THE PERFORMANCE CHARACTERISTICS OF A TYPICAL PILOT-SCALE TRAY DRYER

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ABSTRACT

A pilot-scale tray dryer was assessed to relate the drying temperature (T,°C) and velocity (V = ms^{-1}) to the heater power (H_s) and fan speed (F_s) settings. K-thermocouples and an anemometer were used to measure these drying parameters for 121 setting combinations. Higher fan speed settings reduced the temperature in the drying chamber and multiple regression analyses gave the following relationships: $\ln T = 3.97 + 0.054 H_s - 0.061 F_s$; $r^2 = 0.9350$; $V = 0.4 \exp(0.129 F_s)$; $r^2 = 0.9897$. The relevance of the performance evaluation to downstream processing of PNG agricultural foods was highlighted.

Keywords: *dehydration, convective drying, air velocity, downstream processing.*

INTRODUCTION

The disparity between food supply and the number of people depending on it for survival is still topical. While declaring open the 1995 GASGA International Conference on Grain Drying in Asia at Bangkok, Thailand, the Assistant Director-General of the Food and Agriculture Organisation (FAO) noted that 800 million people go to bed hungry everyday. This was confirmed (Anon 1995) by the World Food Congress that was held in Hungary in its 'Budapest Declaration". Although not the only option, food science and technology has recognised the need to attend to post-harvest issues with a view to arresting pathological, chemical, physical, physiological, and microbiological spoilage factors. Moisture control by drying has proved (Brenndorfer *et al.* 1985; Hall 1989) to be quite effective and this is of particular relevance to Papua New Guinea because of the generally high humidity that prevails in the country.

Drying is often interchangeably used with dehydration in food processing to describe the unit operation in which nearly all the water present in a food is removed by evaporation or sublimation as a result of the application of heat under controlled conditions (Brennan *et al.* 1986). The methods for moisture removal can be conveniently classified (Strumillo and Kudra 1986) into four categories, amongst which is convective drying that passes heated air over the food. Although drying as a food preservation technique is as old as mankind, it continues to receive the attention of downstream processing experts because of the immense advantages it confers on its product. These advantages (and limitations) are well documented in the literature (Hall 1989; Singh 1994) and they have promoted a long-term research to generate drying data on PNG foods. Food dehydration is also a major component of the Food Technology program in the author's Department.

MATERIALS AND METHODS

The Tray Dryer

the schematic diagram of the tray dryer (UOP8-A) is shown in Figure 1. It has a 3 kW heater and four drying trays with each tray measuring 27.5 x 18.5 x 1.5 cm. The trays are not perforated but perforated trays can be fabricated locally to permit two-surface drying. The dryer weighs about 100 kg and its over-

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all dimensions (m) are height, 1.40; length, 2.95; depth, 0.73. The temperature in the drying chamber is controlled by the fan speed and heater power output, both of which are controlled by the settings of knobs. There are 11 settings (including position "0") per controller implying 121 possible combinations of fan speed and heater power output. Despite the controllers, the minimum and maximum temperatures (and relative humidity) obtainable are dependent on ambient conditions and these may vary from one pilot plant to another. Temperature regimes obtained elsewhere may only serve as a guideline and to minimise experimental error, it becomes imperative to assess the dryer's performance under the operating local conditions.

The Assessment

For each of the 121 combinations, four K (chromel-positive; alumel-negative) thermocouples were put on the drying trays and the termocouples were connected to a datalogger (Datataker DT50; Data Electronics (Aust.0 Pty Ltd., Rowville). The datalogger was competed to measure temperatures every 10 sec. and to log-in the average every 30 sec. for 10 min. The temperatures that were logged-in during the last 5 min. were used in the computation as it was assumed that the dryer would have stabilised during this period to reflect the true temperatures. The combinations were randomised and duplicated. The assessment was spread over 6 months (am and pm) to incorporate as much variations in ambient conditions as possible. The ambient temperature around the drier ranged from 22.2° - 30.4°C with a mean of 26.2° ± 2.4°C.

