DESIGN OF COTTON GINNING DRYER CONTROL SYSTEM

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ABSTRACT

The most important factor in preserving the quality of cotton during ginning is the fibre moisture content. At higher moisture content, cotton fibres are stronger but trash is harder to remove. Selecting ginning moisture content is a compromise between good trash removal and quality preservation. In the paper, inlet and outlet moisture content of cotton being fed into and out of the dryer are monitored at temperatures given in the dryer manual and literature. A mathematical model for drying cotton is then formulated by analysing the experimental results, cotton dryer historical records and dryer manual. The results show that there is a linear relationship between the initial moisture content, final moisture content and drying temperature. A control system integrating a Barionet controller to regulate and supply of heat to the system based on the initial moisture content is then proposed. The objective of the control system is to enable online monitoring of the dryer as well as giving early warning signs when the system is about to get out of control hence safeguarding from overheating and avoid under-drying of cotton.

1 INTRODUCTION

Ginneries must produce a quality of lint that brings the grower maximum value while meeting the demands of the spinner and consumer. A standardized sequence that includes dryers to obtain the proper moisture level as well as machines to remove the foreign matter is recommended for processing cotton at the gin. Pre-cleaning equipment operates most efficiently with dry cotton, which allows for easier separation of trash. The moisture content of cotton while it is being cleaned and ginned dramatically affects the processing; therefore, one major task of cotton gin is to properly dry cotton. If wet cotton enters the ginning stream it can cause the gin stand to choke, thereby causing considerable problems for the gin operation. The purpose of any cotton drying system is to remove moisture so that cotton cleaning can be more effective. Dryer stoppages average about 15% of the total production time. The current control system is depended on operator's skill and experience. The operator measures the moisture content of the cotton. The incoming cotton parameters such as cotton variety and cotton moisture are recorded manually by the operator for each module entering and the operator uses these values for reference to adjust the dryer temperature. Then the input or feed rate is adjusted to get the desired quality of drying. Cotton ginning dryer control system that will regulate the drying temperature during the drying process is initiated. Dryer operating temperature will be based on the initial moisture content of the cotton. Initial cotton moisture content ranges from 20% to 75% moisture content. Cotton is dried to 6%-8% moisture content which will enhance the cleaning process efficiently. Hughes and Baker [1] found out that many gin operators did not have the recommended dual temperature control systems on their dryers in South-western United States. However, 48% of the dryers surveyed followed the recommendation of using two temperature control systems the primary and maximum control system. The proposed system will constitute of two temperature sensors and two moisture sensors integrated to the Barionet. Related research on cotton drying and cotton drying control is covered in section 2. Experiments and results analysis are covered in the methodology in section 3. Section 4 comprises of linear regression formulation of the relationship between drying temperature and moisture content. The proposed cotton drying system is discussed in section 5, whilst section 6 is the conclusion of the research.

2 RELATED RESEARCH

Drying in cotton industries is an important process, the moisture content of cotton is very important in the ginning process. Overheating of dryers is a common phenomenon if the process is not regulated and properly controlled. This causes severe losses in equipment, cotton and production time as stated by Jackson et al [2]. Cotton with high moisture content will not clean or gin properly and will not easily separate into single locks but will form wads that may choke and damage gin machinery or entirely stop the ginning process .According to Valco et al [3] cotton with low moisture content may stick to metal surface as a result of static electricity generated on the fibres and cause machinery to choke and stop. Research by Nelson and Neir [4] shows that there were developments that were done in West Texas of using a moisture mirror. Moisture mirror is a device that monitors moisture in the ginning process and uses that information to help the ginner to control all of his moisture systems as well as provides valuable feedback to system performance. Swiss researchers Kretzschmar and Ellison [5] have been proactive in developing high volume instrumentation technology applied to fibre analysis in the ginning process. They developed uster intelligin which monitors and control the ginning process through a system of online sampling stations located throughout the gin, information on fiber moisture and trash colour are fed into a main console were a software anlyses fibre value for optimum dryer temperature and lint cleaning practices. All this is designed to help ginners get the most performance and benefit from their moisture control systems.

