JAMES COOK UNIVERSITY

SCHOOL OF ENGINEERING

EG4011

THESIS PROPOSAL: DETERMINATION OF THE DRYING CHARACTERISTICS OF WET BAGASSE FOR THE USE IN BAGASSE DRYER DESIGN

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Contents

1.0 Introduction

The sugar industry represents a large portion of agriculture around the world, with production in approximately 115 countries, including Brazil, China, Australia, USA and India. In the 2009-10 sugar cane season, 1683 metric tonne of sugarcane was produced worldwide [1]. Sugar is mainly produced from sugarcane, grown mostly in tropical regions of the world. Sugar cane was originally produced as raw sugar for consumption as a food. In recent years, the sugar mills have expanded to include fuel and energy production.

The production of sugar includes 4 main stages; milling, juice clarification and treatment, crystallisation and centrifugal separation [1]. These are all relatively energy intensive processes, relying heavily on a steady supply of steam. There are a number of by-products and solid wastes created during the production of raw sugar. These are bagasse, bagasse fly-ash, sugar cane trash, press mud and molasses. Bagasse is a by-product of the milling process.

Bagasse is a heterogeneous material, consisting of three components, pith, fibre and rind mixed in different proportions. There is considerable difference in the shapes and sizes of each of these components. Pith can be modelled as a spherical particle, fibre as a cylindrical particle and rind as a rectangular shape. Bagasse typically leaves the milling process at 48% moisture content [2].

In sugar industries, bagasse is used as a fuel to the boilers in order to generate steam and electricity. Surplus electricity generated is termed cogeneration and is an important revenue source for sugar industry. This is the most favourable environmental process for utilising bagasse, representing well in life cycle assessment in categories of greenhouse gas emissions, acidification, non-renewable energy input, human toxicity and summer smog [1]. Bagasse is produced in such an excessive amount, that there is a strong driving force to find methods of utilisation. In the past, bagasse has been used as a pulp in the production of paper, as polymer filler [3], landfilling and anaerobic decomposition in a reactor with biogas production.

The following factors contribute to the optimisation of the production of surplus electricity: Bagasse% of cane, fibre % of cane, moisture % of bagasse, boiler efficiency, process steam consumption and electricity consumption in the mill. In optimising the cogeneration process, the calorific value of bagasse is the thermal property of interest. The gross calorific value of bagasse varies significantly with moisture content. With the introduction of cogeneration into sugar mills, methods to optimize the amount of energy extracted from bagasse are required.

It is clearly evident from literature that moisture content greatly contributes to the amount of energy available for electricity and steam generation. Drying bagasse has the potential to increase this amount of available energy has been identified as a potential means to improve the amount of electricity and steam generated [4]. The overall boiler steam production per kilogram of bagasse can be increased by 14 to 22% [5] by reducing the moisture content of bagasse from 50 to 35% via a bagasse dryer.

There are many different methods for the drying of bagasse. These include, flash dryers, superheated steam dryers, rotary dryers and cyclonic dryers. Drying mediums include flue gas and excess steam. Rotary Flighted dryers are advantageous as they can handle a large range of particle sizes; they have a high capacity and have good drying rates. Gilberd (2012) stated that rotary dryers stood out as a favourite for drying bagasse when compared to other types of dryers during dryer design.

In order to design an industrial dryer, key parameters are required. A drying rate model for bagasse is a model of the rate at which the unbound moisture content will change over time during drying called the drying rate model. In flighted rotary dryers the parameters needed for this design model are the angle of repose, bulk density, consolidated density and clump size. The angle of repose is an important property for characterising the loading or holdup inside the flighted rotary dryer drum and the flight unloading profiles. The drying rate depends on clump size and is essential to predicting residence time, drum size and operation characteristics. It is also influenced by the properties of the drying medium.

There is no current drying rate model for bagasse due to a lack in experimental data creating a gap in literature. In order to completely facilitate bagasse dryer design, a drying rate model and various physical properties of bagasse are required. The purpose of this thesis is to conduct a series of experiments to:

- Obtain a drying rate model and characterise the required physical properties of bagasse to facilitate dryer design.

2.0 Literature Review

The following literature review provides a basic understanding of the characteristics of bagasse, the features and relevance of a drying rate model and the techniques used to obtain such rates.

2.1 Bagasse

2.1.1 Physical and Chemical Properties

Bagasse is the heterogeneous, fibrous residue obtained from sugarcane juice extraction (milling process) and consists of cellulose (50%), hemicellulose (25%) and lignin (25%) [6]. It can be subdivided into three components, pith, fibre and rind each with a considerable difference in their shape and size. Pith is a small, spongy, dust like particle found in the centre of sugar cane. It constitutes approximately 5% of a typical sample of bagasse [2]. Pith can be modelled as a spherical particle, with a near unity width/length ratio. Fibre is the inner flesh of the cane stalk, making up 73% of typical bagasse sample. Fibre can be modelled as a cylindrical string like particle. The rind is the outer shell of a sugar cane stalk and is hard, thin and can contain adjacent fibre particles on the inner wall. Rind is characterised as a rectangular shape. Bagasse has a skeletal density (dry solid) of 1470 $\pm$ 30 kg/m^3 and a bulk density of 492 $\pm$ 15 kg/m^3. The bulk density includes void space, which constitutes 66% of the total particle volume [2]. A typical bagasse sample can be seen in Figure 2.1.

Figure 2.1: Photograph of a typical bagasse sample.

Another physical characteristic of bagasse is the angle of repose. During the rotary drum drying process, the material is collected in the bottom section of the drum by the lifting flights, rotates around and then cascades from the top half of the drum. This period of cascading is known as the falling rate period and is characterised as the period in which drying occurs. Figure 2.2 shows a cross sectional view of a flighted rotary dryer where the particles in the falling rate period are coloured in red and the other particles are purple.

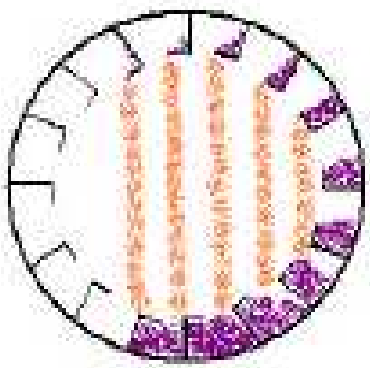

Figure 2.2: Cross-sectional view of a flighted rotary drum.

