

OPTIMIZATION OF COPRA DRYING FACTORS BY TAGUCHI METHOD

M A Satter*

Department of Mechanical Engineering
PNG University of Technology
Lae, Papua New Guinea

Abstract Papua New Guinea is an exporter of dried copra. Drying is necessary for shipment and storage of copra, and also to preserve its quality. The basic drying process involves passing of hot air or combustion gases through a copra bed. Hot air picks up moisture of copra as it passes through the bed. Fresh wet copra contains moisture of about 50% of its weight. The moisture level should be reduced to about 6% to conform to export standards of dried copra. Currently, several types of dryers are used in PNG. They are Ceylon, Samoan and Forced Draft type. Natural drying is also used. The dryers differ in the type of fuels used. Some of them are classified as direct and others as indirect heaters. The efficiency of the dryers varies from 5% to 42%. These dryers are of traditional design. They have many disadvantages some of which are: high heat loss to the surroundings, loss of unsaturated hot air, lack of adequate ventilation, use of expensive fuels, cost, and scorching and discoloring of copra surface. The present study is an attempt to design a dryer that will not have the disadvantages just outlined. The preferred design approach is to look at the various factors that influence copra drying. These may include such factors as temperature, copra size, air velocity, depth of copra bed, humidity of ambient air, and so on. The factors are not equally influential in copra drying. Some have major and others minor influence. The major influencing factors can be identified by Taguchi method for parameter design. An example has been presented illustrating the Taguchi method for optimizing copra-drying parameters.

Keywords: Drying factors, Taguchi method, orthogonal array, ANOVA table

INTRODUCTION

Papua New Guinea (PNG) is a net exporter of copra to international markets. In 1985, PNG produced about 175,000 tonnes (t) of dried copra, but the volume decreased somewhat to 142,600 t in 2000 (Gilmore, 1987, and IP20, 2001). The decrease reflects low copra prices in the international market.

Drying is essential to preserve quality during storage and shipment of copra. Raw wet copra contains about 50% of moisture; this level must be reduced to about 6-8% in order to preserve quality. Besides moisture, copra kernel contains oil, protein, and sugar. The oil content of the wet kernel is about 35% and upon drying, the oil content will be 65 to 70%. Wet copra deteriorates quickly. The presence of protein and sugar makes the fresh kernel ideal for the growth of bacteria, fungi and moulds. Free fatty acids and rancidity can develop that reduce yield of coconut oil, and deteriorate oil quality. It is therefore necessary to reduce the moisture content to about 6% as fast as is practically possible.

Several methods are used for copra drying. They fall

into five basic categories: natural drying, direct heat smoke drying, direct heat smokeless drying, indirect heat natural draft hot air drying, and indirect heat forced draft hot air drying. The drying methods differ in their efficiencies and have varying effects on dried copra quality.

Copra drying depends on many factors such as drying temperature, ambient humidity level, particle size, copra bed size, hot air velocity, method of drying, efficiency of dryer used, physical properties of copra, and so on. The factors do not have equal influence on drying; some may have major influence and others negligibly. So, for the development of an efficient and cost effective dryer, it is necessary to understand the extent of influence these factors have on drying. Taguchi method provides a way of determining the influence of various factors.

The paper first discusses several types of drying methods and dryers currently in use. It then goes on to discuss various drying factors and how to optimize them by Taguchi method. An example of the use of the Taguchi method is given to demonstrate its suitability for designing and developing new generations of copra dryers.

*Email: masatter@mech.unitech.ac.pg

COPRA DRYING METHODS

As mentioned earlier, five basic methods of drying are used for copra manufacture. They are briefly described below.