2.1 Drying Temperature

Cotton should be dried at a temperature around 177˚C according to a study by Anthony and Griffin [6]. They further state that cotton fibres will sometimes scorch and discolour at 232˚C and will always scorch at 260˚C. Cotton will sometimes ignite at 232˚C after long exposure and will instantaneously ignite at temperatures over 288˚C. Exposure to high drying temperatures (above 177˚C) also increases the brittleness of the cotton fibres, which in turn affects lint quality by reducing fibre strength and contributing to fibre breakage. Boykin [7] studied moisture conditioning on fibre quality and gin stand energy requirements and concluded that increasing drying temperature by 50^{o}C decreases lint moisture by 0.81%.

2.2 Cotton Drying Control

Studies on automated cotton drying begun in 1990 the aim was to improve cotton drying in cotton ginning. Byler and Anthony [8] developed a computer based control system which was tested in two gins. The drying temperature set-point was adjusted based on the seed cotton moisture content before and after drying as measured by infrared moisture meters. The control system adjusted the air temperature by opening and closing the modulator valve on the gas line feeding the burner. Scanardo et al [9] computerized the process control system of drying in which infrared moisture meters, video cameras, computers, paddle samplers, pneumatic cylinder were installed in a phased approach over a five year period at two commercial cotton gins. Though the system was partially implemented the components were evaluated and were functioning well for extended period of time. The computer system took reading after every 10 seconds. According to Anthony [10] Dryer temperature sensors should be located as near as possible to the point where cotton and heated air mixed together. Baker,[11] recommended the use of two temperature sensors the primary and maximum control temperature sensors

3 METHODOLOGY

The experiments were conducted so as to determine the relationship between the initial moisture content and the drying temperature. Temperature is the main variable that affects moisture content of the cotton being dried. Cotton is hygroscopic and will gain or lose moisture based on the environmental conditions at which it is stored. Dry cotton placed in damp air will gain moisture and wet cotton placed in dry air will lose moisture. Bales of cotton from the same stack were unloaded into the mixing floor, where the cotton would be mixed and conveyed through the duct to the tower dryer. Initial moisture content was measured and recorded thus the heater was manually adjusted according to the initial moisture content. Two thermocouples were installed to measure the temperature of the heated air before the mix point and the other thermocouple located at the mix point. A mix point is a point where the cotton will first make contact with the drying air. Figure 1 shows the diagrammatic representation of a mix point. Cotton will first make contact with drying air at the mix point at an angle of approach of 30°. The test thermocouples were of 24 gauge wire, twisted and soldered, resulting in a 1.2 mm diameter with a time constant of 3seconds .A thermocouple of this size responds about six times faster than a typical control thermocouple (in flowing air only).These thermocouples were placed in the air and cotton stream, but with an attempt to avoid direct contact with cotton. The final moisture content was recorded using moisture meters, which were inserted at the exit point of the dryer.

