

DEVELOPMENT OF AN ONLINE BAGASSE ANALYSIS SYSTEM USING NIR SPECTROSCOPY

By

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Abstract

THIS PAPER describes the development of an online NIR-based Bagasse Analysis System (BAS) at the Mulgrave Central Mill. It includes performance statistics in calibration and validation for equations developed and describes the electronic linking of a cane analysis system (CAS) with the bagasse system to calculate milling train pol extraction in real time. It also describes the development of NIR calibrations for bagasse calorific value and presents statistics describing the accuracy and precision of these calculated values.

Introduction

A supplementary income stream has become available to the sugar industry through the process of cogeneration. The Australian Government introduced the Mandatory Renewables Energy Target (MRET) on 29 November 1999, which states that an additional 2% of Australia's energy must be derived from renewable energy sources by 2010. This equates to an additional 9500 GWh of renewable electricity (Dixon and Burbidge, 2000).

With this new and potentially expanding market for renewable energy, a new value must be assigned to bagasse produced by a sugar factory based on its potential sale/use for energy production. The development of a real-time Bagasse Analysis System (BAS), combined with an extension of the cane tracking system through the milling train, will provide a representative quality based assessment of bagasse suitable for feed-forward to the boiler station. When linked with a Cane Analysis System (CAS) the effects of mill settings, maceration control and cane quality on milling train pol extraction can be determined in real-time.

Scope

The aims of this work were to:

- Develop an online NIR-based system for bagasse analysis.
- Develop and validate the calibrations required to determine pol extraction and an estimate of bagasse calorific value.
- Develop and validate an extraction monitor using the combined outputs of the CAS and BAS units.

Experimental

The Bagasse Analysis System uses the same hardware and software configuration as the Cane Analysis system (Staunton *et al.*, 1999). A FOSS Direct Light 5000 NIR spectrophotometer mounted within an environmental enclosure providing protection against vibration, temperature and humidity variation, and incursions of dust and water. The system

computer provides a factory interface for the exchange of process information and allows, with appropriate security, remote access for monitoring, control and support over a local/wide area network or the internet.

The system read-head was mounted on the final mill inclined exit chute at the Mulgrave Central Mill as shown in Figure 1.



Fig. 1—System scan head mounting on the final mill exit chute.

Snap samples of bagasse were collected continuously across the passage of a consignment, cooled to room temperature in a sealed container, thoroughly mixed and sub-sampled for constituent analysis. Laboratory reference values for pol and fibre in bagasse were determined using the methods contained in the Laboratory Manual for Australian Sugar Mills, Volume 2 (Anon., 2001). Dry matter and ash values were determined using methods developed by BSES Limited for the calibration of the CAS systems and are available on request.

Calorific value of bagasse

The gross and nett calorific values of bagasse were calculated from laboratory values for fibre, dry matter, ash and pol in bagasse using the following method:

Assumptions

- All ash present is insoluble and has no calorific value.
- Bagasse fibre is 100% cellulose (ignores lignin and hemi-cellulose).
- Pol in bagasse = sucrose in bagasse.
- The contribution of other combustible materials present is negligible.

Literature values (Perry's Chemical Engineering Handbook)

Gross calorific value (GCV) of cellulose (fibre)	= 19.841	MJ/kg
Gross calorific value (GCV) of sucrose (pol)	= 16.514	MJ/kg
Latent heat of vaporisation, water	= 2.262	MJ/kg

Calculations

$$AverageGCV = \frac{(Fibre_b - Ash_b) * 19.841 + Pol_b * 16.514}{((Fibre_b - Ash_b) + Pol_b)} \quad (1)$$

$$GCVBiomass = AverageGCV * \frac{(DryMatter_b - Ash_b)}{100} \quad (2)$$

$$NCVBiomass = GCVBiomass - \frac{(100 - (Drymatter_b - Ash_b)) * 2.262}{100} \quad (3)$$

where: b = bagasse.

Milling train extraction monitor

The extraction monitor calculated pol extraction values in real time using outputs from the CAS and BAS units. Implementation of the system required the development of two separate programs:

- (1) CAS Repeater Software: This program captured sample information from the mill tracking system and analysis results from the CAS and sent them through the mill local area network to the extraction monitor software on the BAS.
- (2) BAS Extraction Monitor: This program placed the information from the CAS in a queue together with its arrival time. The length of the queue was set by a mill latency parameter, an estimate of the time required for the cane to move from CAS to BAS. The queue timer was paused whenever the mill stopped to prevent CAS data being used prematurely.

When CAS data reached the bottom of the queue, the extraction monitor performed the following operations:

- (i) Sample information sent to the BAS for spectral labeling;
- (ii) Pol extraction calculated using live BAS results;
- (iii) Calculated results included in rolling average for current sample;
- (iv) If end of sample received, average extraction calculated and stored.

Pol extraction was calculated using formula (4), which assumes no loss in fibre.

$$Pol_{extraction} = 100 * \left(1 - \frac{Pol_b * Fibre_c}{Fibre_b * Pol_c} \right) \quad (4)$$

where: c = cane, b = bagasse.

Results and discussion

The presentation of the material to the scanner at the scanning point can be critical to the system's analysis success rates and standard errors of prediction. The ideal scanning point presents a continuous (no gaps), lightly compressed (no void volume) stream of material at a constant distance from the scanner.

There were two practical options for the scanning point in bagasse analysis, the exit of the final mill or over the bagasse belt. In most factories scanning over the belt would be

the only option as the bagasse exiting the final mill is usually not controlled. It was fortunate that the Mulgrave Central Mill had recently installed an inclined (45°), diverging exit chute on their final mill which kept the bagasse under compression for several meters. The scan head and viewing glass were mounted on this chute as close as possible to the exit of the mill (Figure 1).

