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Desorption isotherms of sweetened maturing coconut meat at different temperatures

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ABSTRACT

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The main objective of the study was to obtain the desorption isotherms of sweetened maturing coconut meat at different temperatures (50, 60 and 70°C). A static gravimetric technique was used for the desorption isotherm determination of the material using a standard procedure. Results revealed that the desorption isotherms of sweetened maturing coconut meat were of type III according to the BET classification. The increase in the amount of sorbed water at a given water activity with the decrease in temperature is consistent with the theory of physical adsorption. A modified Caurie equation can describe the effect of temperature on the desorption isotherms of sweetened maturing coconut. Using this equation for analysis, the results suggest that when drying of sweetened maturing coconut meat is done at higher temperatures (above 70°C) the equilibrium moisture content (EMC) of the sample is not greatly affected and attains a value of less than 1% dry basis. However, when drying is done at lower temperatures (below 60°C), the relative humidity of the drying air is higher and giving higher EMC of the sample. The net heat of desorption for sweetened maturing coconut meat increases as the moisture content decreases which is expected for most food products. The relationship between the net heat of desorption and moisture content of the product can be expressed by an exponential equation. Using this equation for analysis, the results showed that as the final moisture content of the product decreases the energy requirement increases.

Keywords: desorption isotherms, energy requirement, equilibrium moisture content. maturing coconut

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INTRODUCTION

Efforts have been carried out for the development of new food products from coconut in order to diversify coconut utilization through processing of coconut meat into high valued, non-traditional food products for domestic and export markets. One such product developed is called "coco-crisps", a thinly-sliced and sweetened dehydrated maturing (nine-month old) coconut meat. The product needs to be dried to very low moisture content (1-3% dry basis) to attain the characteristic crispiness. In order to attain such moisture content, the drying temperature needs to be increased from 60-65°C to 75-80°C to wards the end of drying (Truong et al., 1986).

Increasing the drying temperature decreases the equilibrium moisture content thereby attaining the required final moisture content of the product. The equilibrium moisture content of the product is the lowest moisture it can attain for a given relative humidity and temperature of the drying air (Brennan et al., 1976). It is obtained by determining its desorption isotherm at different temperatures. The desorption isotherm is obtained by placing an initially wet material into various atmosphere of increasing relative humidity at constant temperature. The moisture content of the sample attained after equilibrium is plotted against the corresponding relative humidity of the container at which it was stored to yield the desorption isotherm of the product at the given temperature (Henderson, 1952; Labuza, 1968).

For effective and easy use of the desorption isotherm data, accurate but simple equations are necessary. Various isotherm equations which include theoretical, empirical and semi-empirical models have been reported in the literature (Chirife and Iglesias, 1978; Van Den Berg and Bruin, 1981). Important factors in selecting a sorption model for drying purposes, particularly near the end of drying, are closeness of fit to the experimental data and simplicity of the equation (Boquet *et al.*, 1978). In addition, from the desorption isotherm data the net heat of sorption can be obtained which is used in estimating the energy requirements of the dehydration processes (Kiranoudis *et al.*, 1993).

It is therefore important to determine the desorption isotherm property of sweetened maturing coconut meat and to generate the different information mentioned hence, this study.

METHODOLOGY

Desorption isotherm determination

About nine-month old coconuts were obtained from a local farm. The nuts were dehusked split open and deshelled. The meat was sliced into 0.7 mm thick slices using a mechanical slicer, blanched in boiling water for 15 minutes, drained and cooked in 50 % sugar syrup for about 25 minutes. The coconut slices were soaked in the sugar syrup overnight. The following day the coconut slices were drained of the sugar syrup before using them in the desorption isotherm studies. One batch of sample was made for each isotherm temperature.

A static gravimetric technique was used for the desorption determination of the material using the procedure of Diamante et al. (1992). Triplicate samples (2-4 g) of the material were put inside the jars containing salt slurries (Greenspan, 1977) to give different relative humidities in the range of 6 to 81% (Table 1) and placed in incubator set at 50, 60 and 70°C and controlled to $\pm$ 1°C. The same incubator was used for the three isotherm temperatures setting of the incubator to the required level.