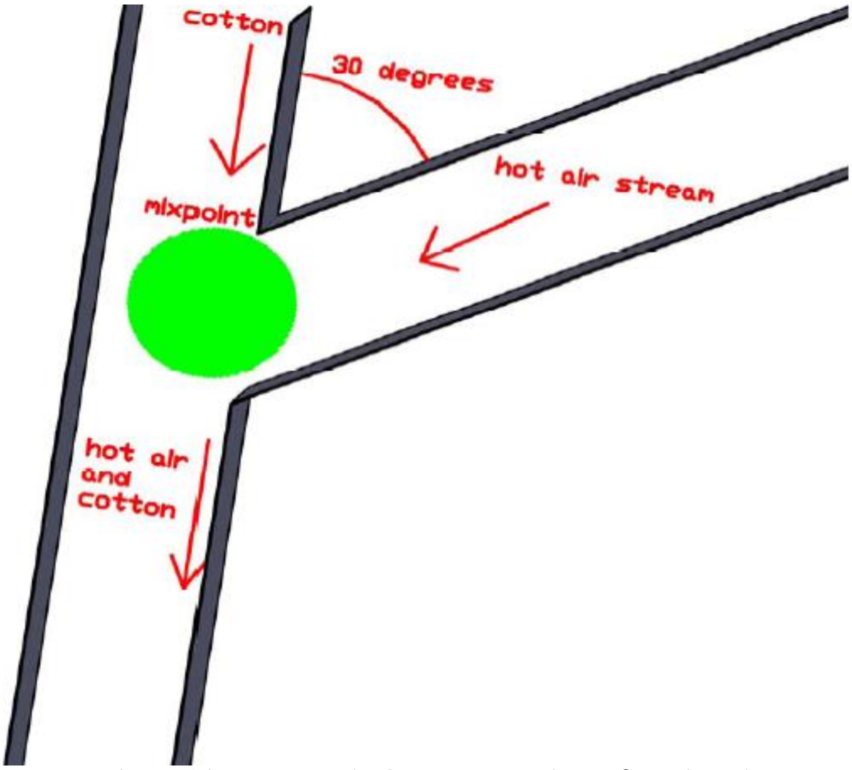

Fig 1: Diagrammatic Representation of a Mixpoint

3.1 Experimental Results

Table 1 shows selected experimental results from the ginning experiments conducted at the ginning depot. The recorded results were recorded at 30 minutes interval starting from mid-morning to sunset.

Table 1: Experimental Results

Initial Moisture content(X_1)	Final Moisture content(X_2)	Drying Temperature (Y)
1) 72 %	7.8%	129°C
2) 49%	6.0 %	92°C
3) 53%	6.7%	105°C
4) 58%	6.0%	101°C
5) 75%	8.0%	127°C
6) 66%	7.2%	102°C
7) 33%	6.2%	91°C
8) 29%	6.0%	90°C
9) 21%	6.3%	91°C
10) 20%	6.5%	90°C

Figure 2 and Figure 3 shows the surface plot and scatter plot for the experimental results.

