### NON-INVASIVE COTTON MOISTURE MEASUREMENT FOR GIN DUCTS AND ITS IMPACT ON COTTON FIBER AND GIN PERFORMANCE A. S. Krajewski S. G. Gordon CSIRO Materials Science and Engineering Belmont, VIC Australia

## <u>Abstract</u>

The management of moisture in cotton during ginning is important in determining final fiber quality and the energy cost to the ginner. Resistance plates are typically used to measure moisture in seed-cotton and lint as it is processed through the gin. Precision of these devices are limited by inaccuracies that arise from the small proportion of cotton used in the test, contamination of the sensor and by the non-linear response to low and high moisture levels. In this paper, we present results of measurements using a new non-invasive capacitance-based cotton moisture measurement system that was used to meter moisture onto cotton before ginning. The effect of moisture on fiber properties is shown, and the energy used to generate humidified and dry air is measured against impacts on fiber quality.

### Introduction

The moisture content in seed-cotton at harvest through to lint in the bale can have significant effects on the quality of the fiber sold to the spinning mill. There are optimum moisture levels for seed-cotton and lint for each harvest and ginning process that enable efficient harvesting, ginning, cleaning, baling, and safe storage. Large amounts of energy are used to dry cotton to improve cleaning and gin processing efficiency, however there is often injudicious use of energy to do this with detrimental effects on fiber quality from drying the fiber too much, e.g. reduced length and increased short fiber content (SFC). The large cost of gas and electricity and discounts applied to shortfalls in fiber quality are forcing ginners to pay closer attention to the management of moisture and energy during cotton ginning.

In this paper we report on trials using a new in-line moisture sensing device to measure the moisture content in lint being moved quickly by air (up to 20 m/sec) in transport ducts between the gin and lint cleaner. The device uses a large capacitance sensor and LEDs with transmission sensors as the active elements for sensing moisture and mass (Krajewski and Gordon, 2009).

In a series of experiments conducted over three days moisture was metered onto spindle and stripper harvested seed-cotton to test the sensor's response to metered changes in moisture, and the effect of adding moisture before ginning on fiber quality. Gas and electricity consumption was also recorded to provide information for a model to manage energy costs whilst maintaining adequate fiber moisture. Adequate fiber moisture for this trial was a value above 6% and below 7%. This value was nominated on the basis that fiber at a moisture content of 6.5% has reasonable resilience against breakage particularly during lint cleaning but is still able to be cleaned satisfactorily. Measured data from Day 3 of the trials was used to simulate a model-system whereby seed-cotton is kept above 6.0% moisture by metering dried and humidified air using the sensor onto the cotton prior to ginning. Energy costs were calculated for this scenario.

# **Methodology**

Experiments were carried out at a high production four stand Lummus gin located in New South Wales Australia that ordinarily gins around 80,000 bales per year. The gin contains extensive pre-cleaning and drying equipment to deal with stripper harvested cotton and is fitted with Sam Jackson Inc. Humidaire burners and hoppers to enable moisture to be added to seed-cotton prior to ginning.

The duct with the non-invasive moisture sensor (referred herein as the moisture sensor or sensor) was custom-fitted into duct work between Gin Stand No. 3 and its first lint cleaner. The sensor and its calibration have been described previously (Krajewski and Gordon, 2010). The sensor is fitted with a data acquisition card that was set to average the sensor's signal and store data every 30 seconds.

Gas consumption was measured using two AL-425 gas flow meters installed in the gas lines before the Sam Jackson Inc. burners supplying the gin hoppers and battery condenser. Overall gas consumption was recorded at the mains gas meter. Electricity use was measured by recording the amperage of the (No. 3) gin motor drive from a control screen in the console room every two minutes.

Figure 1 shows moisture results from the sensor and off-line results measured using a VOMAX 465 microwave moisture tester. These results were measured at the participating gin in June 2011, as part of checks on the sensor after it was commissioned. For these checks fiber samples were withdrawn from the gin duct prior to the sensor during ginning, packed immediately in a zip lock plastic bag and measured as soon as possible. The VOMAX returns a moisture measurement in around a minute, including weighing of the sample, allowing for more measurements and increased precision in the calibration. Previous tests of the sensor (Krajewski and Gordon, 2010) were affected by narrow ranges in the moisture of the cotton tested, although as reported at the time correlations approaching 80% were likely with an increased range of values in the calibration.