In any one flight the particles will cascade from the flight edge when the angle of the plane of the particles at the flight edge is greater than the angle of repose [7]. This can be demonstrated in Figure 2.3, where the flight is outlined in blue and the material is the grey shaded area. The angle of repose of a material is assumed to have a linear relationship with the moisture content [8].

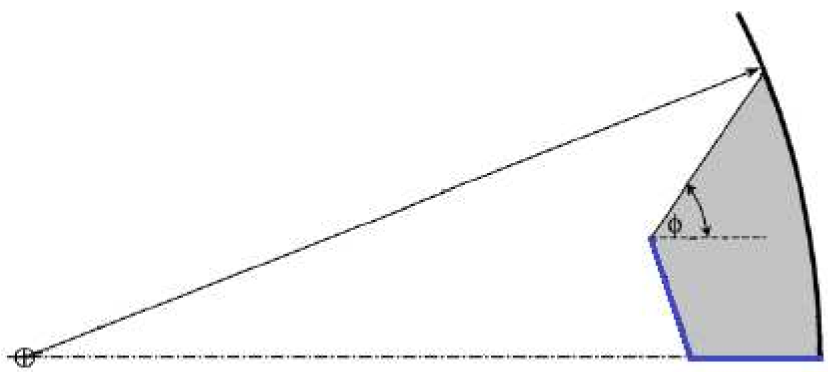

Figure 2.3: Flight discharge position demonstrating angle of repose (ϕ) *[8]*.

Bagasse typically exits the milling process at 48% moisture content [2]. The most dominant chemical components of bagasse are carbon, nitrogen, hydrogen, oxygen, chlorine and sulphur. This composition varies according to region and cane type. A typical ultimate composition of bagasse is shown below in Table 2.1.

Table 2.1: Ultimate Composition of Bagasse *[9]*.

Component	Composition (% dry basis)
C	48.10
H	5.90
N	0.15
O	42.40
Cl	0.07
S	0.02

2.1.2 Thermal Properties

The thermal properties of bagasse are the properties related to the materials ability to perform as a fuel. The properties that are relevant to bagasse dryer design are the heat capacity of the fibre and the heating values of bagasse. The heat capacity of the fibre can be calculated using the Equation 1 [10]:

$$C_p = 0.266 + 0.00116T \tag{1}$$

where Cp is the heat capacity (kJ/kgK) and T is the temperature (K).

The energetic content of bagasse is represented by a calorific value of heating value. It is evident from Table 2.2 demonstrates how the energy content of bagasse decreases with increasing moisture content.

Table 2.2: Moisture content of bagasse and relative calorific values *[1] [11]*.

Moisture Content (%)	Calorific Value (kJ/kg)
0	19,250
35	12,386
48	9,950

2.2 Drying rate models

Unbound moisture in a material can be removed via evaporation or vaporisation. Both moisture removal mechanisms can be modelled by the drying rate. This is essential information to be able to design bagasse dryers. The drying phenomenon of biological products during the falling rate period (cascading particles inside dryer drum) can be controlled by diffusion, the thin layer model and the Reaction Engineering Approach.

2.2.1 Drying Theory

The drying of a material, inside a dryer, occurs in three stages. During the first stage, the material is dried via vaporisation, that is, a warm gas is passed over the material and free surface moisture transfers from the material into the gas (convection). The rate controlling step here is the diffusion of the water vapour across the gas-moisture interface [12]. Figure 2.4 demonstrates the drying mechanisms for the first stage of drying.

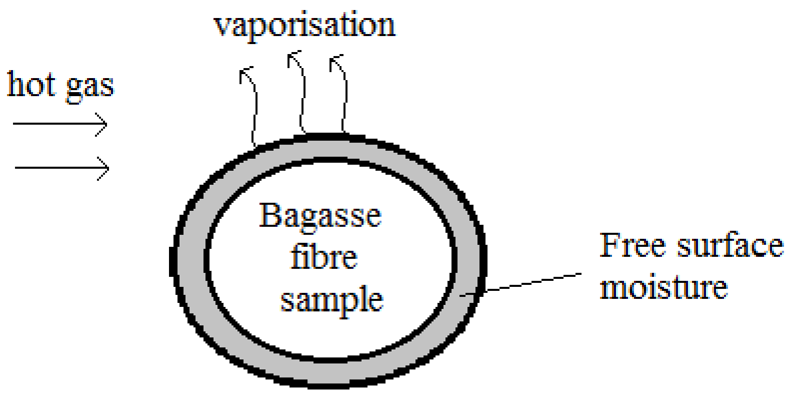

Figure 2.4: Schematic of drying mechanism for first stage of drying.

The vaporisation can be modelled by the thin layer drying model in Equation 2:

$$\frac{dm}{dt} = hA\Delta P \tag{2}$$

Where h is the mass transfer coefficient of the material (m/s), A is the surface area (m^2) and ΔP is the pressure difference between the gas and the thin film of moisture (Pa).

The second stage of drying utilises evaporation to remove the remaining surface film moisture. Evaporation occurs when the vapour pressure of the moisture on the solid surface is equal to the atmospheric pressure [12]. This denotes the first part of the falling rate period. Figure 2.5 demonstrates this mechanism.

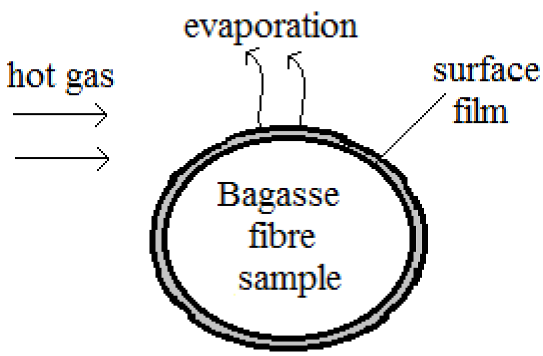

Figure 2.5: Schematic of drying mechanism for the second stage of drying.

The last stage of during characterises the moisture removal from within the solid through to the surface. The rate determining step here is the diffusion of moisture from the inside to the surface and the mass transfer from the surface [12]. Figure 2.6 shows the schematic view of the mechanisms involved in this stage.

