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PROCESS SIMULATION OF PINEAPPLE JUICE SPRAY DRYING

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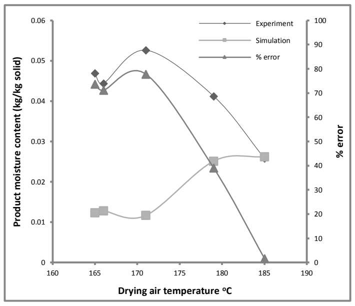
Graphical abstract



Abstract

Pineapple juice is one of the known natural sources of bromelain, a bioactive compound beneficial to health. The dried powder has potential commercial value and is a convenient source of the juice drink. The quality of spray dried pineapple juice is dependent on the powder moisture content. Spray dried pineapple powders with low moisture contents were produced in a lab-scale spray dryer in this study. Powder production of 25% of total solids were obtained by use of DE6 maltodextrin to solids ratio of 0.41:0.59. A heat and mass transfer model of the spray drying process was implemented in Matlab and solved to determine its predictive utility. The simulation results showed agreement with experimental data at high inlet air temperatures but widely diverged at other air temperatures. The error size in predicted product moisture varied from 73% at 165 °C to almost zero at 185 °C while that for the predicted exit air temperatures varied from about 38% to zero over the same temperature range. Accuracy can be improved if transient heat effects, and sub models for the feed drying are included in the model.

Keywords: Moisture content; pineapple juice; maltodextrin; simulation; spray drying

Abstrak

Jus nanas adalah salah satu daripada sumber semula jadi yang diketahui bromelain, sebatian bioaktif memberi manfaat kepada kesihatan. Serbuk kering mempunyai nilai komersil yang berpotensi dan sumber mudah daripada minum jus. Kualiti semburan kering jus nanas bergantung kepada kelembapan serbuk. Sembur serbuk nanas kering dengan kandungan lembapan yang rendah telah dihasilkan dalam semburan pengering berskala makmal dalam kajian ini. Pengeluaran serbuk daripada 25% daripada jumlah pepejal diperolehi oleh penggunaan DE6 maltodekstrin nisbah pepejal daripada 0.41:0.59. Model pemindahan haba dan jisim proses pengeringan semburan telah dilaksanakan pada Matlab dan diselesaikan untuk menentukan utiliti ramalan itu. Keputusan simulasi menunjukkan perjanjian dengan data uji kaji pada suhu udara masuk yang tinggi tetapi secara meluas menyimpang pada suhu udara yang lain. Saiz kesilapan dalam kelembapan produk meramalkan diubah dari 73% pada 165 °C kepada hampir sifar pada 185 °C manakala bagi suhu udara keluar meramalkan diubah daripada kira-kira 38% kepada sifar pada julat suhu yang sama. Ketepatan boleh diperbaiki jika kesan panas yang fana, dan model sub untuk pengeringan makanan yang dimasukkan ke dalam model.

Kata kunci: Kandungan Kelembapan; jus nanas; maltodekstrin; simulasi; semburanpengeringan

1.0 INTRODUCTION

Fruits are rich natural sources of bioactive compounds and polysaccharides that are beneficial to human health. The pineapple (*Ananascomosus*), a source of rare natural dietary bromelain [1], is a tropical fruit widely cultivated in suitable climes worldwide. The fresh fruit and juice is a rich natural source of magnesium, potassium, vitamin C as well as other bioactive compounds and polysaccharides like sucrose[2]. The bromelain, minerals and bioactive compounds have been studied to have salubrious effects on human health. Studies have showed encouraging anti-inflammatory and antimicrobial effects, treatment of indigestion, healthy bones and gums, diuretic effects and immune system boost[1].