Figure 1 – Moisture sensor results versus off-line reference values measured using a VOMAX 465 Microwave Analyser.

Consistent runs of cotton were selected for the moisture sensor trials on each of the three days. All runs were consistent in variety, production method and paddock (field). Growers, production and harvest methods differed between runs. All runs were delivered to the gin as conventional rather than newer round modules. The main selection criterion for each run was that it should be close to the base length grade applied to Australian cotton, i.e. 1.125 inch (28.6 mm). Cotton not achieving the Australian base length grade is currently subject to discounts in the order of 2.5 to 6 cents US/lb. Table 1 lists the production and harvest method for each run along with the average High Volume Instrument (HVI) properties for each run.

Day/Run	Bales/Run	Production method	Harvest	Ginning rate (bales/hour)	MIC	LEN (inch)	STR (g/tex)
7/8/11 - 1	72	Irrigated	Spindle	54	4.28	1.127	33.16
8/8/11 - 2	327	Irrigated	Spindle	54	4.33	1.130	31.66
11/8/11 - 3	219	Skip row – partial irrigation	Stripper	36	4.25	1.124	31.83

Table 1 –	Cotton	runs	measured
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During each run the Humidaire gin hoppers were switched on and off in half hour or slightly longer intervals in order to test the moisture sensor's responsiveness and to affect changes in fiber properties. Gin runs were planned for the afternoons when ambient conditions were nominally driest, so the benefits of moisturizing the seed-cotton before ginning and lint cleaning would be pronounced. However, ambient conditions on all trial days were distinctly wetter than typical, with 5.2 mm of rain recorded in 24 hours before runs started on August 8, 2011, and 3 mm recorded in the 24 hours before runs on August 11th. The run on Day 1 was used

to check moisture sensor values, Humidaire settings and wetting rates. Runs on Days 2 and 3 incorporated several wetting and drying cycles.

Fiber samples from runs on Days 2 and 3 were collected from every bale in the press room and classed by classer and HVI at Auscott Classing Offices, Sydney NSW.

### **Data Analysis**

Statistical analyses of the measured moisture, energy and fiber data were conducted using Minitab 16 and Excel 2007.

A model describing the gin's dryer and humidifier responses to lint moisture as measured by the moisture sensor on Day 3 was transformed into control subroutines using Labview software. Simulation of the drying/humidifying processes was then carried out using the Day 3 dataset. Energy costs were calculated for this simulation using recent gas billing data from the gin.

## **Results and Discussion**

## **Moisture Sensing**

Figures 2 and 3 show moisture sensor traces recorded on Days 2 and 3. The traces show clear incremental gains in seed-cotton moisture when the hoppers were switched on and losses when the hoppers were switched off. According to the Figures moisture of the cotton lint does not change instantaneously when the gin hoppers were switched on. The moisture ramped up slowly when the water was added and decreased at a faster rate when the hoppers were switched off. Sensor traces later in the day towards 1700 hrs, showed increases in moisture as a result of increased relative humidity (RH) late in each day largely as a result of rainfall during the afternoon each day of the trials (see Figures 2a and 3a).



Figure 2 – Cotton moisture variation in ginned lint on Day 2 (8/8/11) with hoppers turned on at 11:40AM (off at 12:28PM), on at 12:55PM (off at 01:40PM), on at 02:40PM (off at 03:18PM) and on at 03:55PM (off at 04:34PM) conditions.



Figure 2a – Temperature, relative humidity and rainfall recorded during gin run on Days 1 (7/8/11) and 2 (8/8/11).



Figure 3 – Cotton moisture variation in ginned lint on Day 3 (11/8/11) with hoppers turned on at 12:10PM (off at 12:28PM), on at 12:55PM (off at 01:16PM), on at 03:36PM (off at 04:08PM) and on at 04:34PM (off at 05:19PM) conditions.



Figure 3a – Temperature, relative humidity and rainfall recorded during gin run on Day 3 (11/8/11).

### **Energy Use and Costs**

Table 2 lists the average volumes of natural gas used by the gin's burners to generate moist and dry air during the trials (Days 2 and 3). Volumes were averaged across gin outputs of 0.94 bales/min for spindle picked cotton (Day 2) to 0.60 bales/min for stripper harvested cotton (Day 3).

