World Journal of Agricultural Sciences 3 (2): 230-236, 2007
ISSN 1817-3047

Spray Dryer Parameters for Fruit Juice Drying

[1]G.R. Chegini and [2]B. Ghobadian

[1]Department of Agricultural Technical Engineering,
Agricultural Engineering College, Aboureihan Campus, University of Tehran, Iran
[2]Department of Agricultural Machinery Mechanical Engineering, Tarbiat Modarres University, Iran

Abstract: Spray drying is one of the most complex methods for fruit juice drying. Fruit juice is very sensitive and affected the different drying parameters. These parameters should be tested and determined before the design of the dryers. With laboratory spray dryer the basic parameters for drying of orange juice with 65% concentration was studied. The investigated parameters include: drying agent material, feed flow rate inlet and outlet air temperature and sticky point temperature. Tests were performed without and with agent materials and studied the different operating condition of spray drying and the sticky point temperature for orange juice powder. The results of statistical analysis of experimental data show that the parameters of inlet air temperature and feed flow rate have significant effect on the dryer yield and wall deposit of spray dryer individually and jointly. Also with the addition of liquid glucose, the optimum conditions have been obtained with feed flow rate of 15 ml min^{-1}, inlet air temperature of 130°C and outlet air temperature of 85°C. For the orange powder containing 2% moisture, the sticky point temperature was 44°C.

Key words: Spray drying · orange juice powder · sticky point temperature

INTRODUCTION

Natural hygroscopic and thermoplastic property of fruit juice is the basis problem in transport and handling of fruit juice powder produced in spray dryer [14]. A pilot plant test is essential for establishing new industrial spray dryer to meet the performance specification. This specification include: type of spray dryer flow current, optimum operation conditions, residence time and air humidity and ancillary equipment that necessary to complete drying without adverse effect on powder quality and prevent formation of unacceptable wall deposit of semi-dried product. Therefore the design of industrial spray dryer required accurate information of drying agent materials behavior. This information must be obtained with primary tests with laboratory spray dryer [5, 14]. For fruit juice powder production two complex problems were available, stickiness of powder and its handling and the other was related to fruit juice natural characteristic that caused no powder production. For preventing of stickiness and production of powder tow ways were, using of drying agent material and using of specific equipment to facilitate the powder handling [5]. Citrus fruit juice hygroscopic reduction required drying agent materials. The agent materials with changing of physical properties of fruit juice aided to drying. These agent materials include corn syrup; natural gums, sucrose, malt dextrin etc…caused powder production and prevent cohesion of particle on spray dryer wall [2, 8, 16, 23].

The limited methods have for production of fruit powder without aided drying materials. Attiyat produced a free flow and good quality tomato powder with industrial spray dryer [1]. Maltini produced peach, pear and apricot powder using vacuum belt dryer and freeze drying [13]. Bahanderi *et al*. studied the condition of producing blackcurrant, raspberry and apricot powder with two laboratory spray dryer using from malt dextrin with DE 6, 12, 19 as aiding drying material and obtained the ratio of additive materials [2]. Gupta with liquid glucose as agent produced the free flow orange juice powder. He used many spray dryer with different atomizing system and found that powder glass film form when the inlet air temperature was higher than the sticky point [11]. Carcmo and Luis studied the technical feasibility spray drying of apple juice [4].

Corresponding Author: Dr. G.R. Chegini, Department of Agricultural Technical Engineering, Agricultural Engineering College, Aboureihan Campus, University of Tehran, Iran

In addition to the powder production, the quality of food spray dryer depend the operating variables. Studying the effect of operating parameters on powder physical properties help us in obtaining the optimum operating conditions of spray dryer and powder characteristics [6, 12, 21]. Welti and Lafunete studied the influence of air temperature and feed rate on residual moisture, carotenoids, essential oil and vitamin C of orange products. They found that the product with lowest moisture and high quality were obtained when outlet air temperature was in the range of 100-110°C [23]. Bhandari *et al.* found that wettability of fruit powder with lower inlet air temperature was better than higher inlet air temperature [2]. Food powder stickiness has been researched in recent years because of it importance in food industry [3, 7, 17, 20]. Rennie *et al.* and Chen *et al.* conducted unconfined yield tests to examine the effect of temperature on the cohesion of whole milk powder [7, 20].