Pineapple ranks third in global tropical fruit production volumes, after banana and citrus. It is commercially cultivated in plantations in Asia, parts of Africa, Latin America and the U.S.A. However, it has the common fruity disadvantage of being perishable and must undergo some form of processing to extend its shelf life. In 2011, annual estimated global production was about 21.9 million tonnes and estimated export earnings about US$1.7 billion. The trade value of processed pineapple accounts for about 75% of the global pineapple trade value[3]. In Malaysia, pineapple ranks first among fruit crops followed by banana and mango in terms of production with a total of 309,331 metric tons harvested in 2011. About 90% of the total harvest is consumed locally while US$904 million was earned from commercial exports of the rest[3]. Fresh raw servings and juices of the fruit are often preferred for consumption to canned, juice concentrate or powder. The juice is a sweet delicious nutritious drink with processing possibilities into a free flowing powder that can be reconstituted into a refreshing drink that closely retains most of its natural nutrition values. The changing dietary habits of consumers and the increased appeal and demand for healthy foods like pineapple juice, which provide important nutrients, prevent nutrition deficiency illness and retain their natural flavours have motivated new processing methods and dried powdered products to satisfy such demands [4-6]. Pineapple juice in powder form offers a convenient nutrient source without wasting time and energy peeling and extracting the juice from the fruit. The powdered juice has a longer stable shelf life compared to other processed forms of pineapple products like canned chunks, juice and concentrate [7, 8]. Additionally, food powders have an enhanced value due to their reduced weight and bulk volume, extended shelf life, minimal storage, transport and handling requirements, and importantly, resistance to physicochemical and microbial spoilage [9, 7].

The spray drying process involves a complex interplay of rates of heat and mass transport, the physicochemical properties of feed and drying gas, the thermal behaviour of the feed during the drying process, and the drying equipment used. The liquid or semi-liquid feed is dispersed as a spray of small drops into hot drying gas. Heat transport occurs from gas to droplet surface and into the droplet core, while mass transport occurs from within the droplet and from its surface into the gas stream. The final powder suffers little or no thermal degradation and almost retains the quality of the original feed. Typical industrial products of the process include fruit juice powder, egg powder, coffee, tea extract, honey powder, milk, flavours, soup powders, baby milk formula, spices and herb extracts, cheese powder, yoghurt powder, vegetable powders, etc [10, 11].

Spray dried products can be subdivided into two rudimentary groups: sticky and non-sticky. Sticky products broadly describes spray-dried powder containing organic acids (citric, malic and tartaric acid) and polysaccharides (glucose, sucrose and fructose) in variable but significant concentrations constituting up to 70% or more of the solids content [12-14].Pineapple juice powder typically belongs in this group. Its spray-dried powders are highly hygroscopic and sticky and adhere to dryer walls or each other, causing sticky or syrupy deposits, clumping and caking during processing and storage[15-17].There is an observed dependence of this phenomena on the amount and type of sugar present, moisture content and the powder glass transition temperature[18, 10]. Common problems of sticky products includes formation of sticky deposits, adhesion to surfaces of drying equipment, clumping and caking of product powder which, causes reduced product yields, reduced product quality and operational problems[15, 16, 18]. Fruit juices are often difficult to spray dry in their natural extracted state without the help of drying aids. Non-sticky products in contrast are easily spray dried into free flowing powders. They contain little or no sugar content, are less hygroscopic and less susceptible to this sticky and caking behaviour however some non-sticky products have been noted to exhibit instances of sticky behaviour[15].

The quality of spray dried juice powders is significantly dependent on its final moisture content. The objective of all drying processes is a reduction in the moisture content of the product. Low moisture content implies a low water activity, inhibited enzymatic activity and resistance to microbial and fungal growth [19, 20]. Process models can be applied to estimate flow rate, temperature and moisture content of air or product and for assessing dryer performance. Such models are usually a macroscopic accounting of mass and energy over the dryer of interest. The estimates are often useful as a first approximation in design and simulation studies and in making engineering decisions. Also of importance is the error size in such calculated estimates compared with experimental data. Such information is very useful in making credible judgements, especially where experimental data is unavailable.