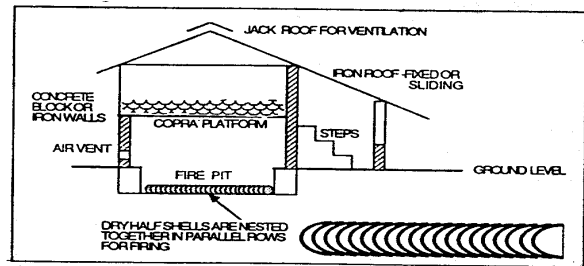
Natural drying involves the use of direct sun in the open. It is the simplest and cheapest method, but is heavily dependent on climatic conditions. The drying temperature range is 25 to 40 degrees Celsius. The drying cycle is about 5 to 7 days to bring the copra moisture level to about 10%. It is thus a slow drying process. Besides, the drying method has adverse effects on copra quality.

The direct heat smoke drying involves the use of traditional fuels such as firewood, copra husks and shells. The copra bed is placed on wire mesh directly above the heat source. The combustion products pass through the copra bed, and remove the free moisture on the copra surface. Although the efficiency of drying is considerably higher than that of natural drying, this method leads to poor quality of dried copra i.e. bad odor and discoloration. The drying cycle time is about 48 hours.

The direct heat smokeless drying is similar to smoke dryer except that it does not produce smoke. A typical example is the Ceylon dryer (Fig. 1). Dried coconut shells are used as fuel. Rows of dried shells are lit at one end and the fire travels slowly along the row. Hot air and combustion gases from the fire are drawn up through the copra bed by natural convection. Copra quality is somewhat better than direct heat smoke drying. The cycle time varies between 24 to 28 hours. The thermal efficiency of Ceylon dryers could be around 43%.

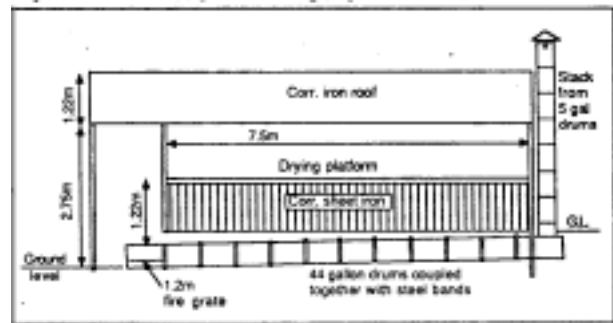
The indirect heat natural draft hot air drying involves the use of a heat exchanger. The products of combustion do not come in contact with the copra. The heat exchanger heats clean air that then passes through the copra bed by natural convection. In the process, the hot air removes the copra moisture. The Samoan kiln is an example of a dryer that uses the indirect heat natural draft principle (Fig. 2). Combustion takes place in metal tubes or drums that act as a heat exchanger. Clean hot air rises from the tubes and passes naturally through a copra bed. Firewood, coconut husks and shells can be used as fuels. Drying time cycle varies between 24 to 48 hours. The thermal efficiency of Samoan dryers could be as low as 5%.

The indirect heat forced draft hot air drying uses the same principle as the above-mentioned natural draft drying, except that a fan is used to force hot air through the copra bed. This method is also more efficient with reduced drying time cycle, which varies between 24 to 28 hours. It is the most expensive drying method with a relatively large initial capital outlay.



Sectional view of a Standard Ceylon Dryer

Fig. 1 Ceylon Dryer (Ref. Gilmore)



Sectional view of a Samoan type dryer

Fig. 2 Samoan Dryer (Ref. Gilmore)

Some of the problems for reduced efficiency of the various dryers are outlined below.

(a) Heat losses from the air prior to its contact with the copra bed occur through the walls and floors of Ceylon dryer. In a Samoan dryer there is a further loss of heat in the form of exhaust gases.

(b) In some cases with half shell copra, air leaving the copra bed is not fully saturated thereby wasting some of the sensible heat that could have been used to evaporate moisture.

(c) Inadequate ventilation is also a common cause for reduced efficiency of the dryers. Restricted airflow can be caused by insufficient open vent area, inadequate roof ventilation and excessive copra depth.