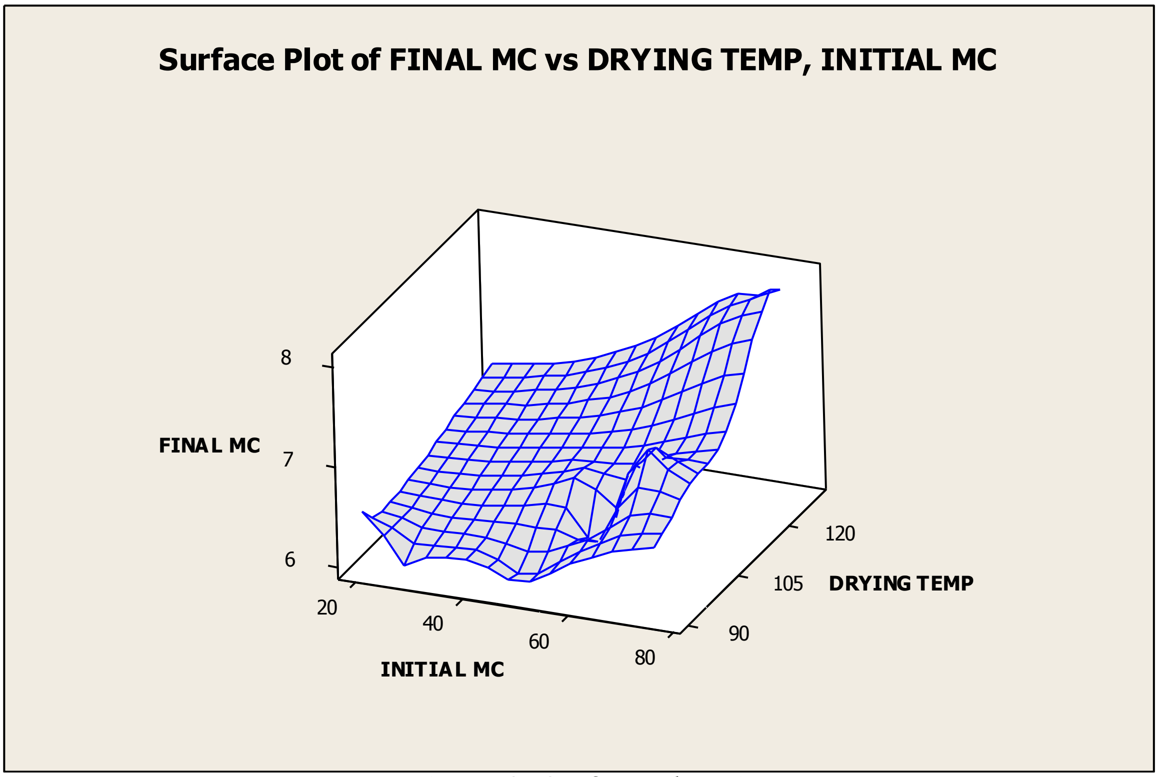

Figure 2: Surface Plot Diagram

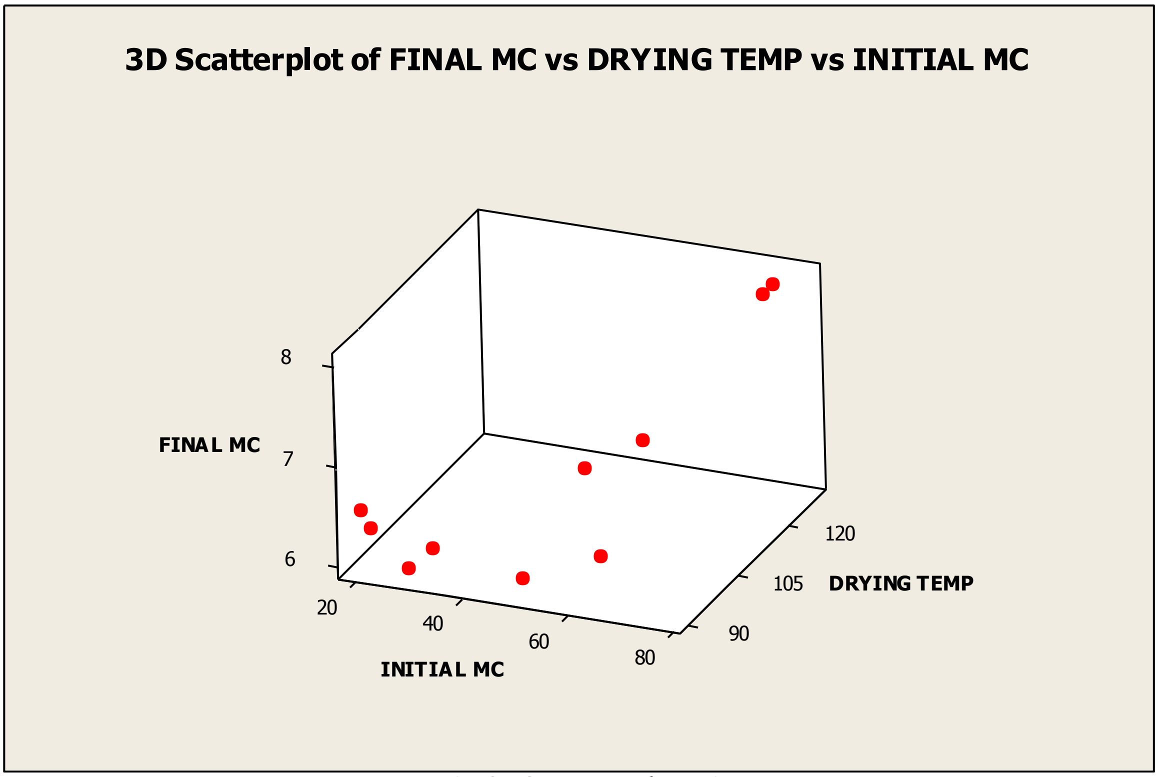

Fig 3: Scatter Plot Diagram

The final moisture content of these selected experiments falls within the recommended range of 6 % -8 % and drying was achieved below the maximum recommended drying temperature of 177℃. According to the drying manuals, the drying temperature should be in the range of 90℃ to 177℃, thus our drying temperatures do not exceed the maximum recommended temperature that in turn affects lint quality by reducing fibre strength and contributing to fibre breakage. Cotton drying is a continuous process and the dyer is parallel flow, cotton is moved through the tower dryer by the momentum of the drying air, cotton will take up to 15 seconds in the dryer.