RESULTS AND DISCUSSION

Table 1 shows typical values that were obtained for the temperatures in the drying chamber. Generally, there was a temperature gradient in the drier with the top-most tray (tray 1) recording the highest temperature. The temperature gradient was possibly due to changes in the density of the air whereby hot air rises and cold air sinks. The gradient was more at high heater power ("10") and low fan speed ("0") settings and it was as little as 0.6° and a large as 35.8°C. Choosing any of the tray's temperature, as the drying temperature cold introduce substantial error in any drying study. An average of the four temperatures per combination was computed and the maximum coefficient of variation was 14.5%. Using the average temperature, the difference in the temperature on any tray was not more than 19.8°C. As expected, the average temperature is recommended for use as the temperature in the drying chamber.

An analysis of variance (not shown) revealed that both heater power (H_s) and fan speed (F_s) settings significantly ($p<0.05$) affected the average temperature (T) in the drying chamber. A multiple regression analysis, which was done using Lotus 1-2-3 statistical software, showed that the dependence can be represented by an equation of the form:

$$\ln T = 3.97 + 0.054\, H_s - 0.0061\, F_s \quad \text{.......................(1)}$$

$r^2 = 0.9350$

% standard error of T-estimate (se) = 6.9

In addition to regression parameters, the mean relative deviation modulus, D_m, is recommended (Sopade and Ajisegiri 1995) in food processing as being valuable in assessing the goodness of fit of an equation.

$$DM = \frac{100}{n} \sum \frac{T_1 - T_{pi}}{T_1} \quad \text{..............................(2)}$$

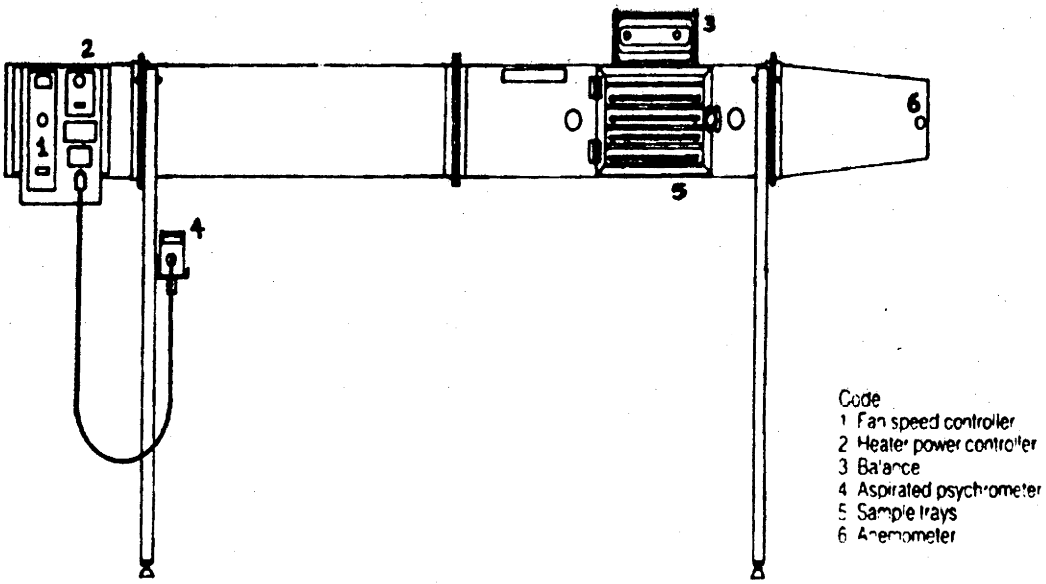
where n = number of experimental data, T_1 and T_{pi} = experimental and predicted temperatures respectively, A D_m of 5.7 was obtained for equation (1). This shows that equation (1) can be used with a reasonable accuracy to obtain the drying temperature when both heater power and fan speed settings are known. Alternatively, both settings can be computed to obtain a pre-determined drying temperature.

The practical importance of this mathematical analysis is that the dryer can be used to obtain drying data at temperatures and airflow within its regime that are representative of local PNG conditions. This will assist the design of an appropriate drier that is representative of the prevailing local conditions. Despite the desirability of dehydration as a downstream processing technique, a trial-and-error approach that arises in the absence of relevant drying data has culminated in a number of failures. Such failures have projected dehydration as unsuitable while neglecting the inaccuracy at the onset of the design.

