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DEGRADATION OF BIOPRODUCTS IN A COCURRENT SPRAY DRYING PROCESS

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Summary. A method for determination of drying and degradation kinetics of different products in a disperse system has been developed in the Faculty of Process and Environmental Engineering, Lodz Technical University. To determine drying and degradation kinetics a 9 m long spray drying tower designed to make *in situ* measurements of all spray drying process parameters was built. Application of PDA (Phase Doppler Anemometry) technique allowed us to find a relation between time and length scale in the tunnel and, as a consequence, to present examples of spray drying and degradation kinetics versus time.

Temperature measurements showed strong temperature gradient in disperse and continuous phases in the vicinity of the atomizer. Slow flattening of the temperature profiles observed along the dryer length results from evaporation and heat losses to the environment.

Experiments show also a rapid decrease of baker's yeast activity in the vicinity of the atomizer. For fine atomization ratio (air/feed 39/5) the degradation of baker's yeast reached 95% after 0.5 sec, while the total residence time was 10 seconds.

Analysis of the results proved that temperatures of the drying agent and atomization ratio are the most decisive factors controlling the drying and degradation kinetics rate.

Keywords: Laser analysis of spray structure, *in situ* measurements, drying kinetics.

INTRODUCTION

A special group of materials dehydrated in spray dryers are the products of high thermal sensitivity, like foodstuffs, pharmaceuticals and biosynthesis products. The bio- and food products as multicomponent systems reveal limited resistance to temperature, time of exposure and the level of dehydration. In this type of products,

under exposure to heat, some physicochemical reactions are activated often leading to various unacceptable changes which may affect the product quality. Degradation of physical properties causes contraction and cracking of material, loss of activity and rehydration abilities, changes of wettability, solubility and dispersivity, and changes of organoleptic properties (flavor, taste, etc.).

Due to broad variety of materials being dried in spray dryers, it seems difficult to develop general principles concerning the kinetics of water removal from these materials [9]. It is necessary to determine individual drying kinetics for each material separately.

The key problem in spray drying which has not been solved yet is the determination of drying kinetics and degradation kinetics for heat sensitive products. The lack of appropriate experimental investigations is due to technical problems in carrying them out. The residence time of particles in the spray dryer does not usually exceed 30 seconds, and is often even shorter. Thus the whole process of dehydration, formation of solid structure, degradation, etc. takes a very short time. Therefore, few attempts have been made so far to determine the kinetics of product drying and degradation, which have been restricted to the analysis of relevant parameters only at the dryer inlet and outlet, e.g. [3], [7].

To determine drying and degradation kinetics in a disperse system a special experimental equipment must be built and new measuring techniques must be developed.

EXPERIMENTAL EQUIPMENT

A method for determination drying and degradation kinetics of different products in a disperse system has been developed in the Faculty of Process and Environmental Engineering, Lodz Technical University. In order to analyze the mechanism of spray drying process a concurrent spray drying tunnel tower (9 m long, 0.5 m in diameter) was designed, built and tested (Fig. 1).

The tunnel is equipped with a 60 kW heating system, exhaust air cooling system, dedusting system and optical glass windows to perform measurements using laser technique (LDA-Laser Doppler Anemometry, PDA-Phase Doppler Anemometry).

Feed is delivered from a stainless steel tank for raw material 0.15 m^3 volume to the nozzle by a monopump. The tank is equipped with cooling/heating steam/water jacket. Two steam generators were used to deliver heating agent to the jacket to maintain required temperature of the drying material.