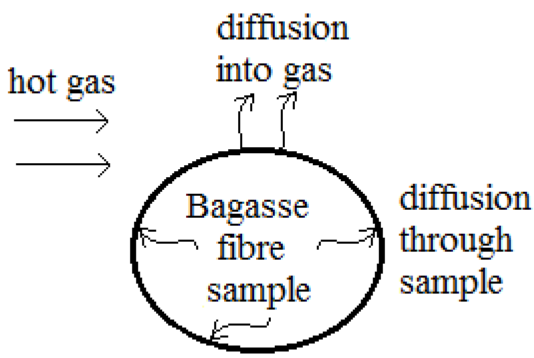

Figure 2.6: Schematic of drying mechanism for the third stage of drying.

The diffusion of the moisture through the sample and into the surrounding gas is modelled by Fick's Second Law shown in Equation 3 [11].

$$\frac{\partial M}{\partial t} = D\Delta^2 M \tag{3}$$

The overall drying rate curve can be seen in figure 2.7. This graph demonstrates when each stage occurs during the drying process.

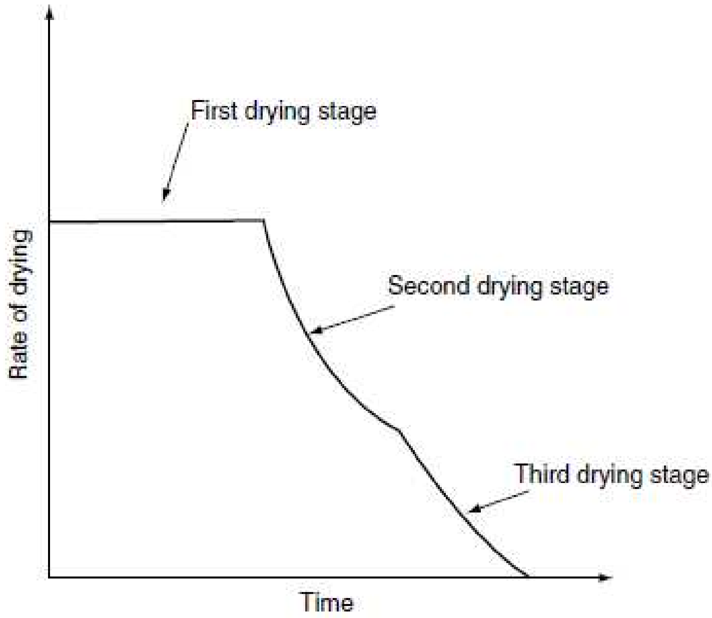

Figure 2.7: Typical drying rate curve *[12]*.

An alternative approach to modelling the drying rate of bagasse is the Reaction Engineering Approach (REA). It visualises drying as an activation-energy-based process that can be applied for thin slabs or single droplets. It was based on the concept that evaporation is an activation process that has to overcome an energy barrier for the removal of moisture to occur. Each material will have a material-specific activation energy curve that relates the driving force for drying as a function of average material moisture. The drying rate (kg/s) using the REA model is demonstrated by Equation 4 [13]:

$$\frac{dm}{dt} = -h_m A \left[\rho_{v,sat} \exp\left(-\frac{\Delta E_v}{RT_d}\right) - \rho_{v,b}\right] \tag{4}$$

where h_m is the mass transfer coefficient (m/s), A is the surface area of the slab (m^2), $\rho_{v,sat}$ and $\rho_{v,b}$ represent the vapour density (kg/m^3) at the slab surface and at the bulk air, respectively, ΔE_v is the activation energy of evaporation (J/kmol), R is the gas constant (8314 J/(kmol K)) and T_d is the drying temperature (K). This is different to diffusion and thin layer drying as it demonstrates the drying rate as a function of temperature [13].

2.2.2 Empirical

There are many different types of empirical drying rate models. They are typically derived by simplifying general series solutions of Fick's second law (Equation 3). Analogous to Newton's Law of cooling, Equation 5 shows Page's Model [11]:

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt^n) \quad (5)$$

Equation 6 shows the Modified Page Model:

$$MR = \frac{M - M_e}{M_0 - M_e} = \exp(-kt)^n \quad (6)$$

Empirical models derive a direct relationship between average moisture content and drying time. They neglect the fundamentals of the drying process and therefore their parameters have no physical meaning. Although they may not be able to give an indication of the important processes occurring during drying, they do describe the drying rate of that material under those particular experimental conditions [11].

2.3 Fibre Drying Rates

Information on combustion of bagasse can be found quite easily, however, experimental data for determining the physical properties of bagasse is scarce in literature. It has not been extensively researched and therefore there is limited data available for verification of the geometric model of a bagasse dryer. The following outlines an experiment that was found in literature on the thin layer drying of olive bagasse.

Friere et al (2001) conducted a series of experiments to determine the drying rate of olive bagasse with experimental conditions outlined in Table 2.3.

Table 2.3: Parameters and range of values used to find the drying rate of olive bagasse.

Parameter	**Range**
Flue gas temperature	125-250°C
Relative humidity	<1%
Gas velocities	0.5-2.0 m/s

The drying rate of olive bagasse was modelled in this experiment using Fick's Law (Equation 3) of diffusion to describe the internal moisture transfer during the falling rate period. The initial moisture content values were obtained by analysing a subsample of each sample before commencing the drying experiment. This was done using a stove at $110 \pm$

1°C over a 48 hour period. It was noted in the drying rate experiments that pyrolysis of bagasse occurs at 240°C and therefore the dryer should not operate beyond this point.

Results from the above experiment provide the following conclusions:

- Higher drying rates are obtained with smaller granularities.
- The entire drying process takes place in the falling rate period.
- The rate of moisture removed was observed to be larger at higher temperatures, verified for all velocities and granularities.
- The experimental results are valid across the entire range of temperatures with the implication of a critical gas velocity (point at which the drying rate is no longer dependant on velocity).
- Gas temperature was noted to be the parameter with the most pronounced effect on the drying kinetics.

In conclusion, it was found that olive bagasse drying may be interpreted using Fick's Law of diffusion [14].