The samples were considered to have reached equilibrium when the sample weight did not vary by more than 1.0 mg after three consecutive weighings. After equilibration, the moisture contents were determined usingthe air oven method at 105 $\pm$ 3 °C for least 15 hours without grinding the samples. The dried samples were cooled in a dessicator with silica gel before weighing. An electronic weighing balance with an accuracy of 0.1 mg. (Mettler AE 200). was used for all weighings. The equilibrium moisture contents (EMC) of the sample were calculated on a percent dry basis. Plots of the equilibrium moisture content against equilibrium relative humidity or water activity at each given temperature yield the desorption isotherms of the samples.

Table 1. Salt solutions and their corresponding relative humidity for a given temperature (Greenspan, 1977)

Name of Salt Solution	Corresponding Relative Humidity (%)		
	50°C	60°C	70°C
Potassium Hydroxide	5.72	5.49	5.32
Lithium Chloride	11.10	10.95	10.75
Magnesium Chloride	30.54	29.26	26.77
Magnesium Nitrate	45.44	42.46	39.47
Cobalt Chloride	50.01	46.74	46.97
Potassium Iodide	64.49	63.11	61.93
Sodium Chloride	74.43	74.50	75.06
Potassium Chloride	81.20	80.25	79.49

Curve fitting of desorption isotherms

The experimental desorption isotherms of sweetened maturing coconut meat were fitted with the selected two- parameter isotherm equations from Boquet et al. (1978) that are commonly used for curve fitting of food materials namely Bradley, Caurie, Halsey, Henderson, Kuhn, Linear, Oswim and Smith equations (Table 2). Some of the equations were linearly transformed to facilitate the regression.

Table 2. Selected two-parameter isotherm equations from Boquet *et al*. (1978).

Name of Equation	Form
Bradley	$ln\,(ln[1/a_w]) = P + Q\,M_e$
Caurie	$ln\,M_e = P + Q\,a_w$
Halsey	$ln(-ln\,a_w) = P + Q\,ln\,M_e$
Henderson	$ln\,(-ln[1-a_w]) = P + Q\,ln\,M_e$
Kuhn	$M_e = P + Q\,1/(ln\,a_w)$
Linear	$M_e = P + Q\,a_w$
Oswin	$ln\,M_e = P + Q\,ln(a_w/[1-a_w])$
Smith	$M_e = P + Q\,ln\,(1-a_w)$

where: P = intercept of the regression equation
Q = slope of the regression equation
M_e = equilibrium moisture content of the sample
a_w = water activity of the sample = ERH/100
ERH = equilibrium relative humidity of surroundings

The best fitting equation based on high coefficient of determination (r^2) and low mean relative percentage deviation (MRPD) values (Lomauro et al., 1985; Diamante *et al.*, 1992) was selected to model the isotherms at each given temperature. The mean relative percentage deviation (MRPD) is defined by the equation below:

$$MRPD = \frac{100}{n} \sum_{i=1}^{n} \frac{(M_i - Mp_i)}{M_i} \quad \text{------------------------} \; (1)$$

where: M_i = experimental moisture content
Mp_i = predicted moisture content
n = number of experimental observations

The constant of the selected equations were related to temperature by linear, logarithmic, exponential and power regressions. The relationship with highest r^2 was chosen as the temperature function for that constant. When there was no definite trend of the constant with respect to temperature the mean value of the constant was used.

RESULTS AND DISCUSSION

Desorption isotherms of sweetened maturing coconut meat

The desorption isotherms of sweetened maturing coconut meat at different temperature (Fig. 1) were of type III according to the BET classification (Brunauer *et al.*, 1938). Type III isotherm is typical for most food proteins (Iglesias and Chirife, 1976). Nine month old coconuts contain about 6-8 protein on dry basis (Truong *et a*l., 1986; Banzon *et al.*, 1990). The increase in the amount of sorbed water at a given water activity with a decrease in temperature is consistent with the theory of physical adsorption (Iglesias *et al.*, 1975). The results agree with the findings of a number of investigators for copra, a smoked-dried coconut product (Diamante, 1995), cocoa beans (Talib *et al.*, 1995) and a number of vegetables (Kiranoudis *et al.*, 1993).