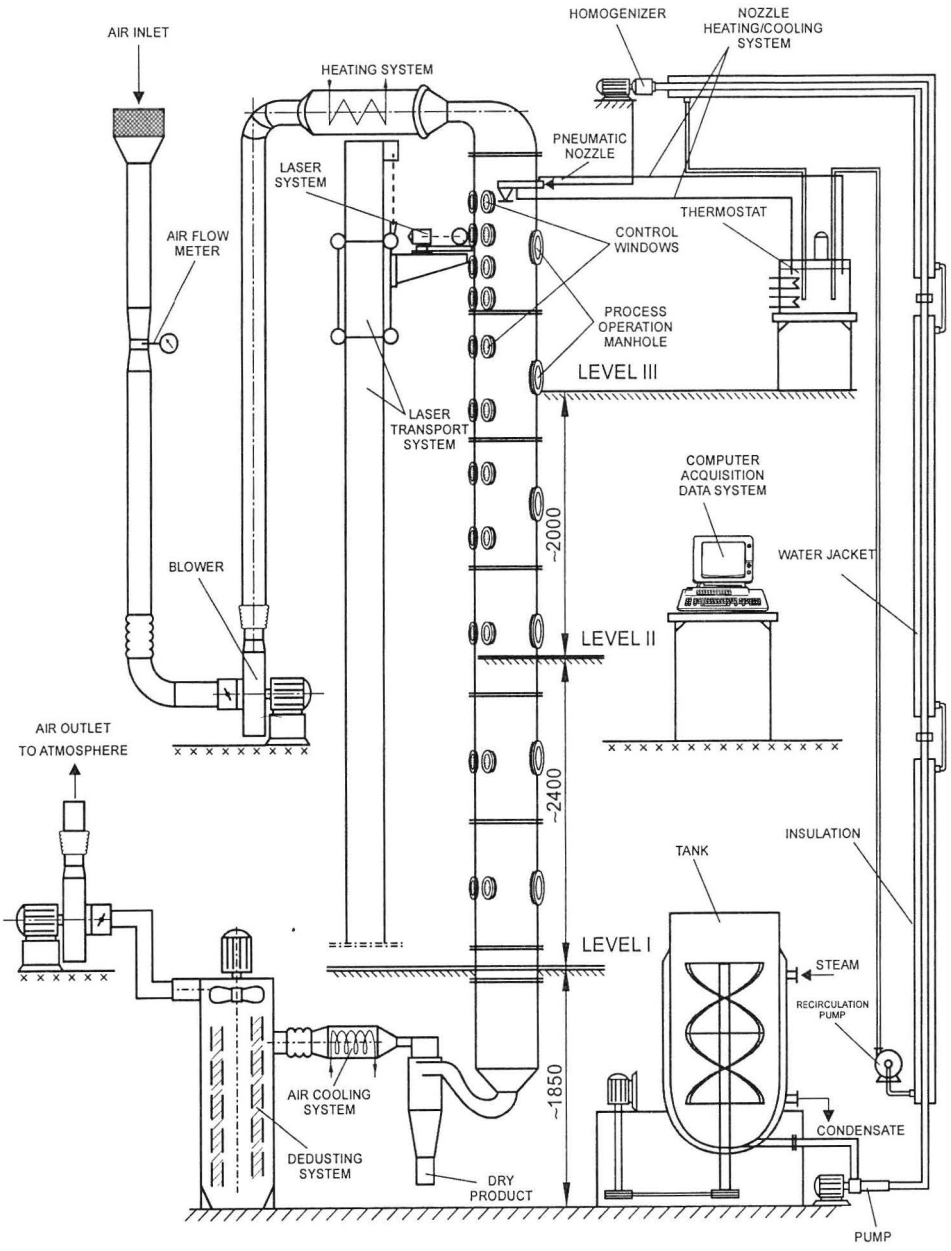

Fig. 1. Experimental set-up.

Each pipe and the nozzle are equipped with a water heated jacket. The heating water was warmed up in a thermostat and delivered to an insulated piping system.

The construction enables taking samples at subsequent time intervals and to make laboratory determination of moisture content, size distribution, etc. at a different distance from the atomizer.

To determine the flowfield in the spray tower and structure of the spray in the cross sectional area and along the length of the tunnel the laser technique was employed (Flowlite System by Dantec, Denmark). The transport system of laser unit enables LDA and PDA measurements at an arbitrary height of the tunnel and in selected points in a given cross section. Elements of the laser unit, i.e. a transmitter and receiver are placed on the optical bench. Dry material is conveyed to the dedusting and cooling system where fine particles are collected and the clean and cool air is discharged to the atmosphere.