4 MATHEMATICAL DRYING MODEL FORMULATION

Regression analysis is a conceptually simple method for investigating functional relationships among variables. The objective of linear regression is to quantify the linear relationship between explanatory variables and response variables, Amyad and Ahmed [12]. Explanatory variables are the initial moisture content (X_1), final moisture content(X_2) and the response variable is the drying temperature (Y) in this paper.

4.1 Model Summary

Modelling of the data is done mathematically using a matrix notation, so as to solve for $\beta_0, \beta_1 \; and \; \beta_2$ which are the coefficients of our variables.

$$Y \, is \, defined \, as \, Y = \beta X_i \tag{1}$$

Where

$$\beta = (X^T X)^{-1} X^T Y \tag{2}$$

From the experimental values in Table 1 these matrix are developed as shown in equation 3

$$x = \begin{bmatrix} 1 & 72 & 7.8 \\ 1 & 49 & 6.0 \\ 1 & 53 & 6.7 \\ 1 & 58 & 6.0 \\ 1 & 75 & 8.0 \\ 1 & 66 & 7.2 \\ 1 & 33 & 6.2 \\ 1 & 29 & 6.0 \\ 1 & 21 & 6.3 \\ 1 & 20 & 6.5 \end{bmatrix} \qquad Y = \begin{bmatrix} 129 \\ 92 \\ 105 \\ 101 \\ 127 \\ 102 \\ 91 \\ 90 \\ 91 \\ 90 \end{bmatrix} \tag{3}$$

Solving for coefficient of β

$$\beta = (X^T X)^{-1} \, X^T Y \tag{4}$$

Thus

$$(X^T X) = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 72 & 49 & 53 & 58 & 75 & 66 & 33 & 29 & 21 & 20 \\ 7.8 & 6.0 & 6.7 & 6.0 & 8.0 & 7.2 & 6.2 & 6.0 & 6.3 & 6.5 \end{bmatrix} \begin{bmatrix} 1 & 72 & 7.8 \\ 1 & 49 & 6.0 \\ 1 & 53 & 6.7 \\ 1 & 58 & 6.0 \\ 1 & 75 & 8.0 \\ 1 & 66 & 7.2 \\ 1 & 33 & 6.2 \\ 1 & 29 & 6.0 \\ 1 & 21 & 6.3 \\ 1 & 20 & 6.5 \end{bmatrix} \tag{5}$$

$$(X^T X) = \begin{bmatrix} 10 & 476 & 66.7 \\ 476 & 26\,510 & 3\,274.8 \\ 66.7 & 3\,274.8 & 449.95 \end{bmatrix} \tag{6}$$

Solving for the determinant of X^TX

$$Det \quad of \quad X^TX \quad = 10[(26\,510 \times 449.95) - (3274.8 \times 3274.8)] - 476[(476 \times 449.95) - (66.7 \times 3274.8) + 66.7[(476 \times 3274.8) - (26\,510 \times 66.7)]]$$

$$= 95\,209.82 \qquad (7)$$

Solving for inverse using matrix of co-factors

$$(X^TX)^{-1} = \frac{1}{95\,209.82}\begin{bmatrix} 1\,203\,859.46 & -4252.96 & -209\,412.2 \\ -4\,252.96 & 50.61 & 998.8 \\ -209\,412.2 & 998.8 & 38\,524 \end{bmatrix} \qquad (8)$$

