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Superheated Steam Drying of Foods-A Review

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Abstract: Superheated steam drying has been known for over 100 years, but its acceptance in industry has been slow. Recently, food industry started accepting this new technology of processing using superheated steam because of its prime function in enhancing color, less shrinkage, better rehydration and decontamination of microbes. In superheated steam drying, drying is not only the primary concern; it includes lower net energy consumption, safe operation, no fire explosion and no oxidation of the product.

Key words: Superheated steam · Shrinkage · Rehydration · Decontamination

INTRODUCTION

Superheated steam drying is a drying technology whereas the drying takes place through direct contact between superheated steam and the product to be dried. Drying with superheated steam is an emergent technology with big potential advantages with respect to energy saving, emission reduction, fire and explosion prevention and product quality [1]. The quality of superheated steam-dried products tends to be better than that from conventional hot air dryer. Superheated steam also allows pasteurization, sterilization and deodorization of food products. This is particularly important for food and pharmaceutical products that require a high standard of hygienic processing. In addition, superheated steam drying can also give higher drying rates in both constant and falling rate periods under certain conditions. Closed system superheated steam drying enables emitted odors, dust, or other hazardous components to be contained and thus mitigate the risks of these hazards. The pollutants are concentrated in the condensate of the effluent steam. On the other hand, desirable organic compounds can also be captured using the superheated steam drying method [2].

Need for Superheated Steam Drying: Hausbrand (1924) introduced the idea of SSD at the beginning of the 20th century, however, it was not until the 1950's that researchers examined the process more closely [3]. Only after the 'oil crisis' in 1970's many papers were published on fundamental studies and applications of Superheated steam drying. Conventional hot air drying is a very energy-intensive operation which accounts for about 15% of the industrial energy consumption in most of industrial countries. The feature of energy saving in superheated steam drying makes the technique a desirable alternative and strict laws regarding environmental pollution offer another incentive to superheated steam drying [5]. Although a broad industrial acceptance has not been reached so far because of a lack of suitable equipment, it seems safe to predict a growing importance of this technique in the future due to its merits [6].

Principle of Drying Using Superheated Steam: Superheated steam is steam that has a temperature above the saturation or boiling point. As water is heated at any specific pressure and reaches its boiling point, it is referred to as saturated steam. Once heated beyond the boiling point, the steam becomes unsaturated or superheated. At this point, the steam can transfer heat to the product that is being dried raising the product's temperature to the boiling temperature and transferring heat to the product. In contrast to saturated steam, a drop in temperature does not cause condensation of the steam as long as the temperature is higher than the saturation temperature. Any moisture that is evaporated does not need to be exhausted, but instead becomes part of the drying medium [7].

Drying Kinetics: Drying of foodstuffs involves several transport mechanisms so that drying behavior can be influenced by a large number of variables.

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The mechanisms involved in the drying process are heat transfer from the external drying medium to the solid surface combined with heat transfer within the material; and mass transfer from the interior of the solid to its surface, followed by external mass transport to the surroundings. One or more mechanisms can control the drying rate, depending on the solid characteristics and the drying agent conditions. No constant drying rate period is observed when drying hygroscopic materials (solids where the water exerts a vapor pressure lower than the saturation pressure) or when the process is internally controlled. In drying with superheated steam, the rate of vapor transport from the solid interface is not limited by mass transfer resistance and thus the rate of evaporation from the surface is heat transfer controlled [8].

Comparison of Superheated Steam Drying with Hot Air Drying: Superheated steam is cleaner, provides higher evaporation rate and less oxidation in food than hot air. The loss of nutrient in superheated steam drying is less. Superheated steam has proven to be attractive drying medium for materials that are not temperature sensitive [9]. Granular products dried faster in superheated steam than in hot air under the same temperature and flow rate conditions. When drying with superheated steam, the water removed from the product during the process become a part of the drying medium, whereas in air drying, the moist air must be replaced by fresh air heated to the desired temperature [10]. The rate of evaporation of water in superheated steam is significantly higher than in dry air except when the superheated steam is relatively close to the saturation temperature. When the steam is near its saturation temperature, the evaporation rate is close to zero [11]. The curves of evaporation of air and superheated steam will intersect at a point called the inversion temperature. Above that point, water evaporation increases as the humidity of the air increases and the evaporation rate is the highest of pure superheated steam.

The general characteristics of the drying process are not altered when superheated steam is used as the drying medium instead of dry air. The major differences include: (1) the condensation on the product surface during the heating period and (2) elevated surface temperature during the constant rate period. The drying rate in superheated steam medium can be faster if (1) the amount of condensation at the product surface is low and (2) the superheated steam temperature is above the inversion temperature. Resistance to moisture movement within the product appear to be reduced for superheated stem drying, thus increasing drying rates during the falling rate periods [12].