The final powder properties of spray dried pineapple juice powder and other juices had been investigated in several studies. Abadio *et al*. [21] examined the effect of maltodextrin concentration and atomization speed on the properties of spray dried pineapple juice. They observed the moisture content of spray dried juice powder to decrease with increase in maltodextrin concentration while the true powder density was significantly dependent on studied variables. The study of effects of inlet air temperature, atomisation pressure and feed flow rate on moisture content of spray dried pineapple juice powder, by Aliyu *et al.* [22], showed no significant dependence on any one of the variables. The product yield of spray dried roselle-pineapple feed was found to be significantly dependent on maltodextrin concentration and drying air temperature in the study by Osman and Endut [23]. Solval *et al.* [24] and Tonon *et al.* [25] showed inlet air temperature to have a significant effect on the moisture content of spray dried cantaloupe juice powder and acai juice powder respectively while Zareifard *et al.* [26] found maltodextrin concentration, inlet air temperature and flow rate had variable effects on the moisture content of spray dried lime juice. The study by Tan *et al.* [27] showed inlet air temperature to be a stronger influence on orange juice powder moisture content compared to maltodextrin concentration while Cheong *et al.* [28] showed the moisture content of spray-dried Gac aril powder to be significantly affected by maltodextrin concentration and inlet air temperature.

The objectives of the study were to produce spray dried pineapple juice powder from a pineapple-maltodextrin juice feed and determine its moisture content, to simulate the spray drying operation using a mass and energy process model and to determine the error size of the predicted product moisture content and exit air temperature with experimental values. The study also analyses the error size in using such process models to simulate fruit juice spray drying operations besides determining the causative factors involved.

2.0 EXPERIMENTAL

2.1 Materials

Average sized, mature and ripe pineapples (*nenas morris)* obtained from a fruit shop was hygienically cleaned, peeled and sliced into small pieces. A Philips kitchen juicer (Model HR2826/BC, Hong Kong) was used to extract the juice and a standard metallic kitchen sieve with fine mesh used to filter out solids. An Ohaus moisture analyser (Model MB25, NJ, USA), a Brookfield rotary viscometer (Model DV-II, MA, USA) and specific gravity glass bottles (50ml) was used for the moisture content and TS, viscosity, and specific gravity determinations on the raw juice, respectively. The measured properties are shown in Table 1. DE 6 maltodextrin (San Soon Yin Sdn. Bhd) was used as drying additive. Using the measured raw juice total solids, a stepwise addition of maltodextrin (DE6) to the raw juice and spray drying of resulting feeds mixtures were carried out to experimentally determine the minimum amount of maltodextrin and operating conditions required for appreciable powder recovery. The measured moisture content, TS, viscosity and specific gravity for the final pineapple juice-maltodextrin mixture are also shown in Table 1.

Table 1 Physical properties of raw pineapple and pineapple-maltodextrin juice[a]

Properties	Raw Pineapple juice	Pineapple-Maltodextrin juice
Moisture content (% w/w) (dry basis)	8.2963	4.556
Viscosity (Ns/m^2)	0.0096	0.0157
Total solids (% w/w) (wet basis)	10.76	19.0
Specific gravity (w/w.H$_2$0) (30 °C/30 °C)	1.026	1.040
Maltodextrin mass (% w/w.TS) (dry basis)	0.0	41.04

[a]all data are the mean of triplicate measurements.

