COTTONSCOPE: A NEW INSTRUMENT FOR MATURITY AND FINENESS MEASUREMENTS. a) INSTRUMENT DESIGN

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ABSTRACT

This paper introduces the Cottonscope instrument. Cottonscope combines into one commercailly available instrument two technologies developed by CSIRO, namely the Siromat^{TM} technology for the determination of fibre maturity, and The Cottonscan^{TM} technology for the determination of fibre fineness (linear density). Results are presented for two well characterized sets of cotton samples and the results are in good agreement with previously published values. It is concluded that Cottonscope provides the industry with an important new instrument for rapid and accurate assessment of the maturity and fineness of cotton samples.

INTRODUCTION

At previous Bremen International Cotton Conferences (Gordon, Naylor and van Sluijs, 2004; Gordon and Naylor, 2008) descriptions have been presented of two new prototype technologies to independently measure fibre maturity and fineness; two important fibre quality attributes that have previously not been routinely evaluated or used by the industry. Since that time significant progress has been made and these two technologies are now available in one commercial instrument called the Cottonscope.

The current paper will introduce and describe the Cottonscope instrument and the following paper from the USDA (Rodgers and Thibodeaux, 2012) will give more examples of the application and use of Cottonscope in their research laboratory.

BACKGROUND

Definitions

As described previously (e.g. Gordon and Naylor, 2008) during the growth phase the cotton fibre has an approximately circular cross-section with a central lumen or vacuole vessel that is largely full of fluid. After growth, as the fibre dries the lumen collapses and the fibre forms a flattened twisted ribbon with a characteristic irregular cross-sectional shape depicted schematically in Figure 1. The fibre maturity and fineness or linear density can be readily defined with reference to Figure 1. (This follows the approach of Pierce and Lord (1939) which has been widely adopted by others inc Thibodeaux et al (2000); Hequet et al (2006); and Montalvo et al (2007).) Fibre maturity (M) is related to the degree of wall thickening i.e. the cell wall area as a fraction of the area of a circle having the same perimeter as the fibre. Fibre fineness or fibre linear density (H) is the mass per unit length of the fibre and is related to the fibre cell wall area.

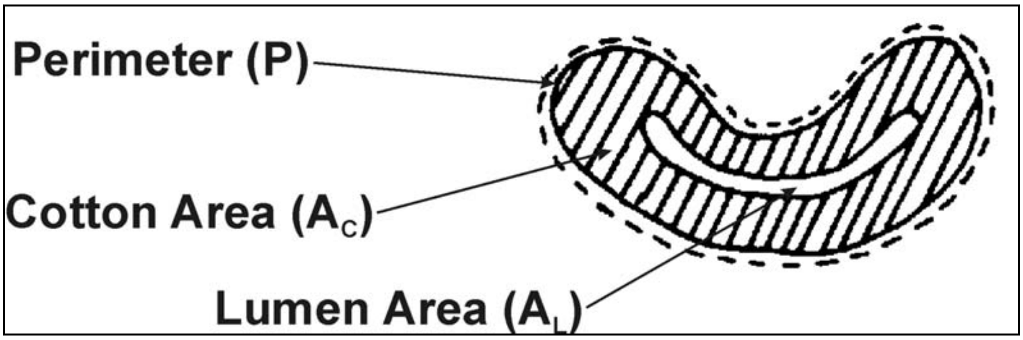

Figure 1. Schematic of a cotton fibre cross-section (modified from Boylston et al, 1990).

For the mathematically inclined:

$$M = 4\pi A_C/(0.577P^2)$$

and:

$$H = \rho A_C$$

where ρ is the cellulose cell wall density and A_C and P are as defined in Figure 1.

As fibre maturity and fineness are readily defined in terms of the characteristics of the fibre cross-section, direct measurement of fibre cross-sections is sometimes considered the reference method for maturity and fineness measurements. Such measurements are however slow and tedious and technically difficult with some particular experimental challenges to avoid introducing biases. It is thus an unsuitable approach for normal commercial measurements. The industry is however fortunate that Hequet et al (2006) have published the results of a large and detailed study of the cross-sectional characteristics of a wide range of different cottons to create a reference set of 104 cottons with well characterised fibre maturity and fineness properties.