Additional energy is required to increase cotton moisture via the gin hoppers and at the battery condenser before pressing. The installation of gas meters prior to each gas burner allowed total gas use to be partitioned into that used for humidifying and drying air. In relative terms gas consumption by the gin hoppers was small (7.6%) in comparison with the gas used to generate humidified air for the battery condenser (13.8%) and to heat air for the dryers (78.6%). In terms of gas energy cost the addition of this moisture requires an extra 0.038 m<sup>3</sup>/bale of gas. Average cost of gas per bale was estimated at AUD\$2.50/bale calculated using information provided by the gas provider (ELGAS <u>http://www.elgas.com.au</u>). On this value the additional cost of gas used to increase the moisture by 1% (from 5.6% to 6.6%) was 34.5 cents AUD/bale.

Days 2 and 5)							
Gin Process	Consumption (%)	Mean M <sup>3</sup> /bale	Mean M <sup>3</sup> /bale				
Gas burner – gin hoppers	$7.6 \pm 1.4$	0.023	0.038				
Gas burner – battery condenser	$13.8 \pm 1.2$	0.054	0.069				
Gas burner - driers	$78.6 \pm 2.5$	0.308	0.394				
Total		0.393	0.501				

Table 2 – Average gas volumes used to generate dry and humidified air during gin trial runs (on Days 2 and 3)

Moist cotton generates more load (work) on the electric motors powering the gin saw and extractor drives. Figure 4 shows the relationship between gin motor amperage and moisture content as measured by the sensor during the trials. The load on the working gin motor (Gin No. 3) without seed-cotton represents ~43% of the total load with seed-cotton. According to the relationship the addition of 1% moisture to lint, to take lint moisture from 5.6% to 6.6%, puts an extra 4% load on the motor (139 A vs. 145 A) or an extra 2.5 kWh/stand. According to the local energy provider Country Energy (<u>http://countryenergy.com.au</u>) the cost of electrical energy to the gin at the time was 30 cents AUD/kWh. This translates as an extra 10 kWh for a four stand gin or an extra five to ten cents AUD/bale depending on throughput.

The additional energy costs can be offset by the improvement in quality of the bale, which nominally translates to a higher price for a bale. The total energy cost for the addition of 1% extra moisture for these trials was between 39.5 and 44.5 cents AUD/bale. These costs are estimates only and can vary substantially

with fluctuations in the price of these energy commodities, and the moisture and cleanliness of the preprocessed cotton. Nevertheless they provide a measure of the additional costs that need to be justified in the nominally improved quality of the classed cotton.



Figure 4 – Cotton moisture impact on the gin stand motor current.

### **Effects on Fiber Quality**

Figures 5 to 9 show changes in HVI length (upper half mean length - UHML), length uniformity (%), short fiber index (SFI) (%), and manual classing and leaf grade measurements with changes in moisture content on Day 3. In general, small positive improvements in length were seen as fiber moisture was increased from 5.6% through to 6.6%. According to the trend line UHML increased 0.01 inches (0.25 mm) upon the addition of 1% moisture. This is not a large effect although the relationship is significant. Similarly, length uniformity and SFI improved; length uniformity increased by 1% and SFI decreased by 0.5% as moisture was increased. The changes reflect many previous studies that have shown benefits of adding moderate amounts of moisture prior to ginning and lint cleaning, Moore and Griffin (1964), Mangialardi and Griffin (1966), Leonard *et al.* (1970), Anthony and Griffin (2001).

Classing and leaf grade did not change with the 1% increase from 5.6% to 6.6% (see Figures 8 and 9).

With no change in classing or leaf grade the main quality determinant on the Day 3 cotton was the fiber's UHML and whether or not a bale achieved the base length grade. Increasing fiber moisture beyond 5.9% on the Day 3 cotton increased the number of bales with UHML values exceeding the base length grade. Bales with UHML values less than 1.125 inches represented 96% of bales with less than 5.9% moisture. This number decreased to 65.4% of bales when moisture was increased above 5.9%.

On current discounts for length (2.5 to 6 cents US/lb) the difference in the number of bales achieving base length (an extra 11 bales per hour) amounts to an additional premium of AUD\$3.83/bale to AUD\$9.18/bale on each bale (ginned on Day 3) depending on the length discount applied. Subtracting the cost of the energy inputs (39.5 to 44.5 cents AUD/bale) gives the grower of the Day 3 cotton a premium in the range of AUD\$3.38/bale to AUD\$8.79/bale.



Figure 5 – Fiber length (UHML) changes with moisture content on Day 3.



