DRYING OF HEAT SENSITIVE MATERIALS OF HIGH MOISTURE CONTENT IN MECHANICALLY SPOUTED BED OF INERT PARTICLES

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Abstract. In drying operation the material characteristics such as heat sensitivity, moisture content and particle size are of great importance, which should be taken into account in selection of proper design and conditions for the process. Rigorous quality requirements, i.e. gentle drying of heat sensitive materials, stable, well-controlled and economic operation can be fulfilled by using Mechanically Spouted Bed (MSB) dryer with inert particles developed to eliminate some drawbacks of the conventional spouted bed dryers. In this paper the construction and the main features of MSB-dryer are presented. Different tasks with special quality demands, namely drying of bovine serum albumin and moisture removal from tomato pulp of thermoplastic behaviour, and a method to accomplish these requirements are shown.

1. INTRODUCTION

Drying in most cases is the final process of production technologies affecting considerably the quality of products. In addition, this is an operation of high energy consumption, too. For right selection of drying method and process parameters many factors must be taken into consideration, such as chemical and physical characteristics of the wet material to be dried, quality requirements of the dried product, furthermore economical aspects. For this, conditions of the preceding operations, and maybe the subsequent ones, should also be taken into account. In drying of heat sensitive materials with biological origin it is especially important to perform the process very carefully, i.e. at low temperature and within short residence time. However, the high moisture content of these materials makes the process difficult. Therefore, intensive heat and mass transfer should be realized at low temperature and within short processing time.

In the past decades several drying methods were developed for materials with high moisture content i.e. for suspensions, pulps and sludges. Drying processes carried out in fluidized or spouted beds have become very popular (Schneider and Bridgewater [1], Re and Freire [2]). Inert bed dryers (e.g. spouted bed with inert particles) provide good conditions for this purpose since the drying process is performed on large and continuously renewing surface, namely in thin layer formed on the surface of inert particles, under intensive contact between the wet material and the drying air.

Spouted bed is a special form of agitated beds, where the circulation of particles is made by air jet introduced with high velocity through a nozzle at the conical bottom of the dryer. Besides the advantages of the conventional spouted beds, this method has some disadvantages, too (Mujumdar [3]).

To eliminate these latter, a Mechanically Spouted Bed dryer with tangential air inlet has been developed. In this device, intensive and well-controlled heat and mass transfer can be carried out where the circulation of particulate solids is made by vertical houseless conveyor screw installed in the vertical axis of the bed. Hot air introduced tangentially through several slots at the bottom provides intensive gas-solid contact. Around the vertical screw (in the "annulus") a dense particle layer is sliding down, while within the central screw zone the particles are conveyed up to the upper zones of the bed. Therefore, similarly to the conventional SB dryers, characteristic circulation of particles takes place in this device. Due to the action of screw, circulation of particles becomes independent of the air flow rate, therefore this latter can be set to optimal value from respect of drying. Comparing to the conventional SB-dryers, the pressure drop and energy demand of MSB dryer are considerably lower, namely 25-30 % and 15-20 % reduction is possible, respectively.

Applying inert particles in the bed of MSB dryers provides good conditions for drying of heat sensitive materials of high moisture content (suspensions, pastes etc.) in a single step continuous process. The suspension, pulp or paste is fed into the sliding down zone of the dryer, where the wet material is distributed on the surface of inert particles as uniform film-like coating. Due to the intensive gas-solid contact on large surface area, and the low thickness of wet material, drying process goes on very rapidly. The dried material wears off from the inert particles because of their intensive movement and friction within the screw. Then, the tiny particles of dried solids are entrapped by air flow leaving the dryer. The product is collected in a cyclone and/or bag filter. Because of the large contact area, the short length of diffusion, and intensive heat and mass transfer, effective drying takes place within very short residence time (several ten seconds), even at relatively low wet bulb temperature. During drying, the following sub-processes take place: *i. formation of wet coating on the inert particles, ii. drying of the coating,* and *iii. abrasion of the dried material* (Pallai et al.[4]).

Considering these sub-processes, in an MSB dryer there are three characteristic zones:

• *Zone of dense layer (annulus)* sliding down counter-currently with the air flow. Formation of wet coating takes place here.

• *Intensive drying zone* close to the gas inlet at the bottom characterised by turbulent (swirling) flow and intensive gas-solid contact. The drying of wet coating takes place here.