Cotton Fibre Maturity Measurement: The Siromat™ Technology

Historically it was known that mature and immature fibres could be distinguished based on their different birefringence properties i.e. different colours when viewed under a polarised light microscope (ASTM D1442, 2000). This method has previously been largely overlooked due to the subjectivity of operators in assessing colour and also the time required for manual assessment and counting. The Siromat™ technology developed at CSIRO is a 21st century adaption of this approach using modern digital colour photography, computer image analysis routines and automation to overcome the deficiencies and limitations of the original methodology (Gordon, Lucas and Phair, 2005; Gordon and Naylor, 2008). Fibre snippets are dispersed on a glass slide and then imaged on a specialist microscope as depicted in Figure 2. Figure 2 also depicts a typical image highlighting the difference between immature and mature cottons and an example of the output of the technology, a histogram of the range of maturity values present within a cotton sample as well as the average maturity value.

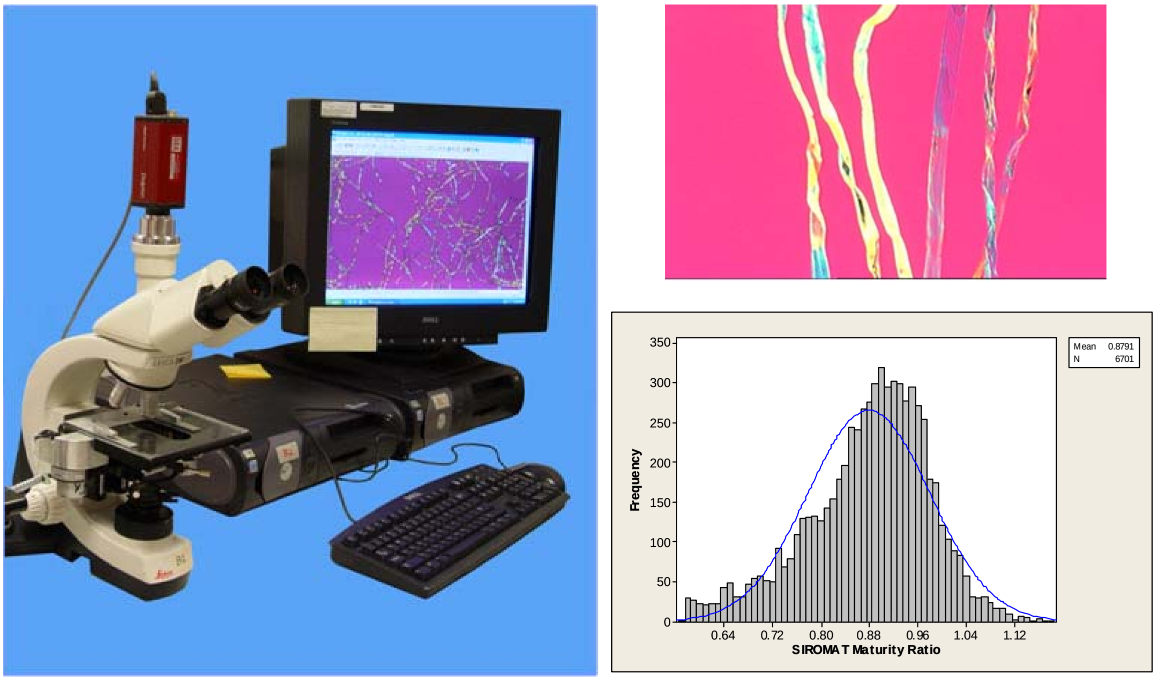

Figure 2. The Siromat™ Technology and Instrument. The polarising microscope, colour digital camera and computer system are shown on the left. The top right frame is an image illustrating the difference between mature and immature fibres (mature fibres on the left and immature fibres on the right). The bottom right frame depicts the histogram output of maturity values within a sample available from the technology.