Figure 6 – Fiber length uniformity changes with moisture content on Day 3.



Figure 7 – Short fiber index changes with moisture content on Day 3.



Figure 8 – Classer's grade changes with moisture content on Day 3.



Figure 9 – Classer's leaf grade changes with moisture content on Day 3.

# An On-line Cotton Moisture Controller

During the ginning process many irregularities in moisture levels occur. They may be caused by properties of raw material like moisture, density and external factors like temperature and RH. These variations are mainly compensated by the dryer and humidifying systems that are usually manually adjusted by the gin manager.

However, manual adjustment is insensitive and causes overlaps in drying and humidification applications. This causes unnecessary gas consumption, which impacts on the overall cost of running the gin. The moisture sensor used in these trials can be used as a moisture controlling device. Such a system can be designed to control driers and humidifiers simultaneously. In the system the moisture sensor would continuously examine the amount of moisture in the cotton by sampling and reporting the cotton condition within set time intervals. A central processing unit (CPU) would collect the moisture data and using fixed delivery times or other feedback sensors control the action of drying or humidifying equipment. A feedback and control system was simulated using Labview software according to the schematic shown in Figure 10.



Figure 10 – Set-up for the humidifiers/dryers moisture control system.

In the system the following assumptions were made about the maximum time delay of material between the module feed and the bale ( $\tau$ fb = 120 sec); between the dryer and the moisture sensor ( $\tau$ ds = 20 sec) and between the sensor and the humidifier ( $\tau$ hs = 5 sec). The sensor measures moisture every  $\tau$ hs = 5 sec and the humidifiers and dryers are preset to certain heating conditions and are not changed. Furthermore, the humidifiers and dryers can be switched on or off separately or simultaneously at any time and use the same amount of gas when switched on.

The control system, derived from Figure 10, and simulated using Labview is depicted in Figure 11.



Figure 11 – Moisture control system showing sensing and control pathways.

In the system a certain fiber moisture value is set as the reference value (Figure 11 - REF. signal); for the simulation the value was set at 6%. When an increase in the fiber moisture above the reference value is detected the humidifiers are switched off and driers are switched on. When the cotton is too dry the dryers are switched off and humidifiers are switched on in order to increase the fiber moisture content. There are periods where humidifiers and dryers can be both switched off, i.e. there is no gas usage during these periods; it was assumed that humidifiers for the battery condenser remained on.

Sensor results from Day 3 (4.1 hours of continuous run) were used to test the simulation. For this period the total simulated time where both dryers and humidifiers could be switched off was 1.067 hours (25% of the time) eliminating a gas cost/bale of AUD \$2.16/bale and a saving of AUD \$83.84 in gas for this period of just over one hour. Extrapolating these savings out to 24 hours production, the total gas savings per day amount to nearly AUD \$500/day. Assuming Day 3 was an average run day in terms of ambient weather conditions and bale moisture content, the total gas savings for 12 weeks of gin operation would be excess of AUD \$40,000.

The histogram in Figure 12 compares the moisture signals before and after the moisture control is applied by the simulation. The analysis indicates that controlling humidifiers and dryers improve moisture distribution, which has a measurable effect on fiber quality (length).



Figure 12 – Moisture points distribution around the reference value.

## **Conclusion**

In this paper we present a moisture sensor that accurately measures the moisture of ginned lint before lint cleaning. The sensor was successfully used to track the moisture of ginned lint travelling at 20 m/sec through a modern, commercial gin. Energy consumption by the gin's dryers and humidifiers was measured and fiber quality values were measured against changes in fiber moisture content, which was varied at set intervals using Samuel Jackson gin hoppers.

The results indicate the sensor can be used to control dryers and humidifiers in order to keep fiber moisture consistent and in doing so improve fiber quality and reduce gas consumption. Brief analyses of the energy added to the bale in order to alter fiber quality were conducted. These showed the cost of adding moisture via the gin hoppers was small compared to the gains in fiber quality, largely through the ability to maintain base grade fiber length when fiber moisture was above 5.9%.

Information from the analysis was combined to develop a control system for the gin's dryers and humidifiers. Using data from trials on Day 3 a simulation of the control system showed a large amount of gas energy could be conserved, with associated large savings each season to gin operating costs (gas).

The trials provide further evidence that the non-invasive moisture sensing device was is sensitive and reliable enough to be used to reduce energy costs and improve fiber quality.

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