DRYING OF KENAF IN A FLAT BED BOX DRYER FOR ANIMAL FEED

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ABSTRACT

Kenaf drying tests were carried out using the 2.44x2.44x0.91 m flat bed box dryer with the triangular section canopy cover on top. The drying curves obtained were z-shape with very little drop in moisture content during the initial 4 hours of drying followed by a straight line constant drying curve and ended with very little drop in moisture content towards the last few hours of drying. With the kerosene burner set to give a hot air temperature of 85˚C, the drying duration was about 20 hours and the overall thermal efficiency was about 33%. On the other hand, with the kerosene burner set to give a hot air temperature of 70˚C, the drying duration was 24 hours and the overall thermal efficiency was about 46%. The average drying cost per kg of water removed for the two drying air temperatures was RM0.46 and RM0.44 respectively.

Keywords: *Animal Feed, Flat Bed Box Dryer, Kenaf Drying*

1. INTRODUCTION

Good green fodder and high dry matter yields with high crude protein content (> 20%) can be produced from young kenaf (Hibiscus cannabinus L.) of 4-6 weeks old. The moisture content of kenaf at harvest is usually very high up to 80-85% (wet basis). Drying of the very wet kenaf to safe storage moisture content of about 10% (wet basis) must be carried out within 48 hours to minimise the degradation of the kenaf due to bacterial and fungal attacks. For the production of processed feed products such as pellets, cubes and feeding blocks, it may be dried to about 20% (wet basis). One of the most important drying requirements is that the leaf protein (> 20%) is not destroyed or denatured during the drying process and that the colour of the dried product should remain green and not turn dark or black [3]. Up-scaling of the drying and processing technologies will then be carried out for commercial feed production.

Sun-drying kenaf to produce hay is not feasible because of the frequent rainfall under our local weather conditions. To enable the production of the animal feed the whole year round, efficient and cost effective artificial drying systems have to be developed. In this regard, the cost of kenaf drying must be sufficiently low for the total cost of kenaf feed to be low enough to compete effectively with other sources of animal feed in the global market.

Flat bed box dryers are presently being used in MARDI for drying of kenaf to produce small batches of around 100 kg of dried product. The modification carried out on the box dryer by MARDI is to improve the drying thermal efficiency. The modification includes the fabrication of a triangular section canopy to cover the box dryer to retain the hot drying air within the enclosed environment [4]. Saturated air in the canopy is released to the atmosphere via a vent near the top of the canopy cover. The objective of the present study is to evaluate the performance of the flatbed box dryer, with the canopy cover on top, for drying of kenaf and to analyse the costs of drying.

2. DRYING MECHANISM AND THEORY

During the drying process, heat is used to evaporate the moisture from the kenaf while a flow of air carries away the evaporated moisture. The two mechanisms involved in the drying process are (1) the migration of moisture from the interior of the kenaf leaves and stems to the surfaces and (2) the evaporation of moisture from the surfaces to the surrounding air. The rate of drying is determined from the moisture content and the temperature of the kenaf and the temperature, the relative humidity and the velocity of the air in contact with the kenaf [2].

The capacity of air to remove moisture is principally dependent upon its initial temperature and humidity: the greater the temperature and the lower the humidity the greater is the moisture removal capacity of the air. The relationship between temperature, humidity and other thermodynamic properties can be represented by a psychometric chart [1].

3. METHODOLOGY AND MATERIALS

Drying tests were carried out on the flat bed box dryer that is commercially available in Malaysia. The box dryer has a 2.44 x 2.44 m (or 8 x 8 ft) perforated sheet floor above a plenum and can accommodate up to 38 cm (or 15 inches) depth of kenaf. The freshly harvested kenaf was chopped to 60 cm length mechanically and then loaded into the dryer. The weight of the kenaf was recorded (Plate 1), the top surface layer of the kenaf was levelled (Plate 2) and the canopy cover, with its air outlet vent fully opened, was placed over the box covering it completely. The kerosene burner was lighted to heat up the drying air from ambient temperatures to the pre-set plenum temperature (of 85°C in the first series of tests and to 70°C in the second series of tests. The amount of fuel used was recorded by topping up the fuel tank using a measuring cylinder. The heated air was forced through the kenaf from the plenum below the bed by a 30.5 cm (or 12 inch) diameter fan that is driven by a 0.75W motor.