COPRA DRYING FACTORS

Copra drying depends on a number of factors. They are related to environmental conditions, physical properties of copra, and the drying principles used. Some of the factors may include temperature, humidity of air, air velocity, copra particle size, depth of copra bed, height of copra bed from the heat source, thermal efficiency of the dryer used, efficiency of moisture absorption by hot air, and so on. This long list of factors may have varying degrees of influence on the drying process. Also, not all factors have equal influence on drying of copra. It is important to know the effect of each of the factors on drying for designing an efficient copra dryer. It is possible to design experiments to test the effects of the factors. According to *factorial design of experiment*, 27 experiments are required to test three factors at three levels. However, the number of experiments can be reduced using Taguchi's Method of experimental design [Taguchi]. This is discussed in the following section.

TAGUCHI METHOD

Taguchi method [Taguchi] utilizes the concept of signal-to-noise ratio (S/N ratio) to measure the ‘robustness’ of functions of products, processes or technologies. Many types of S/N ratios are calculated depending on the problem being studied. In the present study, the S/N ratio is calculated between copra drying factors as demonstrated in the following section.

When faced with many factors to consider, Taguchi method recommends the use of ‘fractional factorial design’ [Clements]. It is a small sample of combinations normally found in a full factorial design. The fractional factorial design is represented in an orthogonal array. Orthogonality implies a type of mathematical balance. It gives a representative and balanced sample of possible combinations of tests. It allows the experimenter to obtain quickly the main effects of the factors being tested.

To design an experiment we first select the factors that will be used as experimental factors and the variables we will measure as the responses. All other factors are considered to hold constant. These factors are also called noise factors and to account for them, we assign an error value in the analysis. For each selected factor, the number of levels or settings is also determined. The next step is to arrange the factors and the resulting output (response variable) in an orthogonal array. In this case we will use the L₉ orthogonal array.

In order to determine if a factor has a nonlinear or dynamic relationship to the response variable, it should be tested at three or more levels. The orthogonal array for testing factors at three levels has been chosen. The three levels are low, medium and high, and represented by the numerals 1, 2, 3 respectively. Each row of the array represents an experimental run and its combination of factor levels. The order in which experimental runs are made is selected randomly. The response of each combination is recorded at the end of the corresponding row.

In the experimental design, let the selected factors be temperature, copra particle size and air velocity. They are designated as factors A, B, and C respectively. Each factor has been tested at three levels such as low, medium and high. The levels are designated by the numerals 1, 2, 3 respectively. The response variable is the time (in minutes) taken to remove copra moisture by 20% from the initial level of 50%. The three levels of temperature are 40, 60 and 80 degrees Celsius. The three levels of copra size are 5mm, 10mm strips and 1/8th of the whole nut. For air velocity, the three levels are 0.93, 1.3, and 1.37 m/s respectively. Table 1 shows the experimental design.

Table 1: The L₉ Orthogonal array

Run	Factors			Responses
	A	B	C	
1	1	1	1	112.0
2	1	2	2	165.5
3	1	3	3	172.0
4	2	1	2	59.5
5	2	2	3	72.5
6	2	3	1	89.0
7	3	1	3	42.0
8	3	2	1	43.5
9	3	3	2	54.0
				Σx=810

CALCULATIONS

Several steps of calculations are needed to arrive at the S/N ratios for each of the factors (Clements, 1991). These are outlined below.

Step 1: Calculate the Correction Factor (CF).
 $CF = (\sum x)^2 / N = (810)^2 / 9 = 72900$

Step 2: Calculate the magnitude of the experiment.
 This is also called sum squares of the total.
 $SS_{Total} = \sum x^2 - CF = 19908$

Step 3: Calculate the effect of each factor
 $SS_A = ((\sum A_{low})^2 + (\sum A_{medium})^2 + (\sum A_{high})^2) / n - CF$
 $SS_A = 17217.17$
 $SS_B = 1783.17$
 $SS_C = 334.5$

Step 4: Calculate Error
 $SS_E = SS_{Total} - SS_A - SS_B - SS_C$
 $SS_E = 573.16$

Step 5: Create an ANOVA table (Table 2)

The ANOVA table contains the factors of the experiment, the SS values of the factors, the degrees of freedom, variances and the S/N ratios designated as F ratios.