This work is aimed at identifying the main basic data that is necessary to design fruit industrial spray dryer. Factors include: additive materials, optimum operating parameters and stickiness of powder.

MATERIALS AND METHODS

Materials: The experiments performed using a Buchi model laboratory spray dryer. In this dryer, feed with rate 7.5-42 ml min^{-1} by peristaltic pump transport on rotary atomizer with 25000-rpm speed. Electricity heater heated inlet air until 80-200°C. Cyclone with effective diameter 10 cm separated the air-powder mix. The parameters of inlet/outlet temperature, feed rate and inlet air volume were controllable. The content of Iranian concentrated orange juice (source, variety) was given in Table 1.

The agents and their proportion with orange juice are chosen based on previous investigations [8, 14, 16]. Agents should reduce the hygroscopic and thermoplastic property with the variation of the fruit juice properties and should not alter the quality and solubility of the powder produced. The agents used in this research work as aiding materials include malt dextrin and liquid glucose.

The experimental methodology: The production of powder was carried out using agents such as (malt dextrin and liquid glucose). The design of experiments was full factorial with the complete random design. The matrix of experimental design is given in Table 2. According to varied operation condition and agent materials the powder physical properties were measured. The effect of operation parameters on yield and powder deposit and the wall temperature in the point of set up sensors was also studied. The number of experiments was 48, with 3 replications and the total number of experiments to be performed reached 144.

The spray dryer was situated in a laboratory with stable condition and environment. The ambient air temperature was about 20-25°C and relative humidity of 35-45%. Before starting the tests, the atmospheric conditions were measured with a digital thermometer and humidifier with the accuracy of 1°C and 1%. In all of experiments, atomizer speed and air volume were constant at 25000 rpm and 650 $cm^3\ s^{-1}$.

Powder physical analysis: The powder samples produced during experiments were kept in closed vessels until the analysis stage. The powder physical properties measured include: bulk density, particle size, residual moisture, insoluble solid, deposit of walls and dryer yield. The

Fig. 1: The experimental equipment for measuring the sticky point temperature

Table 1: Iranian concentrated orange juice content

Total solids	63%
Total sugar	42-45 g/100 ml
Citric acid	8-12 g/100 ml
pH	3

Table 2: The matrix of experimental design

	Levels			
Factors	1	2	3	4
Type of agent	Without additive	Liquid glucose	Malto dextrin	--
Inlet air temperature (°C)	130	140	150	--
Feed flow rate (ml/min)	15	20	25	30

Table 3: Measurement methods of powder physical properties

Powder properties	Methods and calculation [19-22]
M_c (Moisture content)	Mass lost after 5 to 10g of powder in an oven controlled temperature (105°C) during 4 h.
B_d (Bulk density)	20g of powder was weighed into a 100ml graduated cylinder then gently dropped 10 times onto a rubber mat from a height of 15 cm.
P_s (Mean particle size)	Using an inverted metallurgical microscope (Model PME3, Olympus Optical). That was connected to a computerized data acquisition and analysis system.
I_s (Insoluble solids)	With dissolving 10g powder in water at 25°C in 20 s.
Y (Yield)	$Y = \frac{P.S_p}{L.S_f} * 100$
S_{pt} (Sticky point temperature)	Temperature that particle powder beginning to stickiness.
R_t (Residence time)	Period time of atomization beginning until the first powder production.

methodology adopted by the earlier researchers and chosen in this case is explained in Table 3.

The residence time: Sufficient residence time is essential to permit completion of the drying operation. The role of residence time in spray dryer is important in order to prevent under or over sizing of drying chamber.

The sticky point temperature: The sticky point temperature measurement was measured by using experimental equipment (Fig. 1). Amount of powder put on soft plate and turn on heater, the temperature that particles' beginning to cohesion is sticky point temperature.

RESULTS AND DISCUSSION

Drying without additive materials: Basic design factors include: air flow current, operation condition of dryer, the orange juice characteristics, residence time, the suitable drying agent and sticky point temperature. The suitable air flow current for food materials in this method is co-current because the heat damage is very low [14, 16]. For suitable viscosity and undamaged concentrated orange, the maximum feed temperature was measured under 65°C. Also atomization was very hard at temperature of less than 5°C. So according to previous research and performed tests, the best temperature of feed concentrated is obtained 20-35°C [11, 16].