Plate 1: Weighing the chopped kenaf before loading into the dryer box

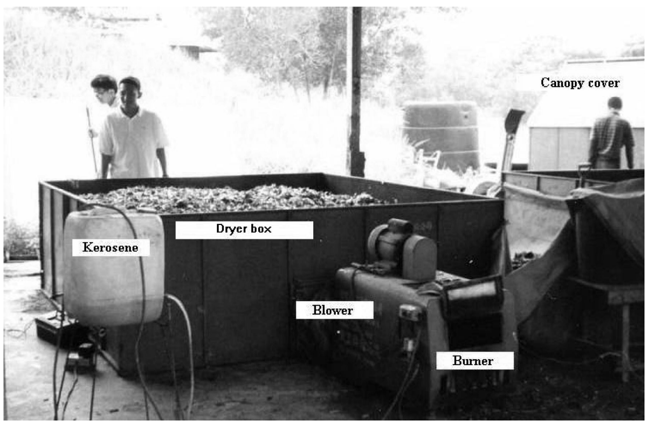

Plate 2: The box dryer and its components

The ambient air temperatures, plenum air temperatures, and drying air temperatures at selected 8 points in the dryer box were recorded at 2 hours intervals. Kenaf samples were taken from the same 8 points every 2 hours for determining the moisture contents using the infra-red moisture meter and using the oven-dry method. The canopy door was lifted up every 4 hours to stir the kenaf manually. The drying was continued until the moisture content of kenaf had dropped to about 8-9% (wet basis). The quality of the dried kenaf was assessed by the visual method.

4. RESULTS AND DISCUSSION

A. DRYING CURVES OF KENAF

The results of the kenaf drying tests in the flat bed box dryer with the canopy cover on top are summarised and presented in Figures 1 and 2. In the drying test with the burner hot air temperature set at 85˚C, 455.2 kg of kenaf at 66.56% moisture content was dried to 75 kg at 8.24% moisture content in 20 hours using 72.14 litres of kerosene. In another test in which the burner hot air temperature was set at 70˚C, 2,465 kg of kenaf at 80.25 % moisture content was dried to 68 kg at 8.3% moisture content in 24 hours using 55.15 litres of kerosene.

Referring to Figures 1 and 2, it can be seen that there was no drop in moisture content during the initial 4 hours of drying. This can be attributed to the phenomena of deep bed drying. As the hot dry air moved through the thick bed of kenaf in the box dryer, the hot unsaturated air absorbs moisture from the bottom layer of kenaf until it becomes saturated. Then as it moved through the remaining layers of kenaf material, the saturated air lost some of its moisture back to the upper layers of kenaf in the