2.2 Methods

2.2.1 *Spray Drying Of Pineapple-Maltodextrin Feed*

The pineapple juice-maltodextrin feed was spray-dried under concurrent drying conditions using a laboratory scale spray dryer (Dawnyx Technology Sdn. Bhd) shown schematically in Figure 1. The drying chamber, cyclone and powder collectors were made of 1cm thick toughened, thermally stable glass. The drying configuration is concurrent with hot drying air and feed flowing from top to bottom. In operation, ambient air of known temperature and humidity measured with a digital reader (Springfield, USA) is filtered, compressed and passed through the air-heating chamber at a rate of 450 – 500L/min. The air is heated up by an electric resistance heater (165 – 185 °C) before being fed into the drying chamber. The compressed atomiser air is at ambient temperature. The temperature of the feed mixture is held constant using an agitated hot plate and fed through a hygienic peristaltic pump (Masterflex Model 7518-10, Cole-Parmer, USA) to a two-fluid stainless steel spray nozzle with liquid orifice of 0.5mm. The feed and compressed air to the atomiser is varied as required for each experimental run but maintained at a 1:1 ratio. The inside diameter of the drying chamber is 0.3m and the vertical distance from atomiser tip to the centre-line axis of the exit side tube to the cyclone is 0.485m. The outlet air temperature is continuously monitored with a digital thermocouple during each drying process. The resulting powder and were separated in the cyclone separator and the dried powder samples collected from a flask at the base of the cyclone. A drying run was considered successful when dry powder was collected inside the flask at the base of the cyclone. The powder samples were stored in airtight glass containers in a desiccator until analysed. The operating parameters for each run are presented in Table 2.

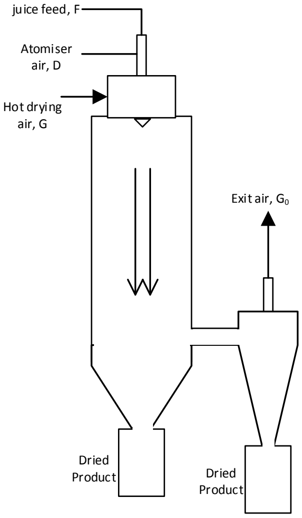


Figure 1 Schematic of spray drying process

Table 2 Operating parameters for spray drying experiments

Variable	Run A	Run B	Run C	Run D	Run E
Feed temp (°C)	30.5	30	29.5	29	30
Feed flow rate(mL/min)	20	24	19.25	37	34
Drying air temp (°C)	165	166	171	179	185
Drying air flow rate (x10^{-3} m^3/s)	8.0	8.33	7.83	7.92	7.5
Drying air humidity(kg $H_2$0/kg dry air)	0.0083	0.0073	0.0086	0.0083	0.0097
Atomizer air temp(°C)	30.5	29	30	29	30
Atomizer air humidity (kg $H_2$0/kg dry air)	0.0198	0.0189	0.0171	0.0123	0.0125
U (W/m^2.K)	1.5049	1.5049	1.5065	1.5123	1.5144

2.2.2 Measurement Of Moisture Content

Moisture contents of the spray-dried powders were determined using an Ohaus moisture analyser (Model MB25, NJ, USA). The samples were dried to a constant mass at a drying temperature of 70°C. Average values of moisture contents for each sample were calculated from triplicate measurements.

2.2.3 Model Of The Process

For a spray dryer in continuous operation with negligible deposition of product on the drying chamber walls, conservation equations of heat and mass can be written to account for all the input and output streams of mass and energy. Conventional wisdom requires the mass and energy streams to be based on a unit mass of a bone-dry component in the stream. The hot air and feed are the inlet sources of energy and mass while the outlet air, product and heat losses from the drying chamber represent the energy and mass flows from the dryer. Using the notation in Figure 1, the following equations for the moisture component about the spray dryer can be written [29]:

Moisture mass rate in feed (kg/s) = FX_1 (1)
Moisture mass rate in hot air (kg/s) = GY_1 (2)
Moisture mass rate in atomizer air (kg/s) = DY_2 (3)
Moisture mass rate in product (kg/s) = FX_0 (4)
Moisture mass rate in exit air (kg/s) = G_0Y_0 (5)

where F = mass flow rate of atomised dry feed (kg/s) into the dryer, X_1 = feed moisture content (kg H_2O/kg solid), G = hot dry gas flow rate (kg/s) into the dryer, Y_1= hot air moisture content (kg H_2O/kg dry air), D = atomiser dry gas flow rate (kg/s), Y_2 = atomiser air humidity (kg H_2O/kg dry air). X_0 = product moisture content (kg H_2O/kg solid), G_0 = outlet dry gas flow rate (kg/s), and Y_0 = outlet air moisture content (kg H_2O/kg dry air). A mass balance over the dryer gives the following equation [29]:

$$G_0Y_0 - (GY_1 + DY_2) = F(X_1 - X_0)$$

$$Y_0 = \left(\frac{F(X_1-X_0)+(GY_1+DY_2)}{G_0}\right) \tag{6}$$

In a similar manner, a heat balance over the spray dryer gives the inlet energy as:

$$H_{in} = G\left[Cp_a(T_{a1} - T_{ref}) + Y_1[\lambda + Cp_v(T_{a1} - T_{ref})]\right] + D\left[Cp_a(T_{a2} - T_{ref}) + Y_2[\lambda + Cp_v(T_{a2} - T_{ref})]\right] + F[X_1Cp_l(T_l - T_{ref}) + Cp_s(T_s - T_{ref})] \tag{7}$$

where H_{in} = total energy into dryer (J), Cp_a = specific heat capacity of dry air (J/kg.K), T_{a1} = temperature of hot drying air (°C), T_{ref} = reference temperature (0 °C), λ = latent heat of vaporisation of water at 0 °C (2500 kJ/kg), T_{a2} = Atomiser air temperature (K), Cp_v = specific heat capacity of water vapour (J/kg.K), Cp_l = specific heat capacity of liquid water (J/kg.K), T_l = temperature of water in solid (°C), Cp_s = specific heat capacity of feed solid (J/kg.K) and T_s = temperature of feed solids (°C). The Cp_s is a composite of the maltodextrin and sucrose content of the feed and is calculated from correlations in Patel *et al*. [30] as:

$$Cp_s = W_mCp_m + W_sCp_{sc} \tag{8}$$

where W_m = weight fraction of Maltodextrin in solid, Cp_m = specific heat capacity of maltodextrin (J/kg.K), W_s = weight fraction of Maltodextrin in solid, Cp_{sc} = specific heat capacity of sucrose (J/kg.K). The value of the atomiser air temperature, feed solids and water in feed are assumed same since they collectively enter the dryer through the atomiser. The equation for the outlet energy takes a similar form as Eq. 7:

$$H_{out} = G_0\left[Cp_a(T_0 - T_{ref}) + Y_0[\lambda + Cp_v(T_0 - T_{ref})]\right] + F[X_0 Cp_l(T_{l0} - T_{ref}) + Cp_s(T_{s0} - T_{ref})] + UA(T_0 - T_a) \quad (9)$$

where T_0 = outlet drying air temperature (°C), T_{l0} = Product moisture temperature (°C), T_{s0} = product solid temperature (°C), U = overall heat transfer coefficient at external dryer wall surface (W/m^2.K), A = dryer heat loss surface area (0.6602 m^2) and T_a = atmospheric temperature (°C). For no mass or heat accumulation, since the input values and atmospheric temperature are known Eq. 7 and 9 can be rewritten as:

$$H_{in} = G_0\left[Cp_a(T_0 - T_{ref}) + Y_0[\lambda + Cp_v(T_0 - T_{ref})]\right] + F[X_0 Cp_l(T_{l0} - T_{ref}) + Cp_s(T_{s0} - T_{ref})] + UA(T_0 - T_a) \quad (10)$$