With the primary data, spray drying of orange juice performed at 3 steps. At first concentrated orange was used without any agent materials. Results indicated that in all of the tests no powder was produced and the materials cohered to wall chamber and cyclone. Secondly as the tests continued a hard glass film was shaped on walls. Thirdly as the operating condition was changed such inlet air temperature and feed flow rate the powder

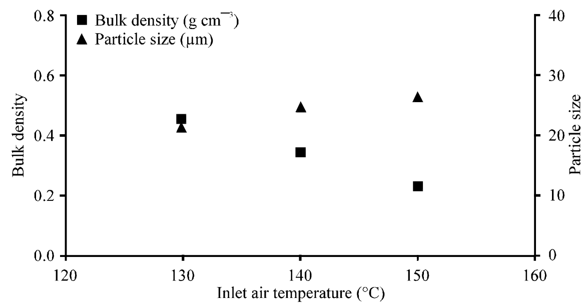

Fig. 2: The effect of inlet air temperature on bulk density and particle size

yield and production didn't improve. Addition of agent materials i.e. (sucrose, glucose or fructose) gave fruit the hygroscopic and thermoplastic characteristic, so when fruit juice dried or dehydrated particles of powder stickiness. In food materials with irregular structure, water plays as a plasticizer factor and change the materials structure. A little of water reduce glass transition temperature until under home temperature [8, 17, 18].

Drying with agent materials: Experiments performed with adding malt dextrin to orange concentrated. With this agent material, yield was better. At different dryer operating condition, physical properties of powder were measured (Table 4). Results indicated that with malt dextrin, yield was increased to18-35% and was deposit on walls between 65 to 82%. The particles in cyclone and chamber were accumulated and powder physical properties were measured. The bulk density of powder was 0.5-0.8 g cm^{-3} and the mean particle size ranged from 20 to 30 μm.

Figure 2 showed the effect of inlet air temperature on the bulk density and particle size of orange powder. Figure indicates at constant feed flow rate, increasing the inlet air temperature, reduced the bulk density. This

Table 4: Orange powder physical properties

Type of drying agent	Inlet air temperature (°C)	Outlet air temperature (°C)	Feed flow rate ml min^{-1}	Bulk density (g cm^{-3})	Moisture content (%)	Insoluble solid (%)	Yield (%)
Malto dextrin	130	70	15	0.5	2.50	20.00	35.00
	130	71	20	0.45	2.20	21.10	34.00
	130	73	25	0.42	2.10	22.15	34.00
	130	75	30	0.40	2.10	22.20	32.00
	140	85	15	0.38	2.45	24.42	33.00
	140	85	20	0.34	2.42	25.12	32.00
	140	83	25	0.32	2.40	25.35	30.00
	140	84	30	0.30	2.35	25.38	28.00
	150	95	15	0.27	2.25	26.10	25.00
	150	92	20	0.25	2.20	26.25	22.00
	150	96	25	0.23	2.15	26.35	19.00
	150	95	30	0.21	2.10	26.40	18.00

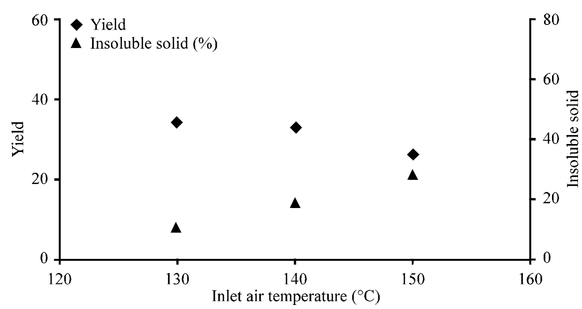

Fig. 3: The effect of inlet air temperature on yield and insoluble solid

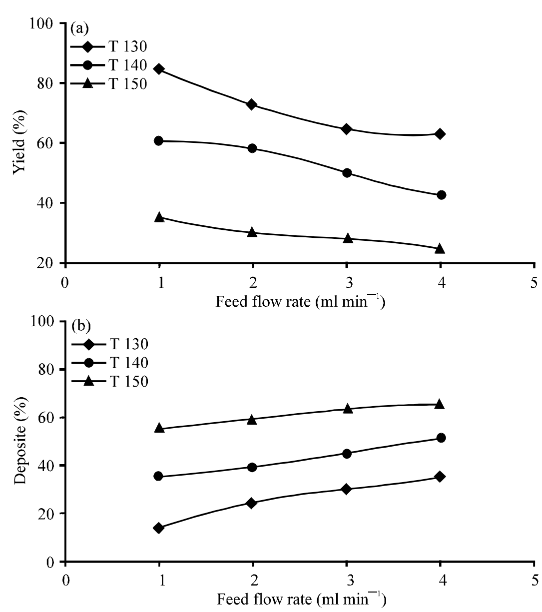

Fig. 4: The effect of inlet air temperature and feed flow rate on yield and deposit