• *Zone of mechanical spout* (rotation area of the screw conveyor) where the particles are transported vertically upward, co-currently with the air flow. Abrasion takes place here.

To control these processes and product quality, it is very important to know the whole time of circulation, and the time available for given sub-processes, i.e. the residence times of particles in different zones. To measure the time of circulation radioactive tracer technique was used applying ^{60}Co isotope (Szentmarjay and Pallai [5]). It was shown that the labelled particles spent about 70% of the whole circulation time in the annulus, 10% in the screw zone, and about 20% in the bottom part of dryer, i.e. in the „whirling drying zone". The drying time available for the wet material can be influenced by the air flow rate and temperature, and by the thickness of coating on the particles. This latter depends on the circulation time of particles set by the rotation speed of the conveyor screw, as well as on the feeding rate of wet material.

2. DRYING EXPERIMENTS AND METHODS

Drying experiments were performed in two MSB dryers of different scales. The bigger laboratory scale equipment shown in Fig. 1 used to dry tomato pulp consisted of a cylindrical column with ID = 145 mm and 800 mm height, and a conical bottom part contracted to 110 mm diameter in 70 mm height. The wet material (solution or suspension) was fed into the annulus from both sides using a peristaltic pump. The dried fine particles were separated from the outlet air by cyclone and bag filter. Data acquisition and process control was carried out by PC based controlling system.

2.1 Drying of tomato concentrate

Tomato powder has great importance among the dried vegetables. The raw material is tomato concentrate of 75 w/w% water content. The task in this work was to produce dried but well rehydratable tomato powder of about 5-6 w/w% moisture content without remarkable changes in colour and vitamin C content. However, thermoplastic nature of tomato (similarly to several other fruits having relatively high carbohydrate content of low melting points) makes the drying operation rather problematic because at certain conditions, namely at critical temperature - moisture content values shown in Fig. 2 the powder becomes deliquescent and sticky. As it is seen from the curve, the lower the moisture content, the higher the temperature at which the tomato becomes plastic and sticky (Karatas and Esin [7]).

To solve this problem it was decided to jump over that critical moisture content - temperature value as quickly as possible by applying very short drying time using appropriately selected drying conditions, also considering quality demands. For this, relation between the drying time and coating thickness has been determined as is shown in Fig. 3.

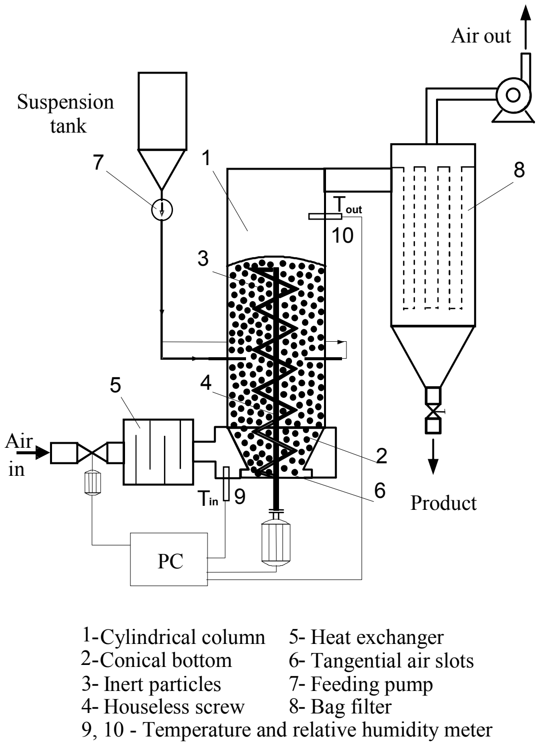

Fig. 1: Experimental MSB-dryer system

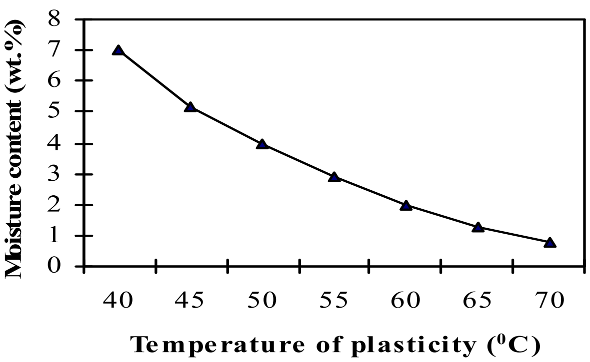

Fig. 2: Thermoplasticity of tomato powder vs. moisture content (Gould [6])