2.4 Conclusion

It has been identified that there is little knowledge of the drying rate of bagasse and relevant physical property data required for bagasse dryer design. A series of experiments will be conducted in order to fill this gap in literature. Experimental procedures and results for similar materials will be used a s a rough outline for the methodology of these experiments.

3.0 Methodology

It was identified that there is need for experimental data pertaining to the drying rate model of bagasse and a number of physical property data in order to verify the bagasse dryer model. The following section outlines the experimental approaches that will be taken in order to collect this data.

3.1 Bagasse Material Properties

The physical properties that will be determined in this thesis are:

- the angle of repose of bagasse (ϕ)
- the drying rate of bagasse (dm/dt)

- clump characteristics of bagasse
- bulk density of bagasse (ρ_b)
- consolidated density of bagasse (ρ_{cons})

3.1.1 Sample Preparation

The bagasse used in the following experiments will be sourced fresh from Pioneer Mill during the crush season. It will be sampled via the cone and quartering method so as to produce reliable results. This technique requires the bagasse to be formed into a cone shaped heap on a flat surface, flattened with a spatula and divided into four identical volumes. One portion is taken and the entire procedure is repeated until only 1/16 of the original mass remains as seen in figure 3.1. This method is heavily operator dependant and is only suitable for materials with poor flow behaviour and thus little segregation [15]. This technique will be utilised throughout all of the experiments.

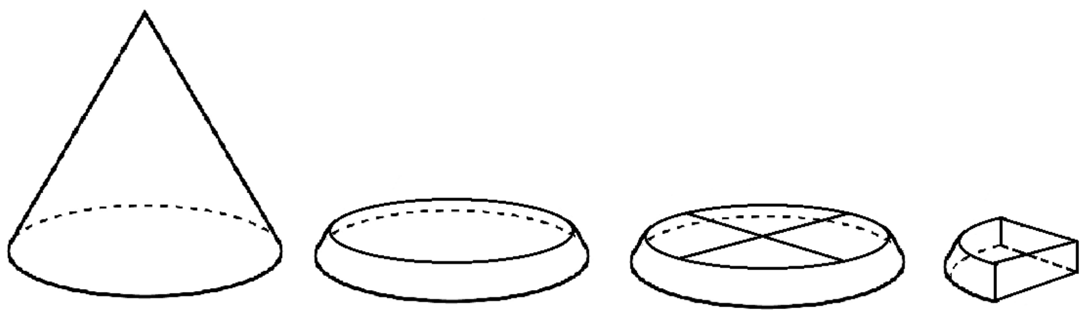

Figure 3.1: Cone and quartering sampling technique.

3.1.2 Density of Bagasse

Finding the bulk ρ_b and consolidated density ρ_{cons} of bagasse (kg/m^3) is a simple experiment using a bucket. The bulk density can be found by tarring the weight of a bucket, filling it with bagasse and recording its mass. This density will include the air voids between bagasse particles. The consolidated density is conducted in a similar manner; however this time the bucket is tapped on the side in order to remove some of the air voids. Both density values will be found at varying moisture contents ranging from 50-38%. Each sample will also be put into the small rotary drum and then photographed. This will determine the drum density. All three density types are required for bagasse dryer modelling.

3.2 Flighted Rotary Drum

The flighted rotary drum, featured in figure 3.2, will be used to determine the angle of repose, the clump size, and also to verify the design loading of the drum. The geometric configuration of the flighted rotary drum is described in Table 3.1.

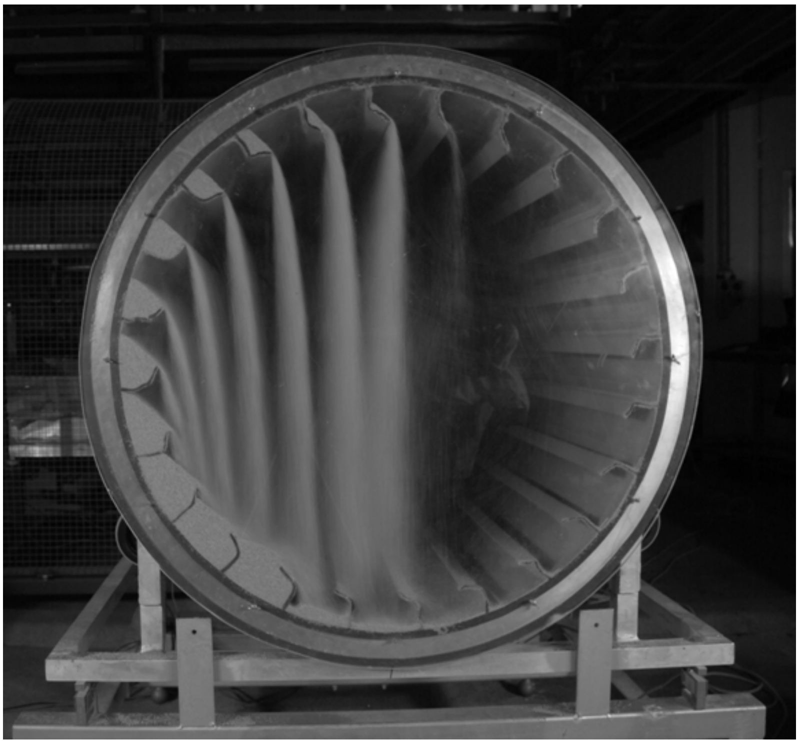

Figure 3.2: Photograph of the pilot scale flighted rotary drum.

Table 3.1: Geometric configuration of the pilot scale flighted rotary drum.

Parameter	Value
Length of Dryer	1.15 m
Radius of dryer	0.375 m
Flight base length	0.033 m
Flight tip length	0.030 m
Flight base angle	90°
Flight tip angle	124°
Flight thickness	0.002 m
Number of flights	24

3.2.1 Angle of Repose

An important characteristic of a material, when modelling its drying behaviour, is the angle of repose which is a function of the moisture content of the material. To find the angle of repose of bagasse, 10 samples with known initial moisture content will be placed inside the pilot scale flighted rotary drum shown in figure 3.2. A photo image will be taken at different moisture contents in the range of 35-50% and analysed using ImageJ Software. The drum will have a fixed rotational speed of 3 rpm for all 10 samples. Table 3.2 shows the measured variables involved for the determination of the angle of repose.

Table 3.2: Measured variables for angle of repose experiments.