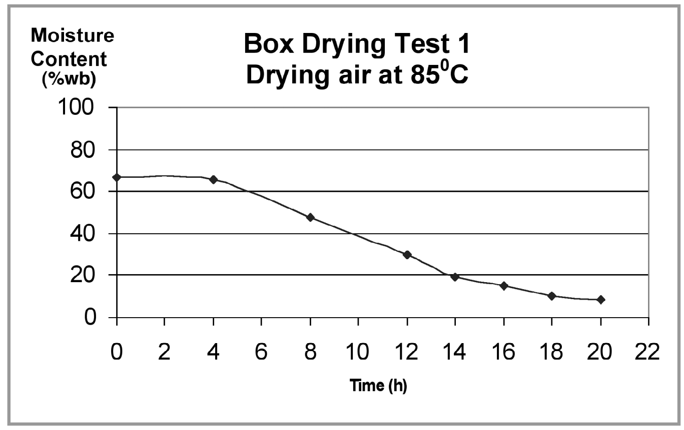

Figure 1: Typical drying curve when drying at 85ºC

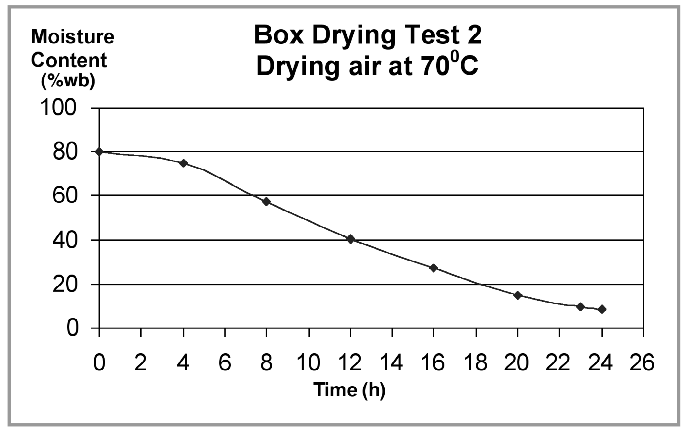

Figure 2: Typical drying curve when drying at 70˚C

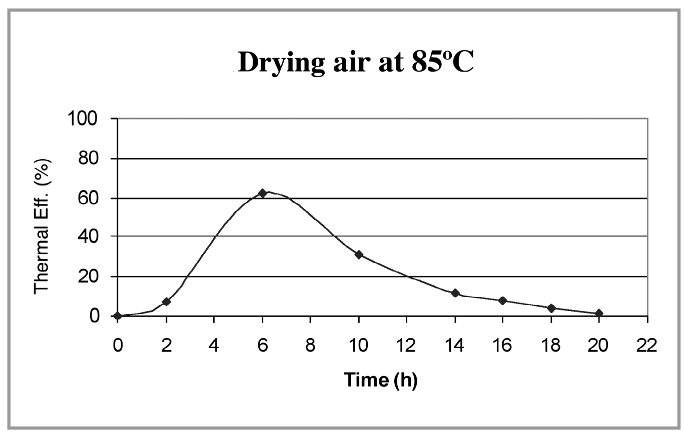

Figure 3: Thermal Efficiency curve when drying at 85˚C

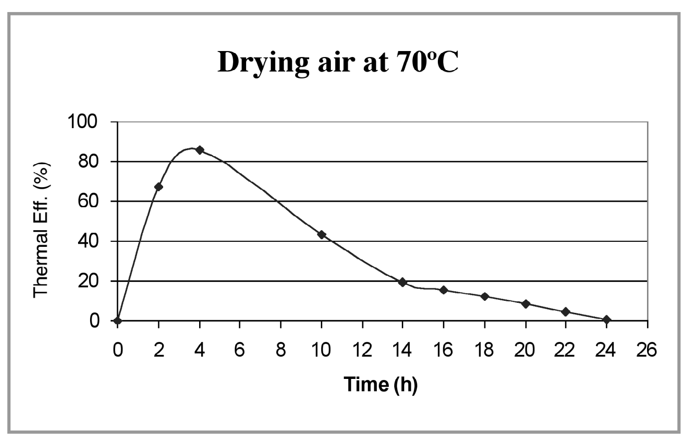

Figure 4: Thermal Efficiency curve when drying at 70˚C

box dryer. Thus, during the initial 4 hours of drying, there were 2 distinct drying zones within the dryer box, namely the drying zones and the rewetting zone. Manually stirring the kenaf materials at this stage (after 4 hour drying) removed the two distinct drying zones and created a uniform mixture of semi-wet and semi-dry kenaf materials throughout the box dryer.

After the initial 4 hours of drying (and the initial stirring), the drying rate becomes fairly constant before it starts to decrease quickly to almost zero to give an overall drying curve that was stretched-out-Z-shaped (refer to Figures 1 and 2). During the constant drying phase, there are three distinct drying zones within the box dryer. Drying took place within a discrete drying zone and below it is the dried zone where the kenaf material was in equilibrium with the air. Above the drying zone is the un-dried zone wherein the moisture content of the kenaf material remains unchanged. The manual stirring (at 4 hourly intervals) removed the three distinct drying zones and created a uniform mixture of dried and semi-dried kenaf materials throughout the box dryer each time.

Towards the last past part of the drying curve, the individual kenaf materials were losing moisture at a very much reduced rate until there was no more drop in moisture content. At this stage of drying, the moisture content of kenaf material had been reduced to fairly close to its equilibrium moisture content.

Theoretically, the kenaf materials are hydroscopic and they will lose or gain moisture until an equilibrium is reached with the surrounding air. The equilibrium moisture content is dependent on the relative humidity (RH) and the temperature of the drying air. The equilibrium moisture content represents the lowest possible moisture content that the kenaf materials can be dried to (for the given prevailing temperature and humidity of the drying air).