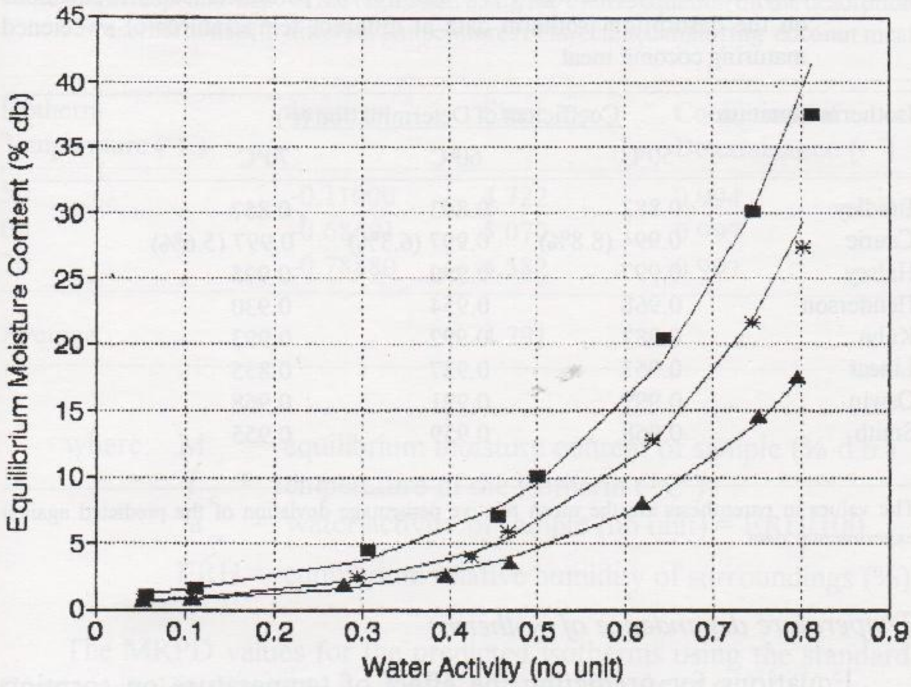

Figure 1. Experimental desorption isotherms of sweetened maturing coconut meat at different temperatures (■ -50°C, *-60°C, ▲ -70°C)

Curve fitting of desorption isotherms

Table 3 shows the r^2 values for the regression of the different equations. The Caurie equation gave consistently higher values of r^2 than the other equations. This is closely followed by Halsey and Kuhn equations, respectively. The mean relative percentage deviation (MRPD) values for the Caurie equation were calculated and showed that they were all below 10% (Table 3). Lower values of MRPD indicate a good fit of the equations (Boquet *et al.*, 1978 Lomauro *et al.*, 1985). This contention is further supported by the good fit of the predicted curve with the experimental data points as shown in figure 1. Diamante (1995 and 1997) also found that the Caurie equation can also describe the adsorption isotherms of copra and peanut-sweetpotato cookie, respectively.

Table 3. Coefficient of determination (r^2) for fitting of two-parameter isotherm equations on the desorption isotherm data at different temperatures of sweetened maturing coconut meat

Isotherm Equation	Coefficient of Determination (r^2)		
	50°C	60°C	70°C
Bradley	0.882	0.863	0.857
Caurie	0.994 (8.8%)	0.997 (6.3%)	0.997 (5.6%)
Halsey	0.997	0.990	0.995
Henderson	0.968	0.954	0.930
Kuhn	0.982	0.992	0.993
Linear	0.953	0.937	0.835
Oswin	0.999	0.991	0.968
Smith	0.968	0.959	0.955

The values in parenthesis are the mean relative percentage deviation of the predicted against experimental data

Temperature dependence of isotherms

Equations for predicting the effect of temperature on sorption isotherms of foods are important because of the limited data available at higher temperatures. These equations will enable the interpolation and extrapolation (with caution) of the limited data to other temperatures, and are particularly useful for desorption operations such as drying which occur at higher temperatures.

Table 4 shows the slopes and intercepts for regression of the Caurie equation to desorption isotherms of sweetened maturing coconut at different temperatures. Generally the intercepts decrease with temperature while the slope did not show a definite trend. The intercept values from Table 4 were related to temperature by linear, logarithmic, exponential and power regressions. The average slope over the temperature range of the isotherms was then obtained. The resulting modified Caurie equation with temperature factor is shown below:

$$\ln M_e = 7.854 - 2.052 \ln T_c + 4.791\, a_w \quad \text{------------------------} \; (2)$$

Table 4. Intercept and slope of the regression using the Caurie equation on the desorption isotherm data at different temperatures of sweetened maturing coconut meat