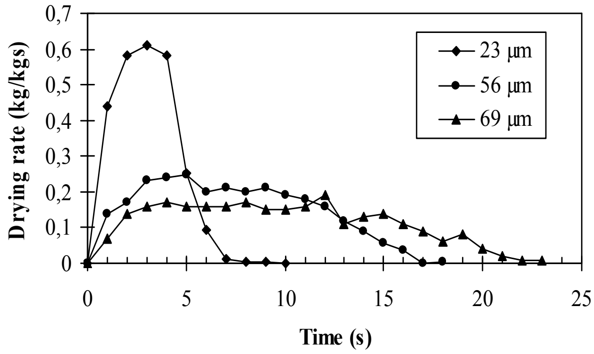

Fig.3: Drying rate curves for tomato concentrate

The results showed that the drying time necessary to achieve the required final moisture content of the product decreased considerably with decreasing coating thickness. This latter was observed by SEM microscopy and was also calculated from the hold-up of the tomato powder in the dryer and the surface area of the inert particles. Drying rate was calculated from the reduction of moisture content per unit time. The conditions to obtain very thin film coating of 25-30 μm were determined experimentally. The construction parameters together with the most important process parameters are shown in Table 1. Under such conditions very short drying time (7- 8 s) and excellent product quality were achieved. Colour and flavour tests gave evidence that there were not remarkable changes in these quality indicators during drying carried out with the selected process parameters.

The value of rehydration: 15.9 (moisture content of the rehydrated product, X_r /moisture content of the dried product, X_d) also showed good rehydration ability. The 10 % loss in ascorbic acid content measured in the dried product as a maximum was considered acceptable.

Table 1: Construction parameters of the bigger laboratory scale MSB dryer and the operational conditions used in drying of tomato concentrate

Total height of the dryer	(m)	0.87
Inner diameter	(m)	0.145
Mass of the inert particle bed	(kg)	3.75
Height of the inert particle bed	(m)	0.35
Inert packing		Hostaform
Size of inert particles	(mm)	7.6
Rotation speed of the conveyor screw	(min^{-1})	400
Outer diameter of the conveyor screw	(m)	4.5×10^{-2}
Air flow rate	(Nm^3/h)	70
Feeding rate of tomato concentrate	(cm^3/min)	20
Inlet air temperature	(°C)	65
Outlet air temperature	(°C)	40
Drying time	**(s)**	**7-8**
Thickness of the coating	(μm)	25-30

2.2 Formation of bovine serum albumin powders from solutions in MSB dryer

The aim of this study was to investigate the drying of protein solutions on the surface of inert particles in MSB dryer, as well as to determine the optimum process conditions to obtain dried powder-like product of particle size under 20 μm with preserved soluble protein content higher than 90 %. For this, a smaller laboratory scale MSB dryer was used with construction parameters shown in Table 2. As model material, bovine serum albumin (BSA) was chosen from which solutions of different concentrations were prepared in double distilled water. The content of BSA was varied from $c_{BSA,w}$ = 20 to 40 g/l. In each run 240 ml of protein solution was fed onto the surface of inert particles with feeding rates of G_s = 3 and 4.5 cm^3/min. The flow rate of drying air was 15 Nm^3/h. The peripheral speed of conveyor screw was varied between Z_p = 0.38 – 0.95 m/s. For drying temperatures, T_{in} = 40, 60 and 80 ˚C were selected. As regards the inert packing, similarly to the drying of tomato pulp, polyformaldehyde spheres of 7.6 mm diameter were used. The degree of protein preservation was expressed as the soluble protein content in the dried product ($c_{BSA,d}$, w/w%). The particle size distribution of product was determined by laser light scattering method (Malvern 2600) from suspension. Process parameters were selected appropriately to obtain coating thickness under 20 microns to assure very fast moisture removal at relatively low temperatures. The calculated drying time, τ_d was around 10 s. The effect of process parameters on the particle size and protein content preservation are shown in Table 3.