Moisture content (%)	50	48	46	44	42	40	38
Results	Photo	Photo	Photo	Photo	Photo	Photo	Photo
Angle of Repose (°)							

3.2.2 Clump Size

Clump size (function of moisture content) is also an important characteristic of bagasse that is found using the flighted rotary dryer. A sample of bagasse will be placed inside the flighted rotary drum and photographs of frontend taken. The photos will be analysed to determine the clump size. These clumps will then be taken and analysed further using an oven. This is to investigate the drying rate of different clump sizes of bagasse. This parameter plays a large role in bagasse dryer design.

3.2.3 Design Loading

The design loading for the drum is determined using the geometric model [16] to decide on a pre-loading value according to equation 7 [17]:

$$M_{design}^{TOT} = \left(1.24\left(2 \times \sum_{f}^{n} M_i\right) - M_{FUF}\right)(1 - \mathcal{R}) \tag{7}$$

The design loading is a function of angle of repose. Because this angle is unknown at this stage, the design loading is determined experimentally. The drum will be loaded with 32kg of bagasse and increased incrementally to 44kg. The drum will be photographed and analysed to find the position of the first unloading flight (FUF). Design loading is achieved when the FUF occurs at the 9 o'clock position. Figure 3.3 shows an under-loaded drum, a design loaded drum and an over-loaded drum. Rotational speed will be fixed at 3rpm and the moisture content of the bagasse fixed at 48%..

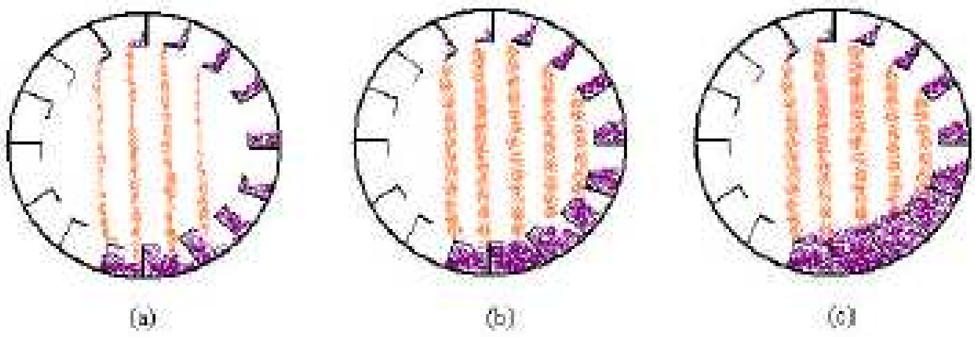

Figure 3.3: (a) under-loaded dryer (b) design loaded dryer (c) over loaded dryer.

3.2.4 Photo Imagery

In order to analyse the rotating material to deduce an angle of repose and clump size, photos will be taken during the experiment. This will be done using a Nikon D80 camera on a tripod stand with the focus settings of focal length 18mm and aperture size of 3.5. Shutter speed of 1/60s in continuous operation mode and in grayscale (2592x3872pixels). There will also be lighting provided to assist with image quality. There will be six 500W spotlights on a tripod with the rest of the room blacked out. The front of the drum will be covered with a polished Perspex plate (5mm thickness) with a black screen used on back of dryer so as not to capture any background images. The drum will also be on an inclination angle of 0°. These photos will be analysed using ImageJ Software.

3.2.5 ImageJ Software

ImageJ Software is a Java-based image processing program designed to display, edit, process, save, and print 8-bit colour and grayscale, 16-bit integer and 32-bit floating point images. It can also measure distances and angles as well as create density histograms. This software will be used to analyse the photo images produced in any of the experiments.

3.3 Drying Rate

In order to measure moisture content (function of clump size) and drying rates, a Sartorius Moisture Analyser, oven and a large capacity drying oven will be utilised. Each of these devices measures the moisture content of the bagasse using the thermo gravimetric method, moisture content is determined directly as a weight loss registered during the drying routine. The experiments will start with the bagasse samples re-wetted as necessary to as close to 48-50% moisture content. Samples will be dried until there is no further loss of moisture. However the region of interest is 50-35%. It is important to note that the three different moisture analysis devices will use different sized samples as they have different drying capacities and mechanisms.

3.3.1 Initial Moisture Content

The moisture content of 10 samples of bagasse will be recorded using the Sartorius device to evaluate the reliability of achieving desired moisture content. Moisture will be added to the samples via a spray bottle to reach pre-defined moisture content. The mass of bagasse and volume of water added will be recorded, and the moisture content of the samples will be re-analysed.

3.3.2 Sartorius Moisture Analyser

The Sartorius moisture analyser, shown in figure 3.3, provides a quick and reliable determination of the moisture content of materials. The device utilises infrared rays to penetrate the sample where the rays are converted into heat energy. Using conductive heat transfer, moisture is removed from the sample. In this process, the sample is weighed before and after being heated and the difference is calculated [18]. Table 3.3 outlines the parameters of the experiment.

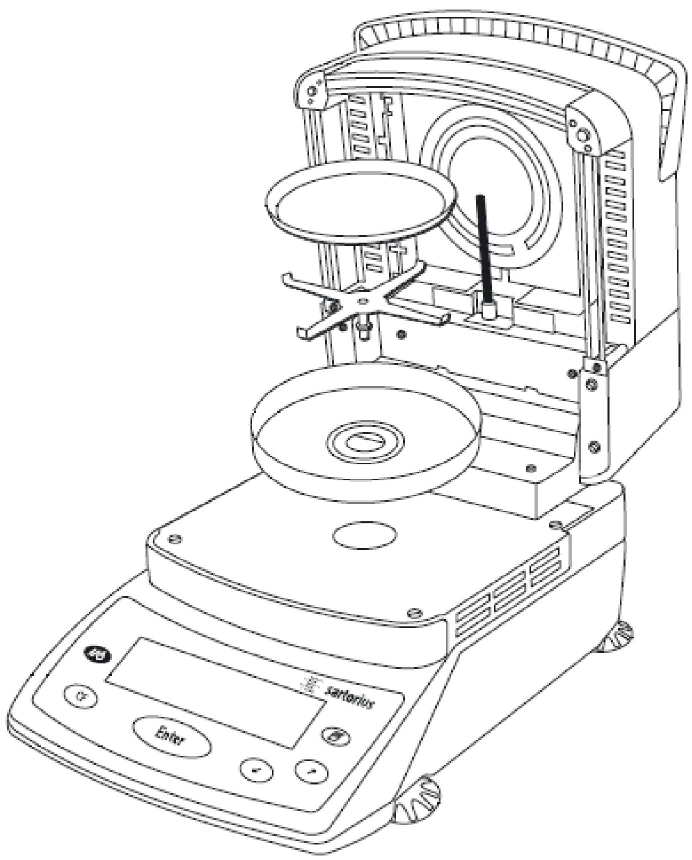

Figure 3.4: Schematic view of the Sartorius moisture analyser.