Isotherm Temperature (°C)	Intercept	Slope	Coefficient of Determination (r^2)
50	-0.11000	4.722	0.994
60	-0.68691	5.070	0.997
70	-0.78880	4.582	0.997
Average:		4.791	

where: M_e = equilibrium moisture content of sample (% d.b.)
T_c = temperature of the isotherm (°C)
a_w = water activity of sample (no unit) = ERH/100
ERH = equilibrium relative humidity of surroundings (%)

The MRPD values for the predicted isotherms using the standard Caurie equation at specific temperature and the modified Caurie equation with temperature factor were calculated and shown in Table 5. The results were very close for both isotherm equations which suggest that the modified Caurie equation can describe the effect of temperature on the desorption isotherms of sweetened maturing coconut meat. Diamante and Munro (1990), Iglesias and Chirife (1976) and Diamante (1995) also found adequate three-parameter isotherm equations with temperature factor to describe the number of food products.

Table 5. Mean relative percentage deviation (MRPD) of the standard and modified Caurie equations for the desorption isotherms at different temperatures of sweetened maturing coconut meat

Isotherm temperature (°C)	Standard Caurie Equation	Modified Caurie Equation
50	8.8%	9.1%
60	6.3%	9.3%
70	5.6%	7.6%

Equations for predicting the effect of temperature on sorption isotherms of foods is very important because of the limited data on sorption isotherms at other temperatures. These equations will make it possible to extrapolate limited data of sorption isotherms at one temperature to other temperatures, thereby determining the temperature effect upon the water actvities and moisture contents of the food sorption isotherm. Diamante and Munro (1990) found that a three-parameter modified Oswin equation can account for the effect of temperature on the desorption isotherms of sweet potato. A three-parameter modified Halsey equation was developed by Iglesias and Chirife (1976) to predict the effect of temperature on sorption isotherms of air-dried beef. Diamante (1995) also reported the use of a three-parameter modified Henderson equation to describe the effect of temperature on the adsorption isotherms of copra (smoked-dried coconut).

Using equation 2, the equilibrium moisture content of sweetened maturing coconut meat can be predicted based on the average ambient air humidity and at different temperatures. The average ambient humidity for the locality is about 0.019 kg water/kg dry air. The predicted equilibrium moisture contents of maturing coconut meat are shown in Table 6. The results showed that the higher the temperature the lower the equilibrium moisture content of the product.

Table 6. Predicted equilibrium moisture content of sweetened maturing coconut meat dried at an average ambient humidity of 0.019 kg water/kg dry air and at different temperatures using the modified Caurie equation

Drying Temperature (°C)	Prevailing Relative Humidity (%)	Equilibrium Moisture Content (% dry basis)
40	40	9.03
50	24	2.65
60	15	1.19
70	9.5	0.66
80	6.5	0.44
90	4.4	0.31
100	3.0	0.23

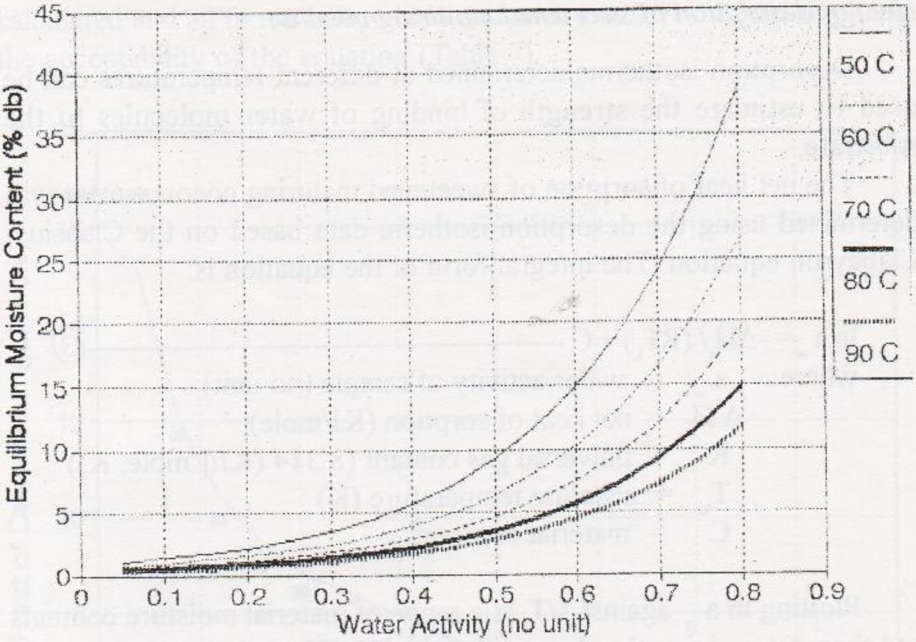

Figure 2. Desorption isotherms of sweetened maturing coconut meat at different temperatures as predicted by the modified Caurie equation