The degree of freedom is almost always one degree less than the number of numbers or number of levels involved. For a factor, the degree of freedom is given by $Df = k - 1$, where k is the number of levels for the factor.

For the error, the degrees of freedom are $Df = N - k$, where k is the number of levels for the factors, and N is the number of numbers in the entire experiment. The variances are calculated by dividing the SS values with respective degrees of freedom. The next step is to

calculate the F ratios (F-test). F ratios are obtained by dividing the factor variances with error variance.

Table 2: ANOVA Table

Factors	SS	Df	V	F
A	17217.17	2	8608.59	90.12
B	1783.17	2	891.59	9.33
C	334.50	2	167.25	1.75
Error	573.16	6	95.53	-
Total	19908.00			

Step-6: This step involves drawing of the effect diagram for each of the dominant factors to discover if a dynamic relationship exists between the factor and its response variable. Average response values are used to draw the effect diagram. The low, medium and high average response values for factor A are 149.83, 73.67, and 46.50 respectively.

DISCUSSIONS OF RESULTS

The results of the experiments are tabulated in Table 2. The F ratios are the S/N values. Three factors have been tested in this experiment. They are temperature, copra particle size and air velocity. The relative F ratios for the factors are 90.12, 9.33, and 1.75 respectively. The results are quite revealing. Out of the three factors, temperature has the greatest effect on copra drying. As expected, moisture removal from wet copra increases with temperature. There is however a limitation to the level of temperature that can be used without compromising on copra quality. Prolonged exposure of copra to temperature beyond 90 C may render the copra surface hard and parched with implications on further moisture removal, oil content and deterioration during storage.

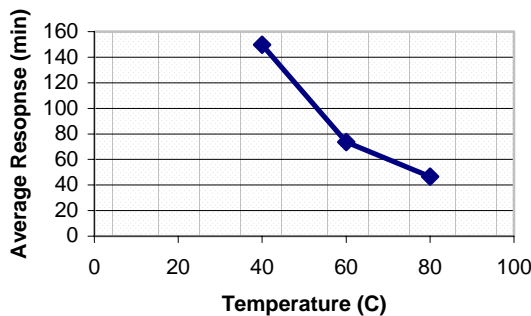


Fig. 3 Effect Diagram

The second factor tested is the particle size. Three sizes were chosen, namely, 5mm, 10mm slices, and 1/8th of the whole nut. Particle size within the range tested has very little effect on drying time cycle. This is understandable because moisture from within the copra kernel may not flow sideways if the slice size is

comparable or greater than kernel thickness. Thinner slices may dry faster because of greater surface area being exposed to heat, but they are not practical as they involve greater cost, storage and shipment problems, and loss of oil content.

Out of the three factors, air velocity has the least effect on drying. The reason is that moisture from within the kernel takes relatively long to reach the surface before being picked up by unsaturated hot air.

The two factors, namely, copra particle size and air velocity may be considered insignificant; the only factor that is of significance is the temperature. In this sense, the number of factors has been optimized. A further set of experiments may be conducted using other factors such as depth of copra bed, ambient humidity level, distance of copra bed and so on. But it may not be necessary to do so because the error variance is relatively small compared to those of the selected factors.

Fig. 3 shows the effect diagram for temperature. It shows that the drying time decreases as temperature decreases, but the moisture removal rate is not linear with temperature.

CONCLUSIONS

Taguchi method of experimentation offers an economical alternative to conventional research. It can scan a large number of factors in a few experimental runs and isolate the dominant factors quickly. The orthogonal arrays are very effective in screening the factors in complex situations.

The study has shown that it is the temperature that requires careful consideration for the design of copra dryers. High setting of temperature at the initial stage of drying is also necessary to achieve high moisture removal rate. The particle size and air velocity are not significantly important. Therefore, variation in their magnitudes will not significantly affect drying efficiency. With these findings, it would be possible to design a copra dryer that will be robust and cost effective.

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