Table 3.3: Parameters for Sartorius Moisture Analyser.

Parameter	**Value**
Number of samples	30
Duration of each sample	15 minutes
Sample size	10g, 3mm
Temperature	80-100°C

3.3.3 Oven

The mechanism for dying inside an oven is convective heat transfer. An atmosphere of hot air inside the oven causes the moisture to diffuse away from the surface of the sample. The temperature used in the oven drying experiments will be 110°C according to experiments conducted Freire et al 2001. To avoid pyrolysis of bagasse, temperature will not exceed 240°C.

A clump of bagasse, identified by image analysis in the flighted rotary drum in section 3.3, will be placed inside the oven with known initial moisture content. The sample will be left to dry for 2 hours until no moisture is left in the sample. The moisture content is manually tracked and weighed at regular time intervals. Data points will be collected more frequently at the beginning of the experiment as the range of interest is 50-35% moisture content. 10 samples will be analysed to determine the drying rate of different clump sizes. Table 3.4 is an indication of the data collected in the oven based drying experiments.

Table 3.4: Measured variables in oven drying rate experiments.

Time (s)					
Weight of sample (g)					

3.3.4 Large Capacity Drying Oven

The Large Capacity Drying Oven (based on the old Spencer Oven), shown in figure 3.5, is a moisture analysis device located inside the laboratory onsite at a sugar mill. Bagasse is placed in a cylindrical container measuring approximately 11inches by 7inches in diameter, the base of which is covered by a layer of 22mesh gauze supporting 100mesh gauze. The container is filled with a 1kg sample of bagasse and dried at a temperature of 110°C. The canisters are weighed back hot at a chosen time interval until the weight loss is less than 2g per 30minutes as outlined in the laboratory manual [19]. One experiment is estimated to take 3-4 hours. The containers are weighed back while they are still hot. Experiment repeated for 10 samples.

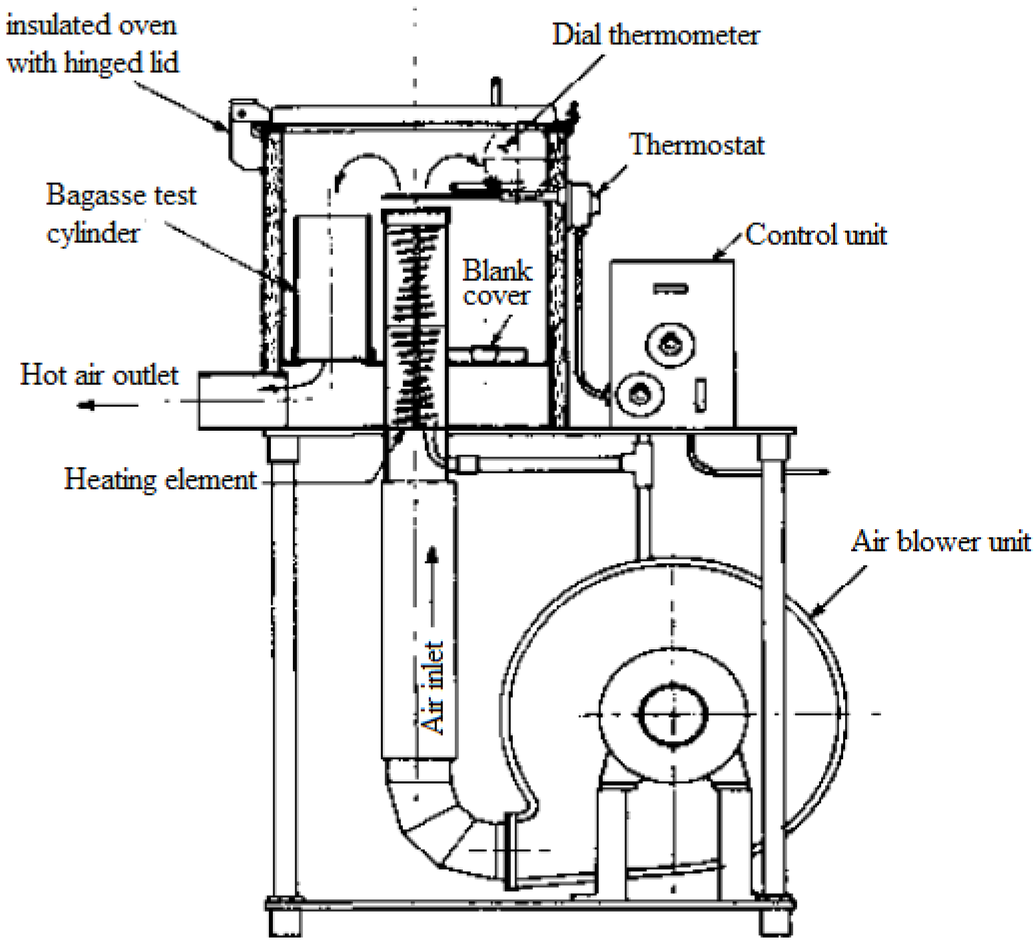

Figure 3.5: Schematic of Large Capacity Drying Oven.

3.4 Data Reliability

The most important part to an experiment is the analysis of the results. In order for the results to be entirely representative of the experiment and supporting theory, the standard deviation and related uncertainties need to be addressed. In an experimental sense, this pertains to the repeatability and reproducibility of the results.

3.4.1 Statistical Analysis

The two components of the test method are reproducibility and repeatability. Reproducibility is the ability of an entire experiment or study to be reproduced, or by someone else working independently. Repeatability is the degree of agreement of test or measurements on replicate specimens with the same observer in the same laboratory. Both of these components are reported as standard deviations. The standard deviation shows how much variation exists from the average value, that is, error propagation of the results. In order to achieve repeatability, each experiment is carried out across at least 10 samples.