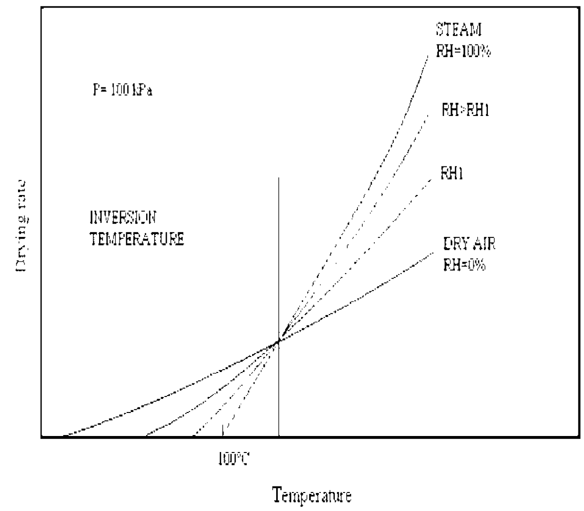

Fig. 1: Drying time Versus Temperature

Quality Attributes of Food Dried Using Superheated Steam: When food products are processed in superheated steam they may become more porous due to increased heat transfer rates causing the moisture in a product to flash into steam, creating many pores. This may have an application in the snack food industry where frying in oil produces the same result [13].

Color: Potato chips dried at higher steam temperatures and high convective heat transfer coefficients suffered had higher porosity, darker color and lower vitamin-C content. However, Hot air drying produced lower porosity, darker color and lower vitamin-C content potato chips [14]. The redness of chicken dried by purely superheated steam drying is increased with the drying temperature. This trend of color changes is attributed to the long exposure time of chicken to high temperature environment when drying with superheated steam, resulting in more browning of sugar-amine, which was the result of the reaction between amine groups of muscle proteins and available reducing sugars in the connective tissue of chicken [15].

Shrinkage: In the case of purely superheated steam, shrinkage of food products seemed to be lower when steam temperature increased due to less drying time. This trend has been observed for steam drying of potato chips. The reason for this is that a higher steam temperature produced samples with larger and more numerous pores, which may result in less shrinkage. However, the opposite trend was found for steam drying of cooked rice, chicken meat and shrimp. By comparing the purely superheated steam and superheated steam + Hot air drying processes, it was found that products dried by Superheated Drying had the least degree of shrinkage due to the shorter period [16].

Microstructure: The microstructure of potato chips dried using superheated steam drying and hot air drying were analyzed. Potato chips had more superior microstructure in superheated steam drying than hot air drying. There is no possibility of case hardening in superheated steam [17].

Rehydration: A study was conducted on drying of carrot cubes using low pressure super heated steam and vacuum drying. It was found rehydrated superheated steam dried carrot cubes are more voluminous than vacuum dried carrot cubes [18]. Nevertheless, the percentage of rehydration of chicken dried by purely SSD was less than those dried by both two-stage combined drying techniques. This is because chicken dried by superheated steam drying was exposed to high-temperature environment for a long duration, making proteins of myofibrilar and collagenous connective tissue denature and lose their water holding ability.

Decontamination: The use of superheated steam as a processing medium can reduce or eliminate microbial load on foods, can solubilize and extract contaminants such as spores, mycotoxins and odors in addition to thermal degradation. The effects of superheated steam as a processing medium on grains contaminated with the Fusarium mycotoxin deoxynivalenol (DON) and with *Geobacillus stearothermophilus* spores with the processing temperature between 110 and 185°C for three steam velocities of 0.65,1.3 and 1.5 m/s showed reductions in DON concentration of up to 52% at 185°C for about 6 min processing time. This was only due to thermal degradation and not to solubilization and extraction [19].

CONCLUSION

Up to now, a broad industrial acceptance of superheated steam drying has not been reached due to the lack of suitable equipment. Moreover, the high steam temperature exceeding the saturation temperature of steam could cause a problem for temperature sensitive food materials which might undergo processes such as browning reaction, discoloration, starch gelatinization, enzyme destruction and protein denaturation. However, in some cases, changes in textural properties due to dehydration by superheated steam could be beneficial. Perhaps it is necessary to include supplementary drying methods, e.g., microwave, radiation, or vacuum to speed up drying rates and to avoid overheating. Much R&D is needed to increase the usage of superheated steam dryer in food industries.

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