Cotton Fibre Fineness Measurement: The Cottonscan™ Technology

In a somewhat complementary way, the Cottonscan™ technology developed at CSIRO is a 21st century adaption of the direct method of measuring fibre linear density or fineness i.e. the mass per unit length (Abbott et al, 2010 & 2011b; Gordon and Naylor, 2008). As shown schematically in Figure 3, prepared and weighed fibre snippets are suspended in an aqueous medium. These suspended snippets are then transported to and imaged as they pass the measurement cell. Figure 3 also shows a typical black and white digital image of the fibre snippets. From a number of such images modern image analysis and statistical techniques are used to calculate the total length of the snippets in the sample and so calculate the fibre fineness value. A number of in-depth published inter-laboratory studies have tested and demonstrated the technical validity and reproducibility of this approach (Abbott et al, 2011a & c).

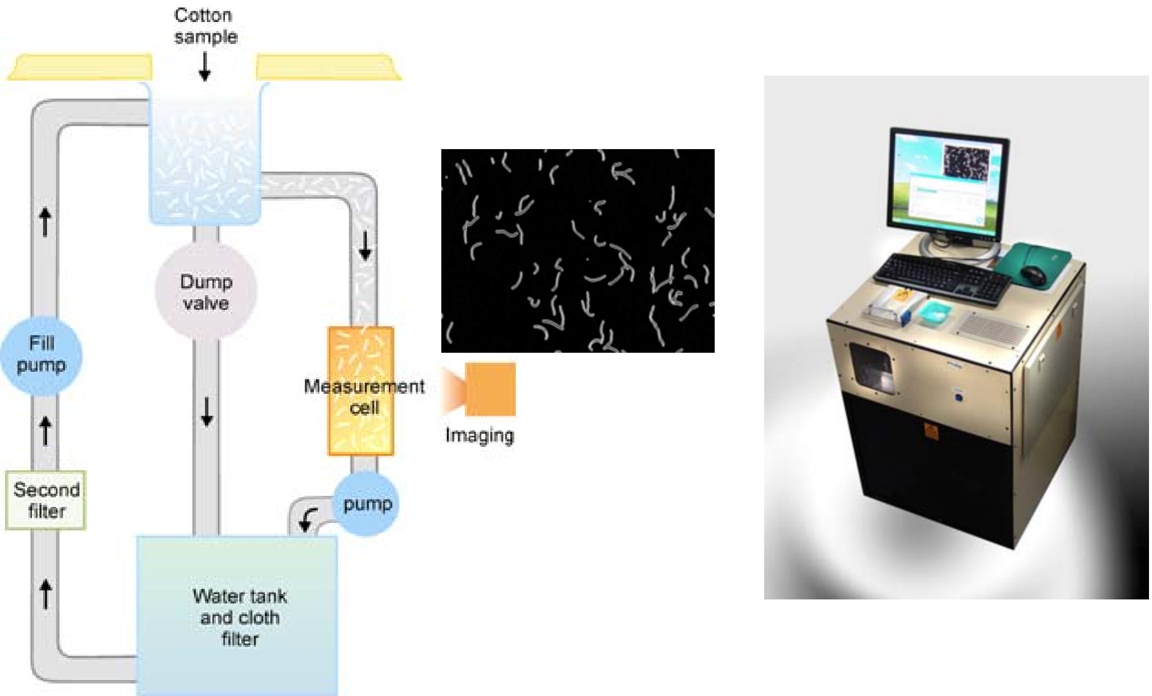

Figure 3. The Cottonscan^{TM} Technology and Instrument. A schematic of the operation of the instrument is shown on the left. The centre frame is a typical black and white image of the suspended snippets as they pass the measurement cell. The frame on the right depicts the instrument.

THE COTTONSCOPE INSTRUMENT

Description

The Cottonscope instrument cleverly incorporates both the Siromat^{TM} and Cottonscan^{TM} technologies into one commercial instrument shown schematically in Figure 4. (An earlier version of the Cottonscope contained only the Siromat^{TM} technology, Brims and Hwang, 2010). Cottonscope is a small and portable instrument weighing approximately six kilograms. It contains a fully automated microscope that captures colour images of cotton snippets in an aqueous suspension. A measurement is completed in approximately 25 seconds, although specimen preparation and weighing currently extends the practical test time to approximately one minute.