To determine spray drying and degradation kinetics three groups of experiments were made:

- measurements of drying agent and sprayed material temperature inside the spray envelope using a microseparator,
- measurements of moisture content by sampling and laboratory analysis of water content and quality index,
- PDA analysis of local and average particle size distributions for different distances from the atomizer and distribution of axial velocity of different droplets fraction.

TEMPERATURE MEASUREMENTS

Temperature and humidity of a drying agent inside the spray envelope are among the most difficult parameters to determine during spray drying. However, information about distribution of gas and spray temperature as well as humidity and moisture content profiles is necessary to evaluate the level of product degradation. The microseparator was used to determine local gas and spray temperature distribution in the cross-sectional area of the tunnel and along the drying tunnel length. The microseparator, a device for temperature measurements, developed by Kieviet and Kerkhof [8] was applied and modified for purposes of the work [6]. The basic idea of the design is to remove particles from the gas stream and then to measure temperature of the cleaned gas stream.

Temperature measurements of spray and drying agent were performed in 4 points (0, 0.06, 0.12, 0.18 m from the axis) along the diameter of the tunnel and in 10 positions along the length of the spray tower. Figure 2 shows examples of local air and spray temperature distributions in the cross-sectional area of the

spray tower for drying of baker's yeast. A strong temperature gradient was found in the vicinity of the atomizer. Further setting of the temperature profile covers the distance of 5.5 m. Large gas temperature drop in the tunnel axis and then its rapid increase to the edge of spray envelope at the distance of 0.2 m from the nozzle is observed. At the distance of 0.8 m the temperature profile is flat and remains unchanged until the end of the drying process.

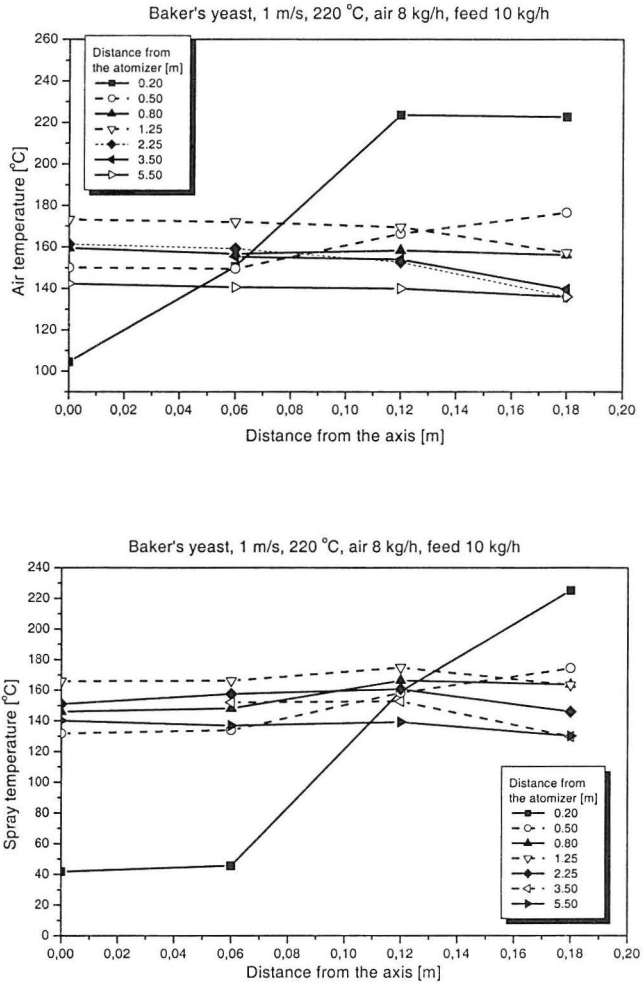

Fig. 2. Air and spray temperature distributions in the cross-sectional area of the spray tower (inlet temp. 220°C, atomizing air 8 kg/h, drying air velocity 1.0 m/s).