Further work is planned to analyse and evaluate theoretically the mass and heat transfer processing during kenaf drying in the box dryer. The present knowledge on the effect of kenaf moisture content, air temperature, air humidity and air flow on the evaporation rate of moisture from each leaf or stem is still not adequate. Empirical relationships can be used to predict the drying time but its accuracy is greatly inhibited by the variability of key drying parameters that are encountered in practice. For examples, the moisture content of the individual leaf and stem of kenaf varies considerably within a batch while the output heat from the burner varies with changes in ambient air temperature resulting in the variation in the temperature of the drying air (refer to Figures 5 and 6 in Appendix 2).

B. THERMAL EFFICIENCY OF KENAF DRYING

The thermal efficiency for a particular interval of time is computed from the ratio of the latent heat utilized to evaporate the moisture from the kenaf to the calorific heat value of the kerosene fuel used during the selected drying intervals. The thermal efficiency curves obtained are plotted and presented in Figures 5 and 6.

At the initial stages of drying, some of the heat supplied by the drying air was being used to raise the temperature of the kenaf materials and as a result the calculated thermal efficiency was low at the start of drying. The thermal efficiency reached its peak after 6 hours of drying when the drying air was set at 85˚C and reached its peak after 4 hours of drying when the drying air is set at 70˚C. The overall thermal efficiency when drying at 85˚C was 33.22% while the overall thermal efficiency when drying at 70˚C was 45.73%.

Further work is planned to modify the box dryer to increase its thermal efficiency by insulating the sides of the box dryer to reduce heat losses and by re-circulating the drying air during the later stages of drying. This latter may be done by installing a blower with a connecting canvas duct from the vertical side of the canopy cover to the plenum of the box dryer.

C. COST OF KENAF DRYING

An analysis of the fixed cost of the box dryer that is made up of 3 main components, namely, the kerosene burner, the blower and the dryer box, is presented in Appendix 1. The total fixed cost of the box dryer (inclusive of the repair and maintenance costs) was found to be RM2.49/h. Based on this value, the dryer fixed cost is computed and presented in Table 1.

The various direct variable costs incurred in the drying tests were calculated and tabulated. It was noted that the drying cost per ton of kenaf (dried weight) was actually lower when drying at 85˚C even though its overall thermal efficiency is lower. This was mainly due to the last part of drying, needed extra 4 hours of very inefficient drying at 70˚C where the thermal efficiency was less than 5% (refer to Figures 3 and 4). The total amount of water removed during the drying at 85oC was 380.2 kg while that during the drying at 70˚C was 397 kg. From these values, the average drying costs per kg of water removed were RM 0.47 and RM 0.46 for the two tests respectively.

Table 1: Summary of the costs of kenaf dring using the box dryer

	Drying air at 85˚C Drying time = 20 h Kerosene used = 72.14 litres	Drying air at 70˚C Drying time = 24 h Kerosene used = 55.15 litres
Dryer fixed cost @ RM 2.49/h	RM 49.80	RM 59.76
Fuel cost @ RM 1.00/litre	RM 72.14	RM 55.15
Electricity cost @ RM 0.20/h	RM 4.00	RM 4.80
Labour cost @ RM 2.00/h for 8 h	RM 16.00	RM 16.00
Overtime rate @ RM 3.00/h	RM 36.00	RM 48.00
Total drying cost	RM 177.94	RM 183.71
Drying cost /ton wet weight	RM 390.91	RM 395.08
Drying cost /ton dried weight	RM 2372.53	RM 2701.62
Drying cost /kg water removed	RM 0.47	RM 0.46

5. CONCLUSION

The overall thermal efficiency for the drying test with the burner hot air temperature set at 85˚C was about 33% while that for the drying test with the burner hot air temperature set at 70˚C was about 46%. The average drying cost per kg of water removed was RM 0.47 and RM 0.46 respectively.

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APPENDIX 1
ANALYSIS OF THE FIXED COSTS OF THE BOX DRYER

	Burner	Blower	Dryer Box	Total
Purchase Price (RM)	1,000.00	1,000.00	6,000.00	
Life (yr)	5	15	20	
Annual use (h/yr)	1000	1000	1000	
Salvage value(%)	10	10	8	
Interest(%)	10	10	10	
Depreciation (RM/yr)	180.00	60.00	276.00	
Capital Cost (RM/yr)	55.00	55.00	324.00	
Tax, Ins. Shelter (RM/yr)	30.00	30.00	180.00	
Annual Fixed Cost (RM/yr)	265.00	145.00	780.00	
Fixed Cost (RM/h)	0.27	0.15	0.78	1.19
Repair and Maintenance (RM/h)	0.50	0.20	0.60	1.30
Total Fixed Cost (RM/h)				2.49

Assumptions made:
The purchase prices of the 3 components of the box dryer are as shown above.
The economic life of the 3 components are as shown above
Salvage value = 10% of purchase price
Interest rate = 10% per annum
Depreciation = straight line
Tax, Insurance, Shelter = 3% of purchase price per annum
Repair and Maintenance = 5, 2 and 1% of purchase price per 100 hours for the burner, blower and dryer box respectively.