Table 1. **Typical temperatures in the dryer at different settings.**

Heater Power Setting	Fan Speed Setting	Temperature (°C)				
		Tray 1	Tray 2	Tray 3	Tray 4	Average
0	0	51.1	52.7	48.2	44.2	49.8
0	1	57.4	57.0	55.5	52.1	55.5
0	5	41.1	41.6	41.6	40.8	41.3
1	6	38.4	38.7	38.7	38.0	38.5
1	7	39.1	39.4	39.4	38.6	39.1
1	9	30.4	30.5	30.6	29.8	30.3
1	10	33.7	33.9	33.8	33.1	33.6
2	4	45.1	46.3	46.2	45.1	45.7
2	7	41.3	41.6	41.7	40.8	41.3
2	8	35.0	35.3	35.3	34.5	35.0
3	2	53.2	52.9	52.5	51.1	52.4
3	3	46.0	47.4	47.3	45.9	46.7
3	5	49.4	50.1	50.1	49.0	49.6
4	0	73.7	70.1	63.4	56.4	65.9
4	1	71.1	68.8	65.3	60.0	66.3
4	2	56.2	55.9	55.4	53.7	55.3
4	10	38.4	38.7	38.6	38.0	38.4
5	0	80.5	76.1	68.4	59.7	71.2
5	1	76.0	73.7	69.6	63.6	70.7
5	2	59.9	59.5	58.7	56.8	58.7
5	5	56.6	57.4	57.4	56.0	56.9
6	7	51.2	51.8	51.9	50.8	51.4
6	8	43.6	44.2	44.1	43.2	43.8
6	10	42.4	42.8	42.8	41.9	42.5
7	0	92.3	86.5	77.3	65.5	80.4
7	5	64.5	65.6	65.4	63.7	64.8
7	10	43.8	44.3	44.3	43.3	43.9
8	0	97.7	91.2	81.4	68.1	84.6
8	2	71.2	71.0	69.7	66.3	69.5
8	10	45.7	46.3	46.2	45.4	45.9
9	4	66.9	69.6	69.4	67.2	68.3
9	5	55.9	57.3	50.6	45.3	52.3
9	6	60.6	61.4	61.4	60.1	60.9
9	7	59.6	60.5	60.5	59.2	59.9
10	0	109.1	100.9	89.0	73.3	93.1
10	1	103.0	98.6	91.6	80.9	93.5
10	9	48.4	49.0	48.8	48.2	48.6
10	10	49.5	50.0	49.8	48.8	49.5

Figure 1. **Schematic diagram of the tray dryer.**



It can be observed from equation (1) and as shown in Figure 2 that an increase in the heater power setting increased the drying temperature, which got reduced when the fan speed setting was increased. The air velocity was measured with an anemometer at the outlet of the dryer (position 6 in Figure 1), which is of a smaller flow area than the drying chamber. Applying the continuity equation which states (Earle 1983) that the product of flow area and velocity is a constant, the actual flow velocity ($V = ms^{-1}$) in the drying chamber was related to the fan speed setting as shown in equation (3):