3.4.2 Regression Analysis

Regression analysis is a statistical technique for estimating the relationship between variables, more specifically the relationship between an independent and dependent variable. This is done by fitting a curve to experimental data. The experimental data obtained from the moisture analysis of bagasse will be analysed using regression in order to find a drying rate model for bagasse. The coefficient of determination (R^2) is used to indicate how well the equation of fit, fits the experimental data. An R^2 value of one means that it fits the data perfectly and an R^2 value of zero mean that the curve does not fit the experimental data at all.

4.0 Project Management Plan

A project management plan sets out the stages of the project according to the proposed methods and indicates the resource issues related to each aspect of the plan. It involves a timeline, resource planning, risk assessment and a cost analysis of the project.

4.1 Timeline

A timeline of the methods proposed in this thesis have been arranged in a Gantt chart in figure 7.1 in Appendix A. This chart provides an indication of the duration of each task and also provides information on the relationship between tasks.

4.2 Resource planning

The bagasse is supplied fresh form the Pioneer Mill and therefore it relies entirely upon the sugar cane crush season. Experiments involving the flighted rotary drum and the drying rate determination cannot begin until this fresh bagasse has been supplied. In the situation where the crush is majorly affected, there is an available supply of stockpiled bagasse. Using this will dramatically reduce the quality of the results. The experiments conducted using the large capacity drying oven is heavily reliant on Pioneer Sugar Mill. These experiments will need to be conducted at their onsite laboratory including site inductions, which requires planning around various people’s schedules. This will be a task that will need to be planned well in advance where repeats of experiments may not be viable.

4.3 Risk Assessment

Risk Assessments are to be carried out before conducting any experiments. They are used in order to assess all associated hazards and potential risks. Figure 7.2 in Appendix A is a copy of the risk assessment completed for the Sartorius moisture analyser. Additional risk assessments will need to be carried out for the flighted rotary drum and ovens.

4.4 Cost Analysis

This thesis is conducted in conjunction with Sucrogen. They will supply the fresh bagasse required for all my experiments. All software required for the analysis of the results is available free of charge online. Any additional costs, such as laboratory equipment, can be covered by the thesis account.

5.0 Conclusion

Bagasse has the capacity to be used effectively for cogeneration. The drying of bagasse has been identified as the most viable method. Bagasse dryer design is currently being undertaken where physical property data and drying rate information is required for model validation. This is experimental data is not currently available in literature; however, the above methodologies will be able to produce such data.

6.0 Reference List

[1] M. K. Chauhan, S. Chaudhary, V. S. and S. Kumar, "Life cycle assessment of sugar industry: A review," *Renewable and Sustainable Energy Reviews,* pp. 3445-3453, 2011.

[2] M. G. Rasul, V. Rudolph and M. Carsky, "Physical Properties of Bagasse," *Fuel,* pp. 905-910, 1999.

[3] R. L. Quirino and R. C. Larock, "Sugarcane Bagasse Composites from Vegetable Oils," *Journal of Applied Polymer Science,* vol. 126, pp. 860-869, 2012.

[4] J. H. Sosa-Arnao and S. A. Nebra, "Bagasse Dryer Role in the Energy Recovery of Water Tube Boilers," *Drying Technology,* vol. 27, pp. 587-594, 2009.

[5] J. Gilberd, "Bagasse Dryer Design and Operational Modelling of Sugar Mill Boiler Systems," *James Cook University Thesis* , pp. 1-69, 2012.

[6] M. Balakrishnan and V. S. Batra, "Valorization of solid waste in sugar factories with possible applications in India :," *Journal of Environmental Management,* no. 92, pp. 2886-2891, 2011.

[7] J. Kelly, "Flight Design in Rotary Dryers," *Drying Technology: An International Journal,* vol. 10, no. 4, pp. 979-993, 1992.

[8] P. F. Britton, M. E. Sheehan and P. A. Schneider, "A physical Description of Solids Transport in Flighted Rotary Dryers," *Powder Technology,* pp. 153-160, 2006.

[9] L. Wilson, W. Yang, W. Blasiak, G. R. John and C. F. Mhilu, "Thermal characterization of tropical biomass feedstocks," *Energy Conversion and Management,* vol. 52, pp. 191-198, 2011.

[10] E. Hugot, "Handbook of Cane Sugar Engineering," *Elsevier,* 1986.

[11] B. Vijayaraj, R. Saravanan and S. Renganarayanan, "Studies on Thin Layer Drying of Bagasse," *International Jornal of Energy Research,* pp. 422-437, 2006.

[12] C. W. Hall , Handbook of Industrial Drying, Taylor & Francis Group, 2006.

[13] N. Fu, M. W. Woo, S. X. Q. Lin, Z. Zhou and X. D. Chen, "Reaction Engineering Approach (REA) to model the drying kinetics of droplets with different initial sizes - experiments and analyses," *Chemical Engineering Science,* vol. 66, pp. 1738-1747, 2011.

[14] F. Friere, A. Figueiredo and P. Ferrao, "Modelling high temperature, thin layer, drying kinetics of olive bagasse," *Journal of Agricultural Engineeirng Research,* vol. 78, no. 4, pp. 397-406, 2001.

[15] "es cubed Limited - Particle Technology," [Online]. Available: http://www.escubed.co.uk/sites/default/files/particle_size_analysis_%28an003%29_sampling_techniques.pdf. [Accessed 7 May 2013].

[16] A. Lee, "Modelling the Solids Transport Phenomena Within Flighted Rotary Dryers," *Doctor of Philosophy (Engineering),* vol. 1, 12th 2008 November.

[17] O. O. Ajayi and M. E. Sheehan, "Design loading of free flowing and cohesive solids in flighted rotary dryers," *Chemical Engineering Science,* vol. 73, pp. 400-411, 2012.

[18] Sartorius Weighing Technology GmbH, *Operating Instructions - Sartorius Moisture Analyser,* 37075 Goettingen, Germany: Sartorius Weighing Technology GmbH, 2012.