Evaporation and heat losses to the environment contribute to a step-wise gas temperature drop along the tunnel length.

Figure 2 shows also spray temperature distribution in the cross-sectional area of the spray tower. The changes of spray temperature have a character similar to the drying agent temperature changes inside the spray envelope. A significant increase of temperature from the axis to the edge of the tunnel is observed at a short distance from the atomizer and then a slow flattening of the temperature profiles occurs. Papadakis and King [10] presented similar observations.

It should be explained, however, that when the sprayed material is partly dried, the temperature recorded by an unshielded thermocouple in the microseparator is in the range of temperature between the spray and gas, so data obtained in this period of drying are burdened with certain, difficult to estimate error.

DRYING AND DEGRADATION KINETICS

In the first step of our work we determined degradation kinetics of baker's yeast as a function of the distance from the atomizer.

Relative CO_2 production (the ratio of current to initial CO_2 production) was chosen as a quality index reflecting yeast activity. Samples of the product were taken and analyzed in the laboratory. We applied Jalecki technique to determine the activity of yeast [11].

Experiments showed a rapid decrease of baker's yeast activity in the vicinity of the atomizer. After this stage of work results of degradation kinetics described the process in geometry of our spray drying tower and could not be used in any other spray drying system. To obtain a more general relationship the length scale must be changed to time scale. Results of PDA measurements were applied to change the length to time scale. A detailed description of this procedure is presented in [2].

In Fig. 3a the effect of atomization ratio on drying kinetics is illustrated. It is observed that for coarse atomization ratio of air/feed 8/10 the drying process is not completed. For finer atomization ratios 39/5 and 39/10, the time necessary to complete the drying process is shorter than 1 sec.

In Fig. 3b the effect of drying air velocity is shown. A shorter drying time was needed to complete the drying process for air velocity of 1.5 m/s than for 0.6 m/s .

Next Fig. 4 presents the effect of atomization ratio and drying air velocity on baker's yeast activity. The atomization ratio and temperature are the most decisive factors for the degradation process rate (as for drying process). For fine atomization

ratio (air/feed 39/5) the degradation of baker's yeast reached 95% after 0.5 sec, while the total residence time was 10 seconds, Fig. 4a, and 3 sec – Fig. 4b.

During the first second of the process a rapid drop of baker's yeast activity was observed.

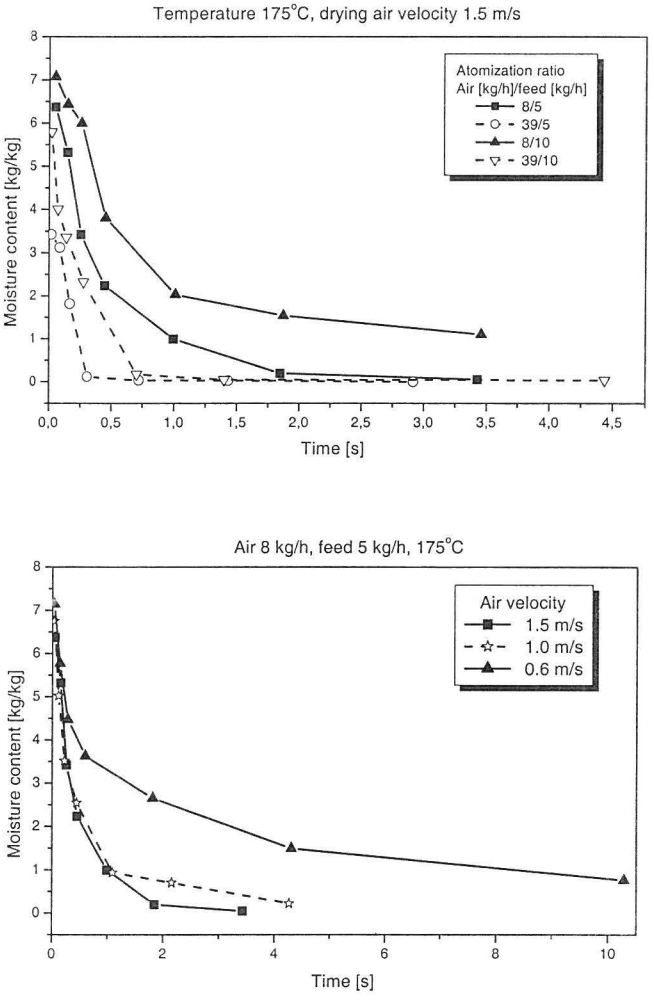

Fig. 3. Drying kinetics of baker's yeast.