$$(X^TX)^{-1} = \begin{bmatrix} 12.644427829 & 0.044669341 & -2.199481104 \\ 0.044669341 & 0.000531562 & -0.010490514 \\ -2.199481104 & -0.010490514 & 0.404622128 \end{bmatrix} \qquad (9)$$

$$(X^TY) = \begin{bmatrix} 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\ 72 & 49 & 53 & 58 & 75 & 66 & 33 & 29 & 21 & 20 \\ 7.8 & 6.0 & 6.7 & 6.0 & 8.0 & 7.2 & 6.2 & 6.0 & 6.3 & 6.5 \end{bmatrix}\begin{bmatrix} 129 \\ 92 \\ 105 \\ 101 \\ 127 \\ 102 \\ 91 \\ 90 \\ 91 \\ 90 \end{bmatrix} = \begin{bmatrix} 1018 \\ 50\,800 \\ 6880.6 \end{bmatrix} \qquad (10)$$

Substituting into Equation 4 to solve for the coefficients

$$\beta = \begin{bmatrix} 12.644427829 & 0.044669341 & -2.199481104 \\ 0.044669341 & 0.000531562 & -0.010490514 \\ -2.199481104 & -0.010490514 & 0.404622128 \end{bmatrix}\begin{bmatrix} 1018 \\ 50\,800 \\ 6880.6 \end{bmatrix} \qquad (11)$$

$$\begin{bmatrix} \beta_0 \\ \beta_1 \\ \beta_2 \end{bmatrix} = \begin{bmatrix} 7.3 \\ 0.2957 \\ 12.05313 \end{bmatrix} \qquad (12)$$

The mathematical model according to the matrix notation is represented as follows

$$\boldsymbol{Y = 7.3 + 0.2957X_1 + 12.05313X_2} \qquad (13)$$

Where, X_1 - Initial moisture content
X_2 -Final moisture content
Y - Drying temperature

Using matrix notation allows for a more compact framework in terms of vectors representing the observations, levels of regressor variables, regression coefficients and random errors. The matrix approach offers the author the opportunity to develop her conceptual understanding of matrix algebra and linear regression model. The linear correlation coefficient r is 94.70% and this shows a strong positive correlation. The coefficient of determination R^2 is 89.70% which shows that the drying temperature (Y) is well explained by the initial moisture content (X_1) and the final moisture content (X_2) as shown in Table 3.

Table 3: Model Summary Table

Model	r	R^2
	0.947	0.897

4.2 Hypothesis Testing of the Cotton Drying Model

This is a test of the significance of the drying temperature and the moisture content taken together. Using the F-ratio which is the ratio of the explained-variance-per-degree-of-freedom used to the unexplained variance-per-degree-of-freedom-unused.

$$F = \frac{\textbf{Explained variance}/(p-1)}{\textbf{Unexplained variance}/(n-p)} \qquad (16)$$

Table 4: ANOVA Table

Model	Sum of squares	Degrees of freedom	Mean Square	F	Significance
Regression	1778.343	2	894.172	30.495	0.000
Residual	205.257	7	29.322		
Total	1993.600	9			

a) Predictors: (Constant), Final moisture content and Initial moisture content.
b) Dependent Variable: Drying Temperature.

Table 4 shows the analysis of variance (ANOVA), it is a statistical methodology for determining information about means. This analysis uses variances both between and within samples. The value of mean square is obtained by dividing sums of squares within the sample by their respective degrees of freedom.
The F test of the significance of the cotton drying equation $Y = 7.3 + 0.2957X_1 + 12.05313X_2$. As shown in Table 4, $p < 0.001$ thus it is reasonable to conclude that our regression equation is a significantly better predictor.

4.2.1 H test

H_0: $\beta = 0$ (There is no linear regression between drying temperature and moisture content.)
H_1 :$\beta \neq 0$(There is a linear relationship between drying temperature and moisture content)
Where H_0 is the null hypothesis

4.2.2 Finding the critical value

F value from the F-Statistics Table is 4.7374 ($F_{critical}$) for the numerator 2 and denominator 7 degrees of freedom intersect.
F calculated as shown in table 4 is 30.495 ($F_{calculated}$) and p = 0.000
Thus if $F_{calculated} > F_{critical;}$ then reject H_0 which states that there is no linear regression between drying temperature and moisture content.
The conclusion is that there is a linear relationship between drying temperature and moisture content since $F_{calculated} > F_{critical.}$

4.3 Residual statistics

The difference between the drying temperature in the experimental results and the predicted drying temperature by the drying model is summarized in this sub-section.