$$V = 0.4 \exp (0.129 F_s) \quad (3)$$

r^2 = 0.9897

se = 4.6

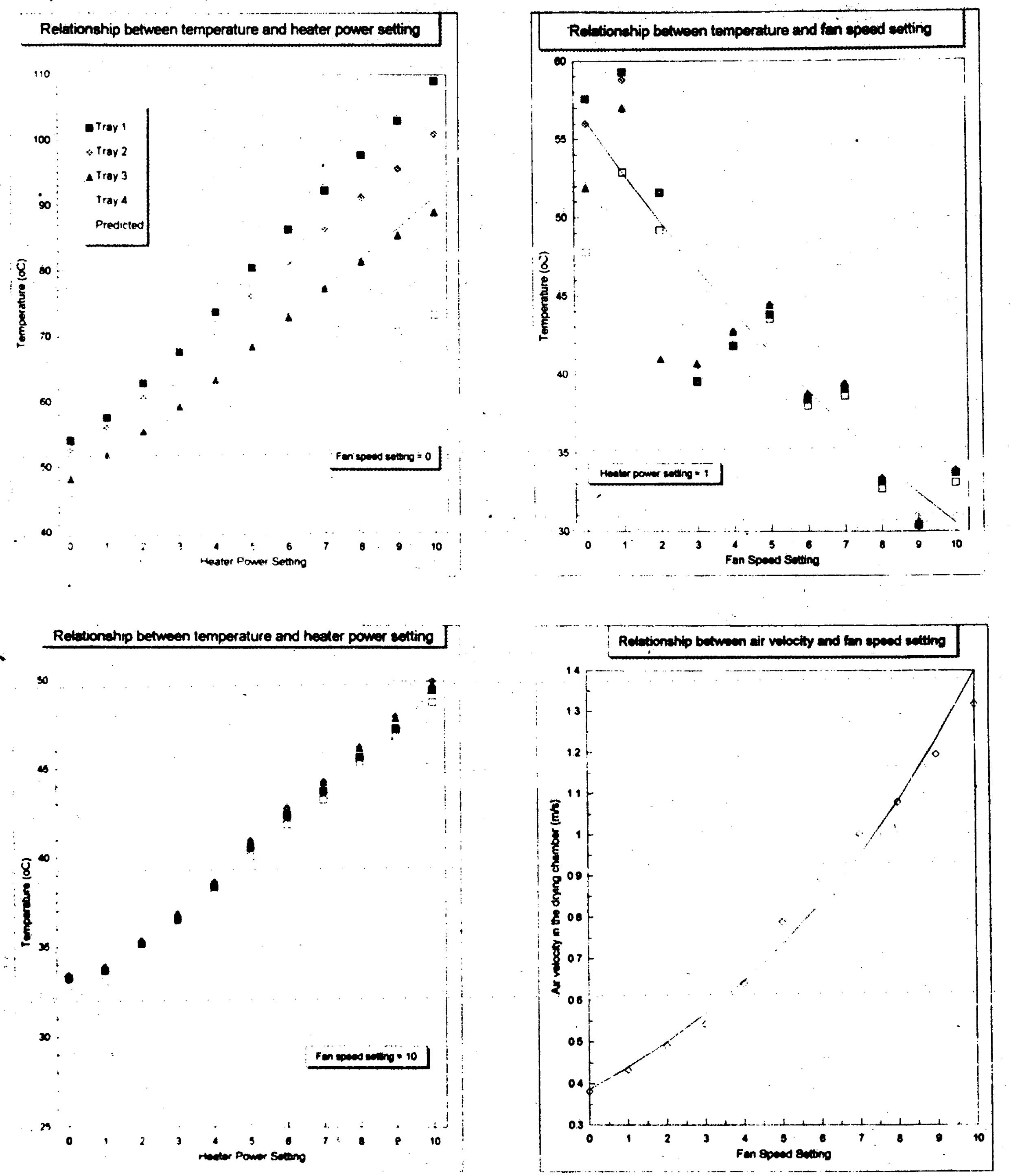
D_m = 3.4

The velocity of the air determines as the driving force for moisture evaporation and its residence time in the drying chamber. Although it is desirable to remove the evaporated moisture with the drying air as fast as possible. The resulting reduction in drying temperature prolongs drying. A balance needs to be struck, therefore, between air velocity and drying temperature for an acceptable drying rate. Apart from the economic implications, slow-drying results in a quality deterioration while too rapid a drying enhances the formation of a hard surface (case-hardening) that inhibits moisture migration from the interior of the food to the surface. The consequence is that the food is not uniformly dried.

CONCLUSIONS

The tray dryer under the local conditions in Lae, is capable of generating a drying temperature of 30^0 - 90^0C with a air velocity that ranges from 0.4 - 1.4 $V = ms^{-1}$. These regimes appear to accommodate conditions in PNG and it is possible to simulate convective drying in different parts of the country once the local conditions are specified. This information should interest academics and entrepreneurs who are using or proposing to use dehydration. They will also find the evaluation valuable as a small scale study of their drying requirements can be conducted to maximise the benefits of dehydration. Relative humidity of the air plays a major role in dehydration as it determines the moisture removing ability (evaporative capacity) of the air. There is no humidity controller on the dryer. When air is heated, the

Figure 2. **Dependence of drying temperature and air velocity on heater power and fan speed settings of the dryer.**



relative humidity decreases but the reduction id dependent on the air's final temperature. A humidity as low as 10% was obtained in this study from an ambient relative humidity that averages 85%. For further reduction in humidity particularly at low drying temperature, it is possible to pass the air through a re-usable desiccant prior to heating. The cost benefit of this option will, however, need to be properly worked out.

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