If the product is in equilibrium with the exit air, the water activity of the product will be equal to the relative humidity of the exit air as given by the equation:

$$a_w = \psi = {}^{P_w}/_{P_{sat}} \quad (11)$$

where ψ = relative humidity of outlet air, P_w = partial pressure of water vapour in exit air (Pa) and P_{sat} = saturation vapour pressure (Pa) which is obtained from[31]:

$$\ln P_{sat} = {}^{C_1}/_{T} + C_2 + C_3T + C_4T^2 + C_5T^3 + C_6 lnT \quad (12)$$

where C_1 = −5.8002206E+03, C_2 = 1.3914993, C_3 = −4.8640239E−02, C_4 = 4.1764768E−05, C_5 = −1.4452093E−08, C_6 = 6.5459673 and T = absolute temperature (K). P_w is related to the outlet air humidity (Y_0) by the equation [31]:

$$Y_0 = 0.621945\frac{P_w}{P - P_w} \quad (13)$$

where P = total prevailing pressure (Pa). Rearranging Eq. 13, P_w is calculated from the equation:

$$P_w = \frac{(Y_0/0.621945)P}{[1 + (Y_0/0.621945)]} \quad (14)$$

The equilibrium moisture content of the product is also a composite of the maltodextrin and sucrose content. But for convenience the product is assumed to be entirely maltodextrin and the equilibrium moisture content is calculated using the Guggenheim-Anderson-de Boer (GAB) model[30]:

$$X_{eq} = \frac{mCKa_w}{(1 - Ka_w)(1 - Ka_w + CKa_w)} \quad (15)$$

where X_{eq} = equilibrium moisture content of product (kg H_2O/kg solid), and m = 0.04, C = 30, K = 0.98 for pure maltodextrin droplets.

3.0 RESULTS AND DISCUSSION

3.1 Properties Of Raw Pineapple Juice And Feed

The measured physical properties of the raw and feed juice are presented in Table 1. The raw pineapple juice has high moisture content and viscosity slightly higher than that for water. The small proportion of total solids, approx. 10%, in the raw juice contrasted with the volume and sweetness of the juice point to a high sucrose and fructose content in the solids. The addition of maltodextrin slightly decreased the feed moisture contents by about 45% from 8.2963 to 4.556 and increased the total solids values from 10.76% to 19%. The feed also showed an increased viscosity value of 15x10^{-3} Ns/m^2 compared to 9.6x10^{-3} Ns/m^2 for the raw juice while the specific gravity showed a 1.36% change from 1.026 to 1.04 (w.juice/w.$H_2$0) at 30°C. The addition of maltodextrin to the raw pineapple juice shows a tendency to increase property values. This is reasonable considering the properties are constitutive of the juice and added maltodextrin.

3.2 Production Of Pineapple Juice Powder

Initial efforts to spray dry the raw pineapple juice at 10.76% (w/w) solids, with no maltodextrin and inlet air temperatures ranging from 110 to 200°C yielded sticky, yellowish deposits on the dryer and cyclone walls. The sticky nature of the raw juice is attributed to presence of low-molecular-weight sugars (glucose, sucrose and fructose) which are more difficult to spray-dry because of their low glass transition temperature and hygroscopic and thermoplastic natures [12]. From the stepwise addition of maltodextrin (DE6) to the raw pineapple juice, a minimum value of 16% (w/w) (dry basis) total solids was required for visible powder production, while powder recovery of about 25% was observed at 19% (w/w) (dry basis) total solids or a sucrose to maltodextrin ratio of 0.59:0.41.This concentration of maltodextrin was used in this study. The recovery percentage from the spray dried mixture is observed to be lower compared to the result of Bhandari *et al.* [12] for the same sucrose to maltodextrin ratio. This can be explained by from the consideration of the juice total solids to be purely sucrose. If the fibre and mineral content are considered the sucrose content value may be much lower. The DE6 additive serves to increase high molecular content of the juice feed and its glass transition temperature. The moisture content is decreased and the resulting powder becomes less hygroscopic. A major drawback of additive use are undesirable effects on final powder characteristics like flavour, taste, colour and nutrients which are desired by consumers and hence, its commercial value [32].