As in the two base technologies, The Cottonscope instrument uses fibre snippets. Snippets, approximately 0.7mm long, are prepared using a specially designed guillotine depicted in Figure 5. In this figure the guillotine is mounted above a digital balance to facilitate the weight measurement. The fibre snippets are then manually transferred to the Cottonscope for measurement.

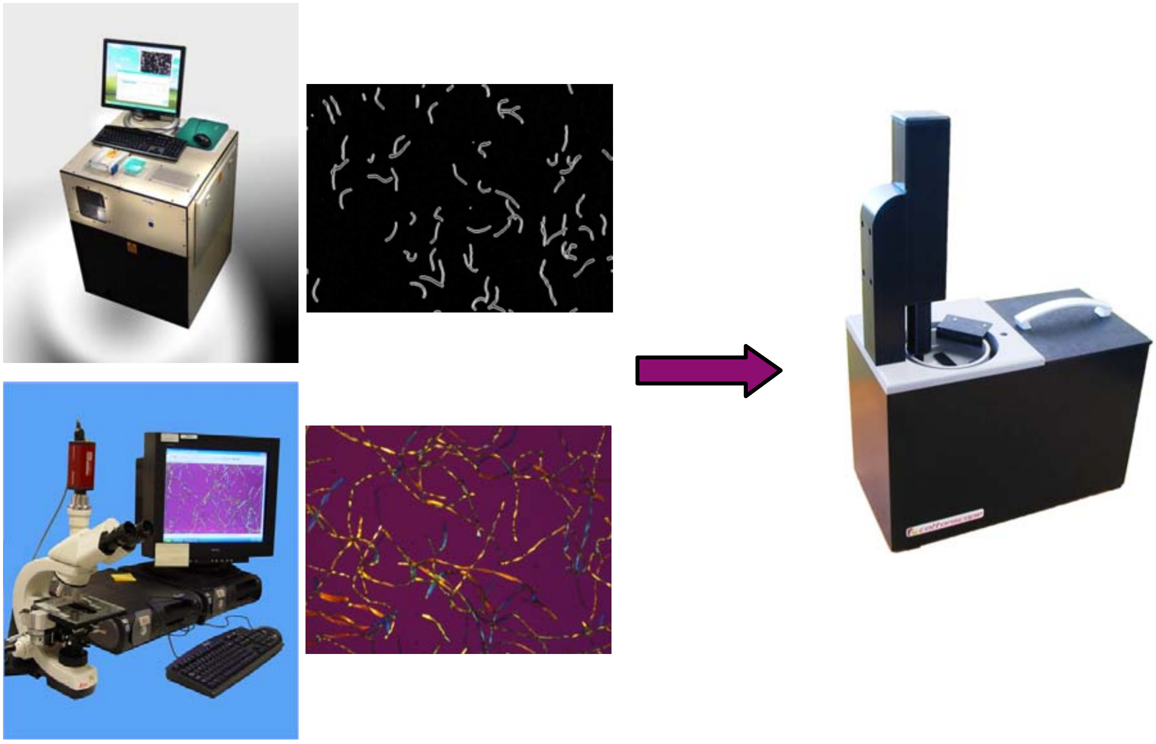

Figure 4. Creation of Cottonscope through the innovative merging of the Cottonscan™ and Siromat™ technologies.

Figure 5. The custom designed 0.7 mm guillotine mounted above the snippet weighing balance. The image shows the underside of guillotine slot and collection trough on the balance.

In the Cottonscope the fibres are suspended in an aqueous medium. They are conveyed into the camera field-of-view, which is permanently part submerged in the aqueous medium, via a rotating magnetic stirrer. A light source consisting of a combination of a green polarised LED light source and a red LED light source combine to illuminate the fibres in a yellow light as illustrated in Figure 6. Using this optical arrangement the fibres appear dark or translucent if immature and red if mature. The more red the fibre, the more mature it is.

Figure 6. Typical Cottonscope image of cotton snippets.

An added feature of the Cottonscope is that it also measures the average fibre ribbon width and the micronaire number.

Further technical information and a video of the operation of the instrument is available online at www.cottonscope.com.