Table5: Model Drying Temperature

	Minimum temperature	Maximum temperature	Number of experiments
Predicted value	88.17	125.85	10

The minimum drying temperature from the drying model as shown in table 5 is 88.17°C and the maximum drying temperature is 125.85°C. From the experimental results in Table1; the minimum drying temperature is 90°C and the maximum drying temperature is 129°C. Hence our percentage error of the model can be calculated.

$$Percentage\ error = 1 - r(correlation\ coefficient)\ \times 100\ \% \qquad \textbf{(17)}$$

$$Percentage\ Error = (1 - 0.9479) \times 100 = 5.21\% \qquad \textbf{(18)}$$

5 DESIGNED COTTON GINNING CONTROL SYSTEM

Figure 4 shows the hardware wiring of the control system. The model for the system is shown in Figure 5. The power supply is on pin 15 and pin 16.The negative wire being on pin 16 and the positive wire is connected on pin 15. Moisture sensor A is inserted in the conveying duct at the mixing floor to measure the initial moisture content of cotton. The temperature sensor A is located at the mix point where cotton will make its initial contact with drying air. Temperature sensor B is inserted in the dryer, so as to give the reading of the temperature in the dryer. Moisture sensor B finally located at the exit channel of the dryer to measure the final moisture content. The volume of air required to supply a continuous flow of cotton to the dryer is $170m^3$/min, thus the fan speed to supply the required volume is 1720 revolution per minute. The unloading separator which sustains such volumetric flow rate requires 22 horsepower. The drying fan to supply hot air to the tower dryer for a five gin stand requires 50 horsepower and a volumetric flow rate of $249m^3$/min. As the heated air and the cotton are mixed, the heated air temperature drops significantly due to sensible heat transfer from the air to the cotton and evaporated moisture (the cotton and evaporated moisture warm as the air cools) and due to latent heat transfer (moisture that is evaporated from the cotton causing it to dry and the air to cool). As the cotton and air continue to flow through the length of the drying system, the heated air temperature will continue to drop due to continued drying as well as heat being transferred out through the walls of the drying system. In case of cotton with moisture content of 15% or less, the cotton bypasses the dryer and is fed straight to the cylinder cleaner. In case of cotton with moisture content of 15% or more, the cotton passes through a dryer and from a dryer it is then fed to the cylinder cleaner.