[19] BUREAU OF SUGAR EXPERIMENT STATIONS QUT, *Laboratory Manuals for Queensland Sugar Mills,* Brisbane: WATSON, FERGUSON AND COMPANY, 1970.

[20] D. Revol, C. L. Briens and J. M. Chabagno, "The design of flighted rotary dryers," *Pwder Technology,* pp. 230-238, 2001.

[21] C. Wardjiman, A. Lee, M. Sheehan and M. Rhodes, "Behaviour of a curtain of particles falling through a horizontally-flowing gas stream," *Powder Technology,* pp. 110-118, 2008.

[22] M. Balakrishnan and V. S. Batra, "Valorization of solid waste in sugar factories with possible applications in India :," *Journal of Environmental Management,* pp. 2886-2891, 2011.

[23] M. M. Nassar, E. A. Ashour and S. S. Wahid, "Thermal Characteristics of Bagasse," *Journal of Applied Polymer Science,* vol. 61, pp. 885-890, 1996.

7.0 Appendix A

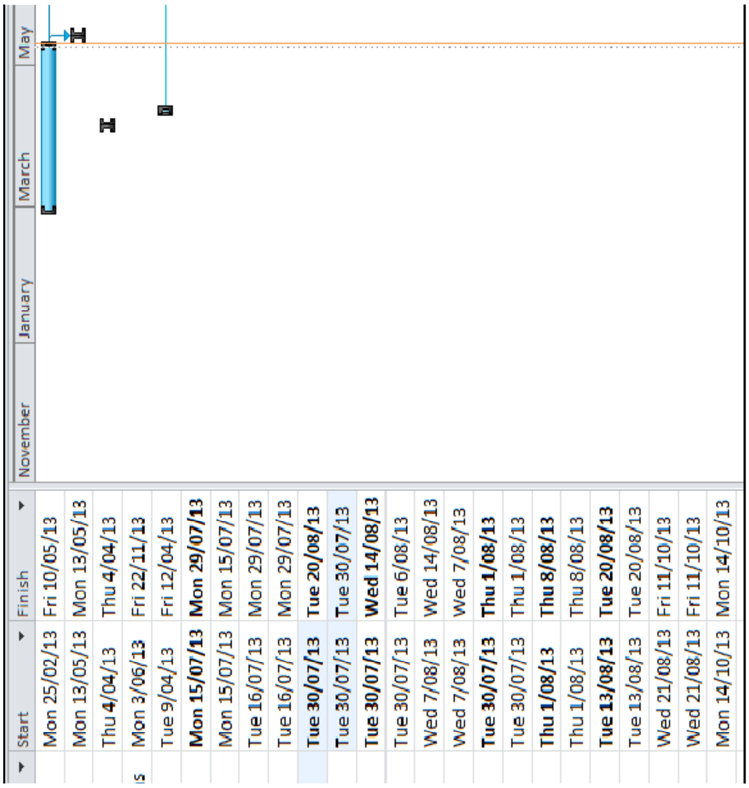

Figure 7.1: Gantt chart of overall Thesis Timeline.

JAMES COOK UNIVERSITY
AUSTRALIA

Townsville Campus
Townsville Qld 4811 Australia
School of Engineering & Physical Sciences

Risk Assessment
Name of Test: Moisture Analysis of Bagasse

Purpose: Thesis			
Operator: Angelina Jolie and Brad Pitt		**Duration:** 9/04/2013 – 30/11/2013	
SDS Attached: (Tick one)	Yes	No	N/A
Major Hazard Types: (Tick at least one)			
Chemical		Mechanical	
Electrical		Thermal	
Environmental		Other:	

SUMMARY OF RISKS

Specific Task/Activity	Potential Hazards/Consequences	Assessed Risk	Risk Control Measures	Reassessed Risk
Prepare Bagasse Sample	-Inhalation of small dust particles may damage health -Small dust particles could	MEDIUM	-Wear appropriate PPE -Conduct in well-ventilated area	LOW

	cause irritation if it gets caught in eye - Flammable solid if dry and ignited		-Use a deep container -Keep sample bagged up when not in use	
Drying Bagasse using Sartorius moisture analyser	-Flammable solid if dry and ignited -Inhalation of small dust particles may damage health -Small dust particles could cause irritation if it gets caught in eye	MEDIUM	-Isolate ignition sources -Conduct in well-ventilated area -Avoid contact with skin and eyes -Wear appropriate PPE -Use small samples only -Keep sample contained	LOW
Operating Sartorius Machine	-Electric shock	MEDIUM	-Equipment tagged and checked -Keep moisture away from electrical connection -Take care when operating machinery	LOW

SUMMARY OF REQUIREMENTS

Personal Protective Equipment	Gloves, safety glasses, lab coat, closed in shoes
Is Training Required **If YES, please state requirements**	Yes/No
Training Manual Location	

SUMMARY OF ACTIVITY

Preparing Bagasse Sample:

- Break up the compressed block of bagasse outside in a well-ventilated area, using gloves. Make sure this is done in a large, deep container.
- Divide the bagasse into small samples utilising the correct techniques.

Determining Moisture Content of Bagasse:

- Apply the sample to the sample pan in a thin, even layer (height: 2 to 5 mm, weight: 5 to15 g);
- Operating Sartorius, determine the moisture content of the sample.
- Apply moisture to the sample in a separate container. Do this using water, at room temperature, in a spray bottle. Ensure there is an even distribution of water, by stirring the bagasse as water is added. This can be done using a stirring rod or using gloves.
- Measure the volume of water added for each sample.
- Record the moisture content of the sample.
- Repeat this until a satisfactory data has been achieved.

ASSESSMENT:

OPERATOR (Student or Technician):

SUPERVISOR:

M. Sheehan. | [signature] | Date: 10/4/13 | Contact No: 15153

Name | Signature

SAFETY ADVISOR:

Ruilan Liu | [signature] | Date: 10/04/13 | Contact No: 14252

Name | Signature

HEAD OF DISCIPLINE:

Bobby Mathew | [signature] | Date: 11/4/13 | Contact No: x15080

Name | Signature

THIS FORM IS TO BE DISPLAYED IN THE IMMEDIATE VICINITY OF THE EXPERIMENT BEING UNDERTAKEN

Figure 7.2: Risk Assessment for Sartorius Moisture Analyzer Experiments.