Typical Results

Figures 7 and 8 show typical results obtained with the Cottonscope instrument in operation at CSIRO. Figure 7 shows the maturity results obtained using Cottonscope for a sub-set of 22 of the fibre maturity reference cottons (Hequet et al, 2006). Figure 8 highlights the fibre fineness values obtained using the Cottonscope instrument for a set of well characterised samples plotted against published values (Abbott et al, 2011). For both sets of data i.e. both figures, the agreement with previously published values is very encouraging.

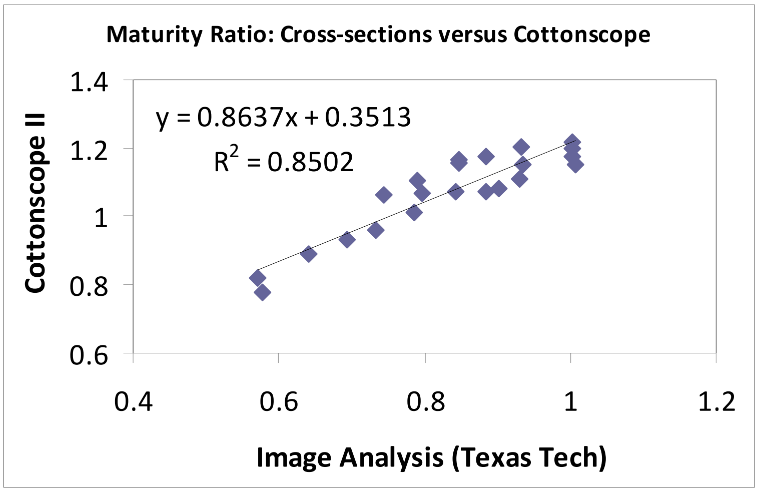

Figure 7. Average fibre maturity measured on the Cottonscope plotted against the published values (Hequet at el, 2006).

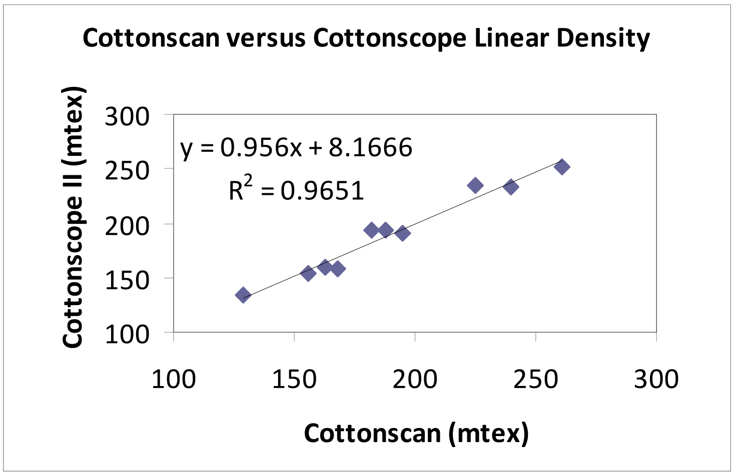

Figure 8. Average fibre fineness (linear density) values measured on the Cottonscope plotted against the published values (Abbott et al, 2011).

One aspect of the commercial usefulness of fibre fineness and maturity information is illustrated in Figure 9, a plot of fibre fineness versus Micronaire values for a large number of commercial samples collected over 18 months from three large Chinese cotton spinning mills. This figure also shows the maturity of each sample with the darker smaller dots representing increasing maturity. The two vertical lines in Figure 9 identify the zone of Micronaire values between 3.5 and 4.9. It is only outside this zone that current commercial practice will discount a cotton: either below 3.5 for fear the sample is immature or above 4.9 due to the perception that the fibre is too coarse. It is interesting that most of the cotton samples in Figure 9 fall in the region where currently there are no price signals. For example the current pricing mechanisms cannot distinguish the two sets of samples labelled as Group 1 (fine and mature) and Group 2 (coarser and less mature) which will produce very different quality yarn. For example Figure 10 reproduced from a previous Bremen conference

(Gordon and Naylor, 2008, also published in Abbott et al, 2010) illustrates the observed change in yarn properties that can result from a 30 mtex change in fibre fineness for a fixed micronaire value.