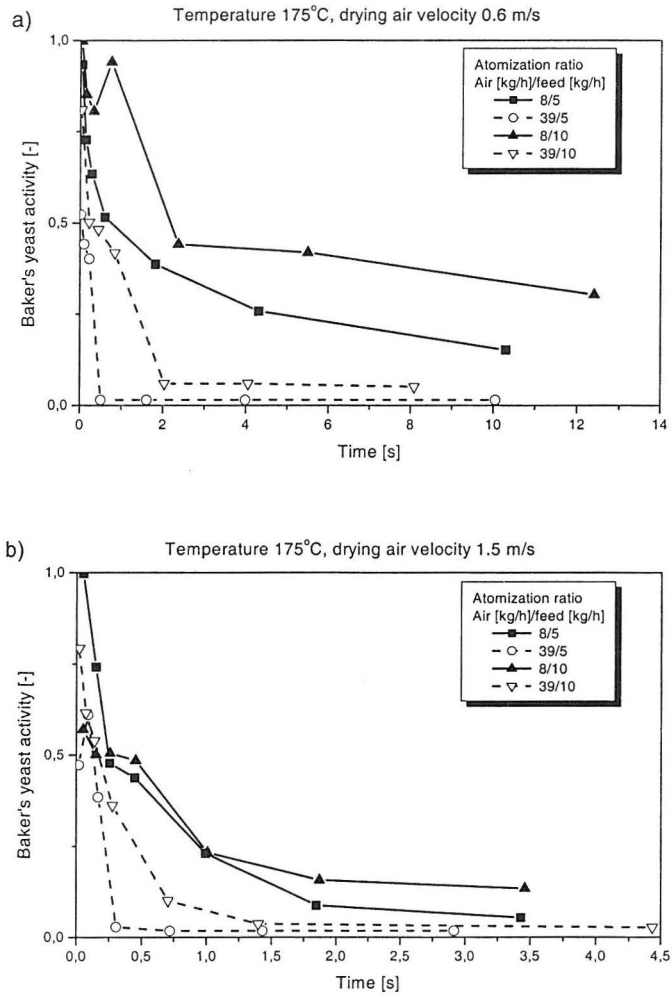

Fig. 4. Degradation kinetics of baker's yeast.

DRYING RATE CURVES

Figure 5 presents the examples of obtained drying rate curves. The Figure shows experimental and calculated results. Experimental and theoretical analysis of the results allowed us to find critical moisture content of the analyzed product.