increment often results in a rapid formation of dried layer at the droplet surface and the particle size was due to skinning over or casehardening of the droplets at the higher temperatures. This leads to the formation of vapor-impermeable films on the drop surface, followed by the formation of vapor bubbles and consequently droplet expansion. The effect can also be referred to the fact that a product of higher moisture content would tend to have a higher bulking weight caused by the presence of water, which is considerably denser than the dry solid [22]. This hardened skin does not allow the moisture to exit from droplet as a consequence the particle size is increased. The research conducted by the other researcher has also confirmed these findings [12, 22].

Figure 3 showed the effect of inlet air temperature on yield and insoluble solid. The figure indicated that increasing the inlet air temperature reduced the yield and increased the insoluble solid. Increasing the inlet air temperature often caused the melting of powder and cohesion wall so the amount of powder production and yield reduced. Also because of creating a rapid formation of dried layer at the droplet surface, no water influenced the inner of particle when dissolved in the water [8, 9].

Using of malt dextrin improved production of powder and yield but had more percent deposit on chamber wall. Therefore the other experiment was made using of liquid glucose as drying agent material. For different spray dryer operating condition, physical properties of powder was measured. Results were shown in Table 5. Using of liquid glucose increased the dryer yield and reduced the wall deposit. Results indicated that with increasing inlet air temperature the bulk density was reduced and particle size and insoluble solid were increased [8, 9].

Table 5: Orange powder physical properties

Type of drying agent	Inlet air temperature (°C)	Outlet air temperature (°C)	Feed flow rate ml/min	Bulk density (g cm^{-3})	Particle size (µm)	Moisture content (%)	Insoluble solid (%)	Yield (%)
Liquid glucose	130	83	15	0.75	24.72	2.52	0.09	85.00
	130	85	20	0.71	29.15	2.15	0.10	72.00
	130	85	25	0.68	28.20	2.75	0.18	65.00
	130	87	30	0.67	28.18	2.65	0.21	62.00
	140	85	15	0.68	31.26	2.05	0.11	60.00
	140	87	20	0.58	31.50	2.12	0.10	58.00
	140	90	25	0.56	32.35	2.05	0.10	50.00
	140	91	30	0.54	32.30	2.02	0.12	42.00
	150	92	15	0.56	33.45	2.00	0.33	35.00
	150	95	20	0.53	33.72	2.00	0.43	30.00
	150	95	25	0.49	33.89	2.05	0.45	27.00
	150	98	30	0.45	33.95	2.10	0.43	25.00

Statistical analysis: For identifying the operation parameters that affected the yield and powder deposit, with statistical method the effect of inlet air temperature and feed flow rate on deposit and yield were analyzed. The results of variance analysis indicated that the independent effective factors of inlet air temperature and feed flow rate on yield and powder deposit were significant in level of 1%. Results of comparison of means (Duncan test) showed in graphs and Fig. 4.

Fig. 4a and 4b indicated that at different inlet air temperature the effect of feed flow rate was variant. At the constant inlet air temperature, increasing the feed flow rate increased the wall deposit and reduced the yield. At constant atomizer speed, increasing the feed flow rate, more liquid was atomized into chamber, so time of drying was reduced and drying incorrect. In this condition particle was contained moisture cohesion to the near particles and increased deposit and reduced yield. Also Fig. 4 showed that in upper inlet air temperature the deposit increased and the yield reduced [21, 22]. Liquid glucose agent was suitable for orange juice drying powder. It reduced the thermoplastic and hygroscopic properties of orange juice and the dryer yield was better than malt dextrin, but wall chamber had considerable percent of deposit (14-65%).

Therefore the other parameter may affect the powder deposit. The results of statistical analysis showed the effect of inlet air temperature and feed flow rate on deposit. So wall temperature was high or atomization was not uniform. Figure 5 showed the distribution of means particle size.