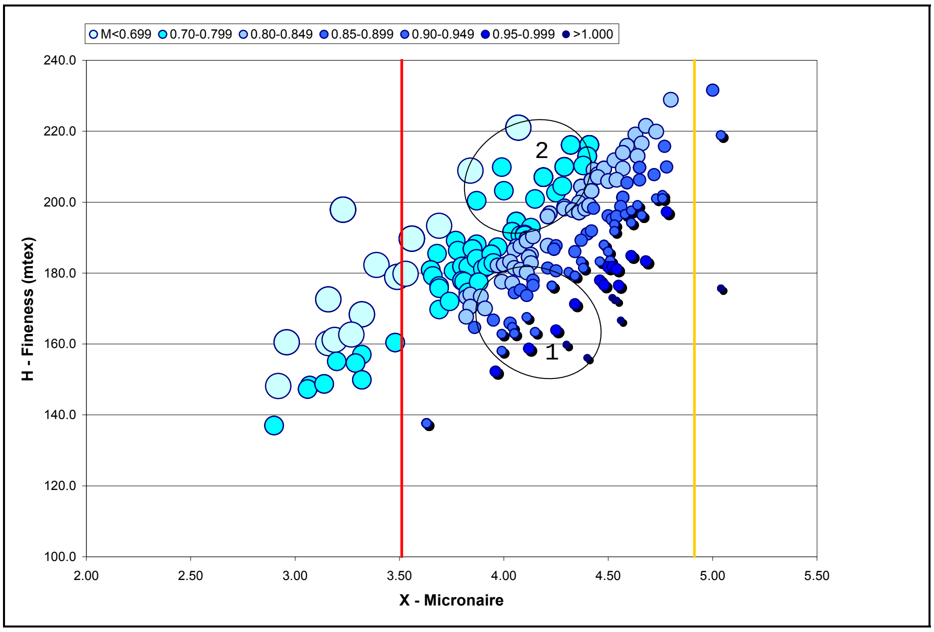

Figure 9. Fineness versus Micronaire values for samples of different origin and maturity from bale laydowns used to produce Ne 40 and Ne 50 count yarn. Fibres identified in Group 1 (circled) are fine and mature in contrast to Group 2 which are coarser and less mature.

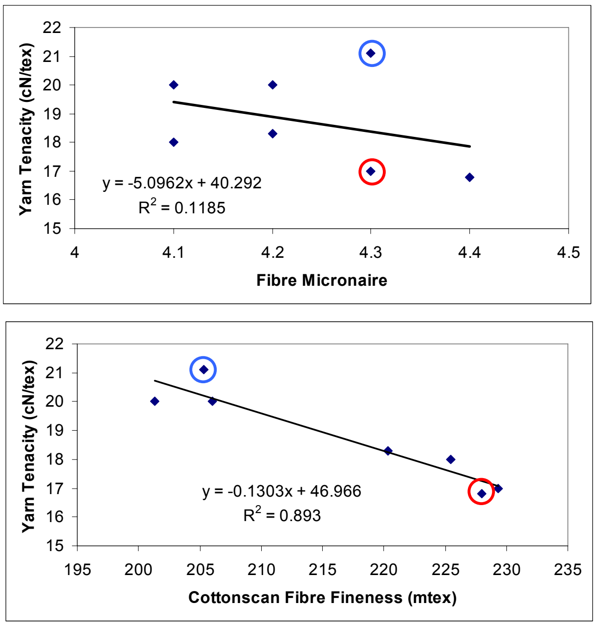

Figure 10. The Relationship between yarn tenacity values and (a) the Micronaire value and (b) the average fibre fineness values (reproduced from Gordon and Naylor, 2008).

Also the range of fibre maturity values present in the 3.9-5.0 Micronaire range in Figure 9 is also significant and could lead to differences in dyeing (Gordon and Naylor, 2008; Gordon et al, 2008).

CONCLUSION

The current paper introduces the commercially available Cottonscope instrument. The new instrument combines both the Siromat^{TM} and Cottonscan^{TM} approaches into one instrument such that both fibre maturity and fineness (linear density) can be measured rapidly, independently and simultaneously. The preliminary results reported here are in good agreement with prior published data and confirm the suitability of Cottonscope as a useful instrument for rapid and accurate assessment of fineness and maturity of cotton samples.

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