APPENDIX 2
DRYING PARAMETERS DURING KENAF DRYING

A. Drying parameters when drying air was set at 85˚C

	Drying Air Temp. (˚C)	Drying Air RH (%)	Exhaust Air Temp.(˚C)	Exhaust Air RH (%)
Average	78.2	18.57	54.6	42.83
Min	37.8	14.08	34.8	22.61
Max	92.3	64.13	81	99.87

The Temperature and RH (Relative Humidity) profiles recorded during the kenaf drying process are presented in Figure 5.

B. Drying parameters when drying air was set at 70˚C

	Drying Air Temp. (˚C)	Drying Air RH (%)	Exhaust Air Temp.(˚C)	Exhaust Air RH (%)
Average	65.2	27.4	44.5	78.5
Min	32.4	15.9	32.3	22.8
Max	84.0	68.5	67.3	100.0

The Temperature and RH (Relative Humidity) profiles recorded during the kenaf drying process are presented in Figure 6.

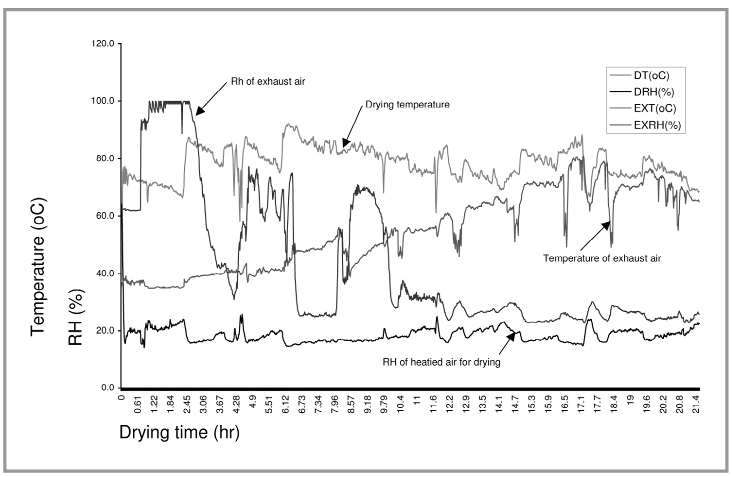

Figure 5: Temperature and RH profiles when drying at 80˚C

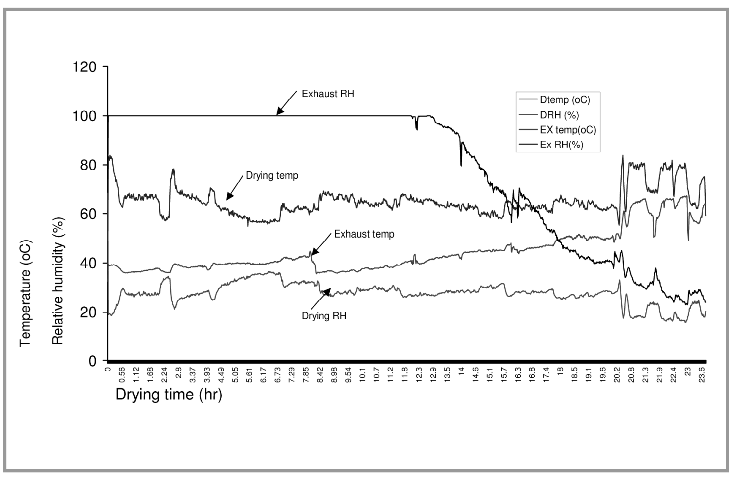

Figure 6: Temperature and RH profiles when drying at 70˚C

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PROFILES

Engr. Ooi Ho Seng
Ooi was the programme leader of the 5 kenaf drying projects that had been implemented under the National Kenaf Research Project that was funded by National Economic Action Council from February 2000 to September 2005. The paper was based on the reseach results of one of the above projects in which Ooi himself was the Project Leader from January 2003 to September 2005.

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