The Figure indicated that the more distribution of particles was ranged less than 40 µm and the lower the

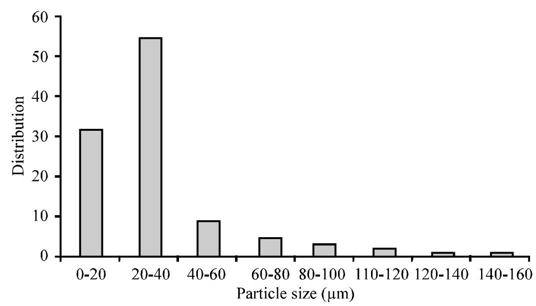

Fig. 5: Distribution of powder particle size

distribution of the other size. So the atomization has uniformed and deposit back to the other parameter of high wall temperature. For studying the effect of wall temperature, four temperature sensors are appointed on chamber in different points. The results of this experiment were shown in Table 6.

At different inlet air temperature, all the point that set up sensor the wall temperature was between 70-138°C. At these points the percent of deposit was considerable, so the wall temperature is an important factor. The previous researchers indicated that the important factor for production of powder was the sticky point temperature. In this temperature particles of powder stick to the other particles and create the cohesion and not free flow powder [18, 20].

With the other test the sticky point temperature of orange juice powder for the different moisture content was obtained (Fig. 6). The results showed that for 2% residual moisture content, the sticky point temperature was 44°C. Because the temperature of the point that sensor is appointed was higher than sticky point temperature deposit is covered (Table 6).

Table 6: Wall temperature in the point of set up sensor

Temperature (°C)			Feed flow	Temp. of point that set up sensor (°C)				Moisture
Feed	Inlet air	Outlet air	rate ml min^{-1}	4	3	2	1	content (%)
20	150	92	15	88	90	97	98	2.10
20	140	85	20	80	80	83	86	2.05
20	130	83	25	74	75	79	84	2.42
30	150	95	30	82	97	97	100	2.05
30	140	87	15	73	89	91	91	2.00
30	130	85	20	70	82	83	85	2.14
40	150	95	25	120	115	138	129	2.00
40	140	90	30	115	117	124	129	2.10
40	130	85	15	110	112	118	118	2.12

Table 7: The operating condition of spray dryer with cooled plate

Temperature (°C)		Feed flow rate	Temperature wall point (°C)		
Inlet air	Outlet air	ml min^{-1}	is cooled	un cooled	un cooled
140	78	15	38	81	79
140	84	20	38	85	84
140	88	25	41	119	111
130	80	15	30	83	78
130	82	20	31	84	80
130	82	25	33	110	109
			no deposit	deposit	deposit

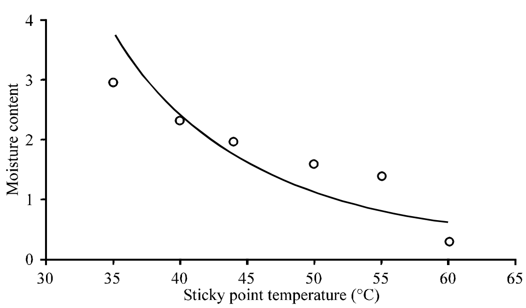

Fig. 6: The sticky point temperature of powder at different residual moisture

For confidence of this result a cooling plate is appointed to the two point of the chamber and the temperature of wall controlled under sticky point temperature. The amount of deposit with comparison the opposite points of wall was measured (Table 7).

The results indicated that in points that the temperature of wall was under sticky point temperature there was not any deposit but in the other point, that wall temperature was high, wall had heavy deposit. At constant atomizer speed, the optimum operating condition of spray dryer was obtained when inlet air temperature was 130°C, outlet air temperature70°C, feed flow rate15 ml min^{-1} and wall temperature under 44°C.

CONCLOSIONS

The results of this research work indicated that drying of orange juice without agent drying materials don't produce powder and changing of the operating parameters don't effect the improvement of powder production. The malt dextrin was an agent drying materials that increased the dryer yield to 18-35% but between 65 to 82% the powder stick to walls. Liquid glucose was suitable agent material for drying of orange juice so the yield increased and the wall deposit considerably was reduced. The results of statistical analysis showed that the inlet air temperature and feed flow rate were significant effect on yield and deposit of powder, with increasing of this parameters, the wall deposit was increased and yield was reduced. The important parameters that play role on powder deposit were the sticky point temperature that for orange juice powder at 2% moisture was 44°C. For correct design of fruit juice industrial spray dryer, the wall temperature must be control at under sticky point temperature. This operable when is added the other equipment such as double wall chamber.