3.3 Pineapple Juice Powder Moisture Content

The measured moisture content of the spray dried pineapple-maltodextrin juice is shown in Table 3. The results showed varying powder moisture contents.

Contrasting the moisture content values with the operating parameters in Table 2, it is observed that the powder moisture content decreased by about 5% from 0.0469 to 0.0444 kg H20/kg dry solids the feed rate increased from 20 mL/min to 24 mL/min for Run A and B respectively. Run C showed increased moisture content of 0.0526kg-H_20/kg-dry solid as airflow rate decreased and air temperature increased compared to Run B. The moisture content of Run E is approximately 37% less than that for Run D and may be explained as the dual effect of the reduced feed rate, and increased air temperature. The complexity of the spray drying process is reflected in these results and showed each parameter to constitutively contribute to the drying process rather than singularly control the direction of the process. The exit temperature of the air varied from 100°C to 107°C and the product temperature is expected to be lower than this values. This observation agrees with utility of the spray drying process in drying heat sensitive products that degrade at the high operating temperatures in other drying systems [11, 33].

3.4 Simulation Of Pineapple Juice Powder Moisture Content

The process model presented in Eq. 1 through Eq. 15 was implemented in custom Matlab code and solved to get estimates of product moisture content and temperatures of the exit streams for each operating condition. The solution method involves the sequential calculation of Eq. 1 through Eq. 9 to get the energy input into the spray dryer. Calculation of required psychometric values were obtained from ASHRAE [31] and IAPWS [34, 35] correlations implemented as functions in the code. The calculated simulation values for all the runs are shown in Table 4. Eq. 10 through Eq. 15 requires iteration to calculate the final required values of moisture content and temperature. This was implemented using the *fzero* function in Matlab. The temperature dependence of relative humidity and heat capacity for the feed solids, water, and humid air were calculated at each iteration step for the prevailing temperature. Figure 3 and figure 4 shows the results of the spray drying process simulation against inlet air temperature for exit air temperature and product moisture content respectively. The simulated exit air temperatures showed a decreasing trend with increased inlet air temperature to equal the last two values. The percent error size decreased from a high of about 38% to a low of zero over the same inlet temperature range. The exit air temperature is determined by three competing energy transfer mechanisms - the heat needed to heat and dry the feed to its final moisture content, the heat demand of evaporated moisture the air stream and finally, the heat loss to ambient air through the dryer walls. The heat loss value can be improved if the dryer wall surface temperature is used in the last term of Eq. 10 instead of the drying air temperature. However, the wall surface temperature varies along the length of the dryer in a transient way that cannot be modelled using the current available data. The moisture content of the product showed an increasing trend with increasing drying air inlet temperature. The trends in the simulated results show wide error sizes compared to experimental data at all the temperatures, except the last one. The percent error varied from about 74% at 165 °C, 39% at 179 °C, to almost zero at 185°C. The causative factor was reasoned to be the poor correlation of the feed drying mechanism by the process model. The low simulation results, compared to the experimental results, indicates the existence of resistances in the drying mechanism that were not captured by the process model. Additionally, the temperature dependence of underlying GAB isotherm sorption coefficients, for DE6 maltodextrin, used in the process simulation were not determined. Literature sources [36, 30] of the DE6 GAB Eq. 15 did not state the temperature dependent equations for the GAB coefficients or the range of applicable temperature for the used coefficients. The GAB parameters [37] C and K are normally expressed as a function of the material's temperature and an extensive literature search failed to yield such expressions for aqueous DE6 maltodextrin. This notwithstanding, the moderate error size of the simulated exit stream temperature is acceptable in the absence of more accurate data while the product moisture results have to be used with caution below 185 °C. The implemented process simulation is potentially useful in providing a quick and simple way of assessing an existing process, estimating required exit variables during design or making sound engineering judgements.

