 2011). Hence, empirical models based on off-line measurement techniques cannot be precisely used for real-time controlling of drying process. As well, more food industries move to continuous processes, in-process monitoring that provides real-time organoleptic characteristics and feedback control that becomes even more necessary to produce

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high-nutritive and cost-effective dried foods. Moreover, tight food process control is gained by reliable and precise controlling and monitoring of the process factors influencing on the food sensorial properties. However, in drying process, these factors are prone to natural inevitable changes, causing variability and difficult to foresee the sensorial attributes of final product. It is also worth mentioning the quality of foodstuffs should be examined during whole process and not only at the end-point. Thus, food unit operations should be exactly monitored and controlled in whole processing duration by use of innovative instruments to guarantee the quality of end products. These are why developing an automatic real-time aroma tracking unit in food dryers is strictly substantial to gain rigorous product sensorial attributes and reach a better understanding of the process for careful optimization of the standard operating approaches.

On the other hand, according to Quality by Design (QbD) philosophy (Drennen, 2007), quality cannot be assessed on a product but must be made and maintained into products from the beginning of a process. According to Food QbD framework, sources of variability in the drying process should be identified and hindered for improving the quality and uniformity of dried products. This can be feasible by application of real-time monitoring devices and techniques with feedback control through in-process measurements (Fig. 1A). In the most of foodstuff drying processes, variability origins affecting on final product quality and homogeneity can be specified, monitored, and even controlled, according to Fig. 1B. Firstly, it is required to find out the relation between drying process parameters and product quality characteristics and then the origins of process variability must be monitored in timely procedure by process analyzers for precise and efficient process control (Fig. 1A). Therefore, newly designed "smart" food dryers based on QbD framework might be more reliable and cost-effective than the common ones.

Evidently, real-time measurement plays a key role in QbD scheme and according to Food and Drug Administration (FDA, 2004), real-time process measurements can be classified into three categories such as at-line, on-line, and in-line analyzers, as illustrated in Fig. 2. In brief, at-line analyzers characterize the favorable properties by withdrawing the product from process, isolating from ambient and analyzing it in close affinity to the process stream. On-line analyzers specify the desired attributes by diverting the sample from the process and returning to the process stream in most cases. In-line analyzers (invasive or non-invasive) are rapid measuring tools or probes to consider the desired characteristics without sample withdrawing by direct placing of them into a process stream. Generally, implementation of real-time measurement units to drying equipments should eventually result in control of the process with the least dried product testing and in-depth process understanding assure the end product quality.

As mentioned earlier, a more useful way to monitor and control the drying process consists of the real-time foodstuffs quality evaluation to get an actual insight about the variables concerning both process and product. Hence, drying services should be implemented with in-process automatic drying parameter manipulations to reduce the undesirable changes in the product properties and process progress. In recent years, electronic nose have been increasingly considered as an option for real-time measurements of sensorial attributes of processed foods, as this instrument provides reliable, non-invasive, and non-destructive measurements without sample withdrawing. It can be also employed in a non-intrusive mode to build up qualitative and quantitative strategies for the in-process monitoring and controlling of a food drying process. However, the advanced version of electronic nose namely electronic mucosa presents numerous advantages over electronic nose due to its additional functionality originating from its biological character. Stability, precision, reliability, rapid response, and robustness of controller are the main specifications of any industrial dryer control system (Jumah & Mujumdar, & Raghavan, 2006), which can be obtained by both instruments. Instrumentation of food dryers with advanced control tools reduces batch failure, improves reliability of process, minimizes labor cost, optimizes energy efficiency, increases predictability of quality, and augments the finished product quality and uniformity.

Electronic nose and electronic mucosa and their potential applications in drying technology

In most cases, food aroma contains complex mixtures of many volatile organic compounds (VOC) with various sensorial and chemical attributes. Any change in the relative concentration amounts of these compounds can often specify the odor of the product. Nonetheless, not all the volatile compounds play an identical role in sample aroma (Peris & Escuder-Gilabert, 2009; Shafiee, Minaei, Moghaddam, Ghasemi-Varnamkhasti, & Barzagar, 2013). The influence of each compound is a function of its concentration and its sensorial threshold (the minimum concentration perceivable by the human nose). The ratio between these two items is known as the odor activity value (OAV). When the OAV of a compound is more than 1, it will affect on food aroma (Mistry, Reineccius, & Olson, 1997).

The change of food aroma during drying process is of great concern to the food technologists who have been spent much funds in the monitoring and automating of their plants for the foodstuffs drying. Nevertheless, variables which are generally considered at drying facilities (moisture and temperature of the inlet and outlet air, temperature and moisture content of products), do not present vision needed to specify the loss of sensorial attributes such as aroma during processing. Undesired aroma loss, change, distortion, or even destruction often occur and result in inappropriate quality of final products. How to attain the