It was found that the soluble protein content remained relatively high in each run, but the process parameters had significant effect on the particle size of the dried product. It was surprising that at higher temperatures (60 or 80 °C) the soluble protein content increased above 90 %. This fact can be explained by the shorter drying time at higher temperatures, that is, the drying time had greater effect on the protein preservation than temperature. The particle size has decreased by increasing circulation time (i.e. by decreasing rotation speed of the conveyor screw, see runs 1-3) showing that longer drying time resulted in better drying thus improving the abrasion of the coating. Similar tendencies are shown in runs 5-7 where the protein content of the solution was varied. It means that at the highest protein concentration (lowest water content) the coating dries faster, promoting the abrasion process. As a result, the mean particle size decreased from 22.8-24.7 (runs 5-6) to 15.4 μm (run 7).

Table 2: Construction parameters of the smaller laboratory scale MSB dryer used for drying BSA

Total height of the dryer (m)	0.60
Inner diameter (m)	0.094
Mass of the inert particle bed (kg)	1.7
Height of the inert particle bed (m)	0.34
Inert packing	Hostaform
Size of inert particles (mm)	7.6
Rotation speed of the conveyor screw (min^{-1})	210-520
Outer diameter of the conveyor screw (m)	3.5×10^{-2}

Table 3: The effect of process conditions on the particle size and soluble protein content

Run	**$c_{BSA,w}$ g/l**	**T_{in} °C**	**T_{out} °C**	**G_s cm^3/min**	**τ_d s**	**d_v μm**	**$c_{BSA,d}$ w/w%**	**RPM min^{-1}**
1	40	40	22.2	4.5	8.8	77.85	87	520
2	40	40	20.3	4.5	9.8	32.80	84	280
3	40	40	24.2	4.5	11.0	21.92	86	210
4	40	40	25.2	3	9.8	18.45	84	280
5	20	60	39.2	3	9.8	22.80	90	280
6	30	60	40.6	3	9.8	24.69	93	280
7	**40**	**60**	**38.3**	**3**	**9.8**	**15.40**	**93**	**280**
8	40	80	50.7	3	9.8	16.99	91	280

3. CONCLUSIONS

In drying of heat sensitive materials with high moisture content (solution, suspension and pulp) a lot of difficulties can arise. Rigorous quality requirements, stable and economic operation can be carried out in mechanically spouted bed (MSB) dryer with inert packing. The main advantage of MSB dryer with inert packing is that drying time can be varied in wide range by controlling the process parameters. In case of adequate selection of feeding rate and bed height, and by appropriate adjusting of the rotation speed, very thin film-like coating can be formed on the surface of inert particles. Due to its low thickness, drying process goes on at high rate and in very short time even at low temperature. Due to these features it is possible to fulfil wide range of requirements in a one-step process. Realization of two drying tasks with special quality requirements (drying of aqueous solution of bovine serum albumin to produce powder-like product with preserved soluble protein content, and moisture removal from tomato pulp of thermoplastic behaviour) were demonstrated.

In case of BSA, by selecting proper process parameters very thin film-like coating was achieved on the particles, resulting in powder-like product with particle size < 20 μm, preserving more than 90 % soluble protein content. The drying of tomato concentrate is a hard task because of its hygroscopic and thermoplastic characteristics. To solve this problem suitable process parameters were determined to form very thin coating of about 25-30 μm. The drying of the pulp took place in 8-10 s, which was short enough to jump over the critical temperature-moisture content ranges at which the tomato coating becomes deliquescent and sticky. By this way a stable, dried powder-like product was produced without remarkable change of colour and flavour, with no notable loss of vitamin C content.

4. NOMENCLATURE

$C_{BSA,w}$	concentration of BSA in the solution	[g/l]
$C_{BSA,d}$	soluble BSA content in the dry powder	[w/w%]
D, d	diameter	[m]
d_v	volume mean particle size	[μm]
G	feeding rate	[kg/h, or cm^3 /min]
T	temperature	[°C]
t	time	[s or min or h]
Z_p	peripheral speed of conveyor screw	[m/s]
X	moisture content	[kg/kg d.b. or [w/w%]

Subscripts

C	circulation
D	dried, dryer
in	air inlet
out	air outlet
r	rehydrated
s	suspension, solution

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6. ACKNOWLEDGEMENT

This work was supported by the Economic Competitiveness Operative Program of the Hungarian National Development Plan funded partly by the Structural Funds of the European Union, No. GVOP-3.1.1.-2004-05-0031/3.0.