Table 3 Exit air temperature and moisture contents of spray dried pineapple-maltodextrin powder

Variable	Run A	Run B	Run C	Run D	Run E
Moisture content (kg H_20/kg dry solid)	0.0469	0.0444	0.0526	0.0412	0.0258
Exit air temp (°C)	101.5	105	102	107	106

Table 4 Calculated spray drying process simulation values

Variable	Run A	Run B	Run C	Run D	Run E
Energy input to dryer (W)	3966	4292	3804	3859	3456
Exit air humidity (kg H_20/kg dry air)	0.01265	0.0222	0.01156	0.0412	0.04399

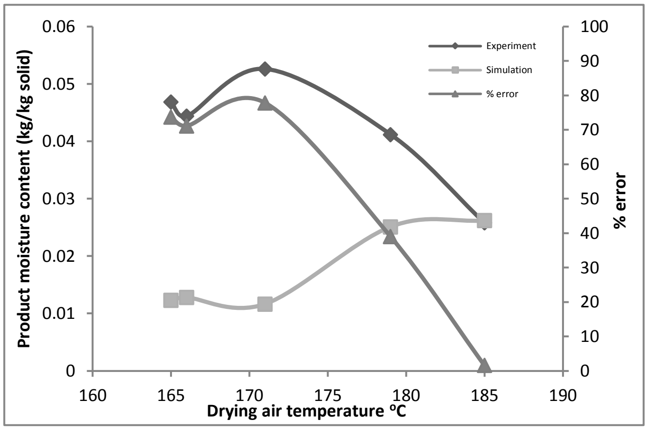


Figure 2 Experimental and simulated exit air temperatures

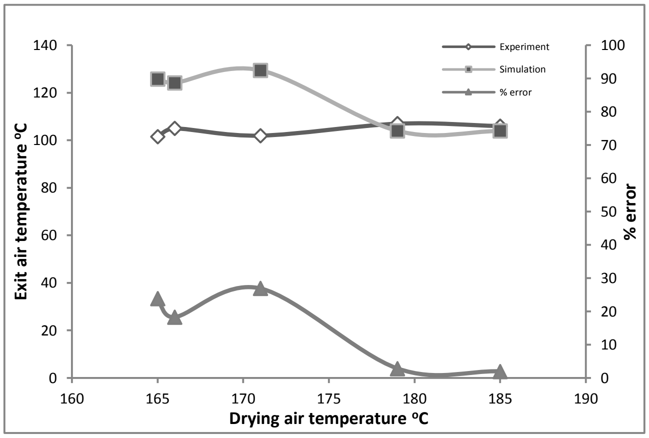


Figure 3 Experimental and simulated product moisture contents

4.0 CONCLUSION

Spray drying of pineapple juice and production of dried powders were achieved using DE6 maltodextrin additive. The possibility of spray drying pineapple juice feed with total solids of 19%, corresponding to sucrose to maltodextrin ratio of 0.59:0.41, was successful with a powder recovery of 25%. The moisture content of the produced powders ranged from 2% to 5% (% w/w.TS) (dry basis) depending on the spray dryer operating variables. The powder moisture content seemed to vary with the changes in feed rate and inlet air temperature compared to other variables in the study but showed no single dependence on any one variable. A simulation of the process was successfully implemented in custom Matlab code to calculate estimates of the exit moisture contents and temperatures of the product and air streams. The error size of the simulation results for the exit air temperatures vary from about 38% to zero as inlet air temperature increased from 165 to 185 °C. The error size for the product moisture content also varied from about 73% to zero over the same temperature range. The errors in exit temperature arise from complex transient energy transfer mechanisms not captured in the model. The feed drying mechanism and the temperature dependent behaviour of GAB sorption coefficients are candidates for the product moisture content error. The simulation accuracy can be improved if transient heating effects, and sub models for heat loss and drying are included within the simulation.

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