Figure 2 shows the reproduced desorption isotherms of sweetened maturing coconut meat at different temperatures using the modified Caurie equation. The isotherms were extrapolated beyond the temperature range of the experiments to highlight the effect of higher temperatures on the desorption isotherms. There was a large increase of the equilibrium moisture content above a water activity of 0.40 and at lower temperatures.

The results suggest that when drying of sweetened maturing coconut meat is done at higher temperatures (above 70°C) the equilibrium moisture content of the sample is not greatly affected and attains a value of less than 1% dry basis. However, when drying is done at lower temperatures (below 60°C), the relative humidity of the drying air is higher and gives a higher equilibrium moisture content of the sample. A food product with high equilibrium moisture content has a slower drying process (Brennan *et al.*, 1976).

Heat of desorption of sweetened maturing coconut

Desorption isotherms determined at different temperatures can be used to estimate the strength of binding of water molecules to the substrate.

The net heat of sorption of sweetened maturing coconut meat was determined using the desorption isotherm data based on the Clausius-Clapeyron equation. The integral form of the equation is:

$$\ln a_w = -\Delta H_s / (RT_k) + C \text{ -- } (3)$$

where: a_w = water activity of sample (no unit)
ΔH_s = net heat of sorption (KJ/mole)
R = universal gas contant (8.314 (KJ/[mole. K])
T_k = absolute temperature (K)
C = material constant

Plotting $\ln a_w$ against $1/T_k$ at a range of material moisture contents and then determining the slope will yield ΔH_s (Risvi, 1986, Tsami *et al.*, 1990; Diamante *et al.*, 1992).

Figure 3 shows the plot of net heat of desorption against moisture content for sweetened maturing coconut meat. The net heat of desorption increases as the moisture content of the sample decreases. Similar results were also obtained by Kiranoudis *et al.* (1993) for several vegetables, Diamante *et al.* (1992) for different types of casein and Tsami *et al.* (1990) for several fruits.

The relationship between the net heat of desorption and moisture content of sweetened maturing coconut meat can be expressed by an exponential equation:

$$\Delta H_s = 19.006 M^{-0.331} \text{ -- } (4)$$

where: M = moisture content of product (% db)

Using the above equation, the values of net heat of desorption were calculated at various moisture contents. The percentage differences between the experimental and predicted net heat of desorption were calculated and all found below 10% and with a mean of 4.50% implying the acceptability of the equation (Table 7).