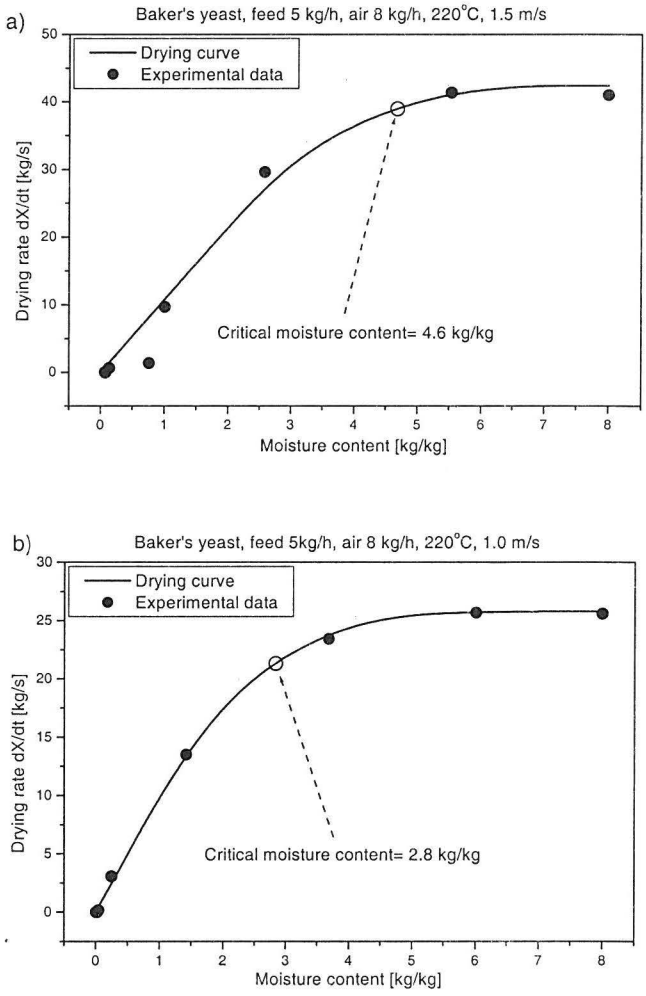

Fig. 5. Drying rate curves for different processes.

It was found in general that the higher drying rate the higher critical moisture content for the same product and at the same atomization ratio. Also higher air velocity leads to higher drying rate (Fig. 5).

Our results confirm the suggestions of Groenewold et al. [4] and Hirschman et al. [5] about the dependence between drying rate and critical moisture content and the influence of drying process parameters on drying rate.

CONCLUSIONS

1. A unique concurrent spray drying tower for continuous observation of drying process was designed, built and tested. Extensive spray drying tests were performed to determine the influence of operating process parameters on the drying and degradation kinetics of heat sensitive products.
2. A profound effect of the atomization ratio and drying agent temperature on the drying and degradation kinetics of spray drying process was found and evaluated.
3. Drying process was faster for finer sprays and the required final moisture content was obtained in the vicinity of the atomizer. Generally, the higher drying rate the higher critical moisture content for the same product and at the same atomization ratio.

ACKNOWLEDGEMENT

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DEGRADACJA BIOPRODUKTÓW PODCZAS SUSZENIA ROZPRYSKOWEGO W UKŁADZIE WSPÓŁPRĄDOWYM

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Streszczenie. W pracy opisano metodę określania kinetyki suszenia i degradacji [11] w układzie dyspersyjnym opracowaną na Wydziale Inżynierii Procesowej i Ochrony Środowiska Politechniki Łódzkiej. Zbudowano suszarkę rozpryskową o długości 9 m umożliwiającą pomiary *in situ* podstawowych parametrów procesu suszenia. Zastosowanie laserowych technik analizy zachowania się rozpylonej strugi materiału umożliwiło przedstawienie kinetyki suszenia i degradacji produktów w funkcji czasu trwania procesu.

Pomiary temperatury gazu i strugi rozpylonego materiału wykazały występowanie silnego gradientu temperatury w obydwu fazach w bezpośredniej bliskości atomizera. W miarę oddalania się od atomizera zaobserwowano stopniowe spłaszczenie profili temperatur spowodowane odparowaniem i stratami ciepła do otoczenia.

W trakcie eksperymentów stwierdzono gwałtowny spadek aktywności drożdży piekarskich już w niewielkiej odległości od atomizera. Dla strugi składającej się z drobnych cząstek (stosunek atomizacji (39/5)) produkt ulegał całkowitej degradacji po czasie 0,5 s, podczas gdy czas przebywania w układzie wynosił 10 sekund.

Analiza uzyskanych wyników wykazała, że temperatura czynnika suszącego oraz stosunek atomizacji są kluczowymi czynnikami kontrolującymi kinetykę suszenia i degradacji w układzie dyspersyjnym.

Słowa kluczowe: laserowa analiza struktury strugi, pomiary *in situ*, kinetyka suszenia.