NOMENCLATURE

$B_{d:}$ Bulk density
I_s: Insoluble solids
L: Feed flow Rate
M_c: Moisture content
P: Rate of powder
P_s: Mean particle size
$R_{t:}$ Residence time
S_f: Present of total solid of feed
S_{pt}: Sticky point temperature)
S_p: Present of total solid of powder
Y: Yield

ACKNOLEDGEMENTS

The financial support of the Aboureihan campus, University of Tehran and Tarbiat Modarres University is gratefully acknowledged.

REFERENCES

1. Attiyat, Y., 1978. Breakthrough in spray drying improve quality, shelf life. Food Eng. Intl., 3: 48-51.
2. Bahandari, B.R., A. Senoussi, E.D. Dumoulin and A. Albert, 1993. Spray drying of concentrated fruit juices. Drying Technol., 11: 1081-1092.
3. Boonyai, P., B. Bahandari and T. Howes, 2004. Stikiness measurement techniques for food powders: A Review. Powder Technol., 145: 34-46.
4. Carcmo, F. and E. Luis, 1998. Technical feasibility of spray drying process of concentrated apple juice. Valdivia, pp: 209-214.
5. Chegini, G.R. and B. Ghobadian, 2004. Estimating the regression based mathematical models of orange juice powder physical properties with operating variable of spray dryer. Proceedings of the IWSIS Symposium, Mumbai, India.
6. Chegini, G.R. and B. Ghobadian, 2005. Effect of spray-drying condition on physical properties of orange juice powder. Drying Technol., 23: 657-668.
7. Chen, X.D. R. Lake and S. Jebson, 1993. Study of milk powder deposition on a large industrial drier. Transaction of the Instantiation of Chemical Engineers, Part C, 71: 180-185.
8. Dolinsky, A., Y. Maletskaya and Y. Snezhkin, 2000. Fruit and vegetable powders production technology on the bases of spray and convective drying methods. Drying Technol., 18: 747-758.
9. Dolinsky, A., 2001. High-temperature spray drying. Drying Technol., 19: 785-806
10. Duck, S., L. Kang and S. Dong, 1997. Processing of powdered jujube juice by spray drying. Drying Technol., 14: 568-574.
11. Gupta, A.S., 1978. Spray drying of orange juice, US Patent, 4112130.
12. Jumah, R.Y., B. Tashtoush, R.R. Shaker and A.F. Zraiy, 2000. Manufacturing parameters and quality characteristics of spray dried jameed. Drying Technol., 18: 967-984.
13. Maltini, E. R. Nani and G. Bertolo, 1986. Vacuum belt drying of fruit juices Without drying aids. Technology of Product Agriculture, pp: 231-238.
14. Masters, K., 1991. Spray drying. 5th Edn. Longman Scientific Technical., London, pp: 756.
15. Masters, K., 1994. Scale-up of Spray dryers. Drying Technol., 12: 235-257.
16. Mujumdar, A.S., 1987. Handbookof industrial drying 2nd Edn., Marcel Dekker, New York, pp: 1238.
17. Ozmen, L. and T.A.G. Langrish, 2002. Comparison of glass transition temperature and sticky point temperature for skim milk powder. Drying Technol., 20: 1177-1192.
18. Papadakos, S.E. and R.E. Bahu, 1992. The sticky issues of drying. Drying Technol., 10: 817-837.
19. Pearson, D., 1985. Laboratory technique in food analysis. Butterworth's, London, pp: 256.
20. Rennie, P.R., X.D. Chen, C. Hargreaves and A.R. Mackereth, 1999. A study of the cohesion of dairy powders. J. Food Eng., 39: 277-285.
21. Viviane, S. Birchal, M. Laura Passos, Gloria, R.S. Wildhagen and A.S. Mujumdar, 2005. Effect of spray drying variable on the whole milk powder quality. Drying Technol., 23: 611-637.
22. Walton, D.E., 2000. The morphology of spray dried particles. Drying Technol., 18: 1945-1983.
23. Welti, J.S. and B. Lafuenete, 1983. Spray drying of comminuted orange products. Chemical Engineering Progress, 79: 80-85.