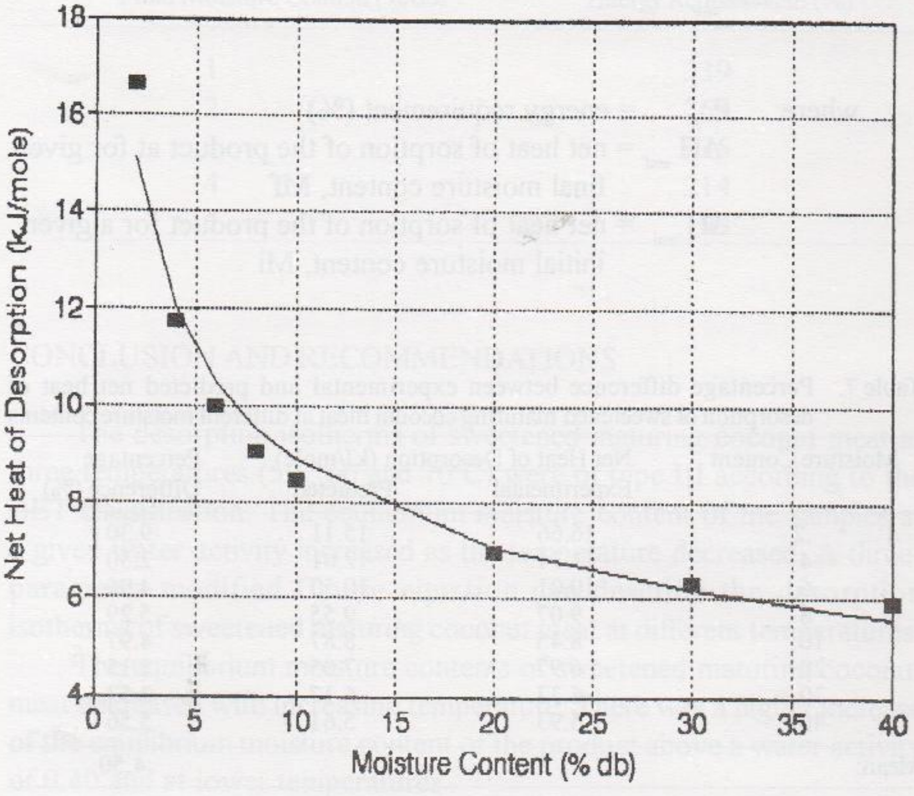

Figure 3. Net heat of desorption as a function of moisture content for sweetened maturing coconut meat

The sweetened maturing coconut meat product is usually dried with an initial moisture content of 40% dry basis down to a final moisture content of about 3% dry basis. Using equation 4, the net heat of desorption at moisture contents of 1 to 5% and 40% dry basis were calculated.

The energy requirement for drying of the product to various final moisture content can be calculated using:

$$E_R = \frac{\Delta H_{smf}}{\Delta H_{smi}} \times 100$$

where: E_R = energy requirement (%)
ΔH_{smf} = net heat of sorption of the product at for given final moisture content, Mf
ΔH_{smi} = net heat of sorption of the product for a given initial moisture content, Mi

Table 7. Percentage difference between experimental and predicted net heat of desorption of sweetened maturing coconut meat at different moisture contents

Moisture Content	Net Heat of Desorption (kJ/mole)		Percentage Difference (%)
	Experimental	Predicted	
2	16.66	15.11	9.30
4	11.74	12.01	2.30
6	10.01	10.50	4.90
8	9.07	9.55	5.29
10	8.45	8.87	4.97
20	6.97	7.05	1.15
30	6.33	6.17	2.53
40	5.93	5.61	5.56
Mean:			4.50

Table 8 presents the results of the analysis. The results showed that as the final moisture content of the product decreases the energy requirement increases. Drying to a final moisture content of 1% dry basis instead of 3%, increased the energy requirement by 104 percent. However, drying to a final moisture of 5% dry basis instead of 3%, decreased the energy requirement by 36 percent only. This is the reason why the remaining few percent of moisture content takes much longer to drive out of the product.

Table 8. Energy requirement for drying of sweetened maturing coconut meat from an initial moisture content of 40% dry basis down to the target final moisture content

Final Moisture Content (% db)	Energy Requirement (%)
1	339
2	269
3	235
4	214
5	199

CONCLUSION AND RECOMMENDATIONS

The desorption isotherms of sweetened maturing coconut meat at three temperatures (50 , 60 and 70°C) were of type III according to the BET classification. The equilibrium moisture content of the samples at a given water activity increased as the temperature decreased. A three-parameter modified Caurie equation can describe the desorption isotherms of sweetened maturing coconut meat at different temperatures.

The equilibrium moisture contents of sweetened maturing coconut meat decreased with increasing temperature. There was a higher increase of the equilibrium moisture content of the product above a water activity of 0.40 and at lower temperatures.

When drying of sweetened maturing coconut meat is done at higher temperatures (above 70°C) the equilibrium moisture content of the sample is not greatly affected and attains a value of less than 1% dry basis. However, when drying is done at lower temperature (below 60° C), the relative humidity of the drying air is higher and gives higher equilibrium moisture content of the sample.

The net heat of desorption for sweetened maturing coconut decreased with moisture content and can be expressed by an exponential equation. As the final moisture content of the product decreases the energy requirement increases.

Based on the results, it is recommended that the drying of sweetened maturing coconut meat should be done at the highest possible temperature which will result in shorter drying time. However, the effect of high temperature on the sensory qualities of the product needs to be assessed. Drying of the product down to the highest acceptable final moisture content should be done in order to reduce the energy requirements of the process.

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