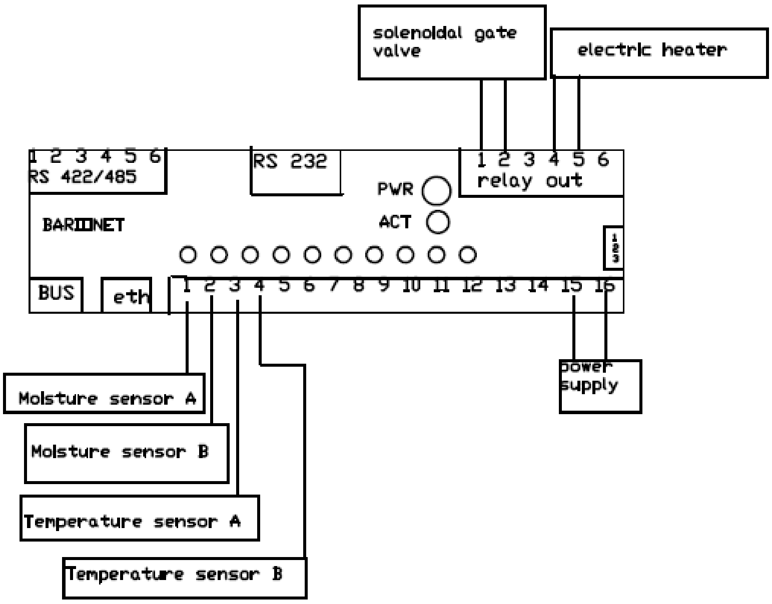

Figure 4: Ginning Control System

6 RESULTS AND DISCUSSIONS

Final moisture content shows that cotton is being dried to the recommended range of 6%-8%. However it have been noted that if dried cotton takes more than 20 minutes to pass through to the next stage of cleaning by cylinder cleaners, there will be a slight change in moisture content at that particular moment. This change is attributed by the following factors

- Environment humidity – If the humidity of the atmosphere is low where the cotton is temporarily stored prior to cleaning, the moisture will slightly decrease. If the humidity of the atmosphere is high the moisture content of cotton moisture will slightly increase. This is mainly due to the hygroscopic nature of cotton fibre, it tends to lose moisture or gain moisture from its surroundings as it tries to achieve equilibrium with environment. The recommendation to the ginners who will implement this system is not to buffer dried cotton prior to cylinder cleaners as storing the dried cotton for more than 20 minutes nullify the whole process of drying.

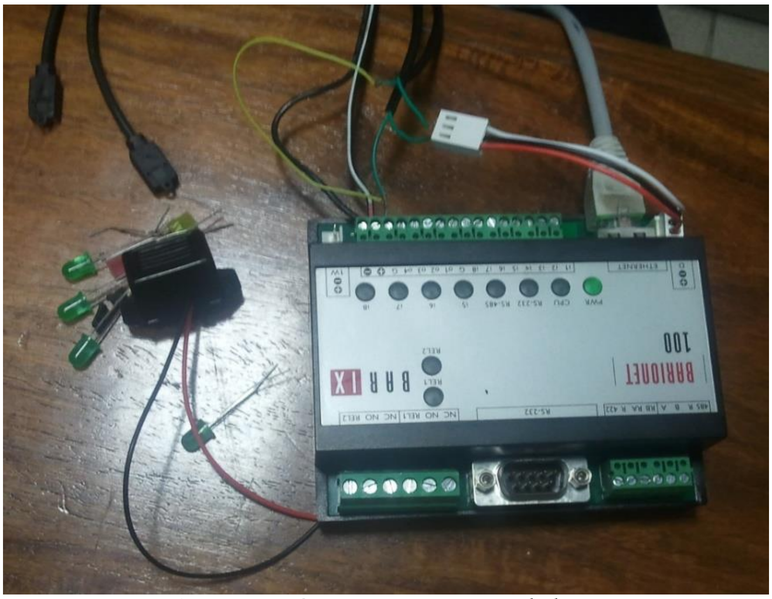

Figure 5: Cotton Dryer Model

- The heat gained by the cotton during the drying phase will still have sufficient energy to continue vaporize moisture in the fibre few moments after drying.

Though the variations in moisture content are observed they are of no effect at all to the final quality of our fibre produced after ginning. The variation range is $\pm 0.05\%$ moisture content.

The drying temperature at the mix point varies to a smaller degree from the set point temperature. This is mainly explained by that the walls of the dryer absorb heat that was intended to dry cotton thus the temperature will decline slightly from the set-point temperature. The walls of the dryer also emit heat to the cotton thus a temperature fluctuating is noted. However the drying system responds very well to cancel out the disturbances thus drying is achieved without any complications.

7 CONCLUSION

In this paper, a drying model is presented. The objective of achieving an optimum drying temperature in the dryer with minimum to no human intervention is achieved. The experiments were conducted so as to determine the relationship between the initial moisture content and the drying temperature. This study confirms that there exists a linear relationship among initial and final moisture content with the drying temperature. There is a continuous monitoring system of the drying temperature, the initial and final moisture content using the Barionet. Used correctly, cotton moisture control systems offer many benefits to growers, gins and textile mills. If the moisture control systems are well chosen, the gin and its customers will reap tremendous dividends.

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