The presentation using this arrangement proved to be very good with the system scanning a continuous, compressed stream of bagasse for the majority of process conditions. Some processing conditions did cause the bagasse matt passing the scan point to break, resulting in the scan collected at the time being rejected as corrupt. These breaks were caused by the bagasse expanding to fill the chute as it traveled up and away from the mill and the frequency of rejections may have been reduced by moving the scanning point closer to the exit of the mill.

Daily scanning success

The daily percentage of samples analysed was one of the system key performance indicators (KPI) with a target of greater than 90%. The trend line for the 2004 season (Figure 2) shows the effects of gaps in the sample stream and system down time on the daily analysis success.

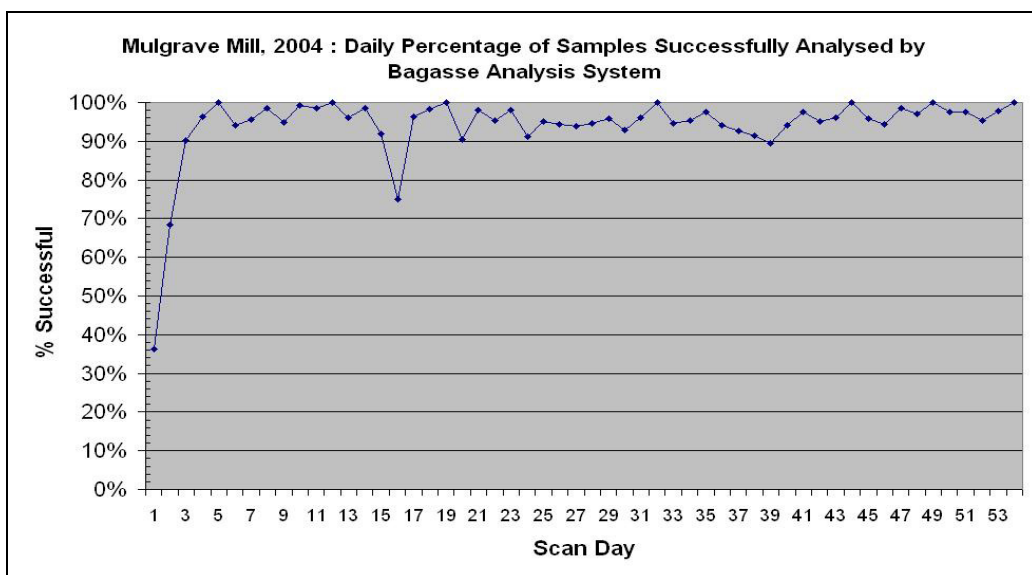


Fig 2—BAS daily analysis success trend.

The low percentages for the first two days were caused by the system spectral library rejecting valid scans as corrupt. Performance improved after online scans were built into the library. Daily success rates were consistently over 90% with the exception of a single result. The reduced performance on this day was caused by a crash in the system software. The cause of the software crash was identified and corrected.

Bagasse calibration equations

The calibration statistics for individual bagasse parameters are shown in Table 1. The error control limit was calculated as 1.2 times the standard error of cross validation (SECV). Error ratios were calculated as the standard deviation of the calibration set divided by the calibration SECV. This parameter indicates the amount of variation in the population left

unexplained by the calibration e.g. error ratio of 2, 50% of the variation is unexplained. It was used during calibration development as a 'robustness indicator', the higher the ratio the more robust the calibration. Bagasse moisture content was calculated from dry matter predictions using formula 5.

$$\text{Moisture\%Bagasse} = 100 - (\text{Drymatter\%Bagasse} - \text{Ash\%Bagasse}) \quad (5)$$

Table 1—Bagasse calibration set (BAS02).

2004 season	Bagasse calibration statistics						Error	
Constituent	SECV	R ²	Mean	Std. Dev.	Effective range	N	Ratio	Control limit
Pol	0.12	0.77	1.27	0.26	0.51–2.05	274	2.2	0.14
Dry matter	0.75	0.99	41.16	9.46	25.67–59.06	1391	12.6	0.9
Fibre	0.88	0.98	46.08	6.5	26.65–59.56	754	7.4	1.06
Ash	0.64	0.93	2.48	2.44	0.00–9.81	1313	3.8	0.77
GCV (MJ/kg)	0.17	0.99	6.87	2.06	0.70–3.05	942	12.1	0.2
NCV (MJ/kg)	0.19	0.99	5.68	2.32	0.0–12.6	861	12.2	0.23

Validation statistics for the BAS02 equation set are shown in Table 2. All standard errors of prediction (SEP) were found to be equal to or higher than the error control limits and correlation coefficients lower than expected. These results were strongly influenced by very high ash levels (> 20%) in bagasse experienced during the trial. The calibration set contained no data with ash levels greater than 9.8%, and predictions for bagasse with higher ash values produced larger than expected errors for all constituents. These larger errors dominated the validation statistics and the inclusion of high ash samples into the calibration populations is expected to improve system performance.

Table 2—Validation results for BAS02 calibration set.

Constituent	SEP	Error limit	R ²	Slope	Bias	Range	N
Pol in bagasse	0.14	0.14	0.70	0.74	−0.02	0.7–1.88	162
Dry matter	1.60	0.9	0.66	0.58	−0.49	45.7–58.1	211
Fibre	1.19	1.06	0.78	0.83	−0.29	42.7–55.2	197
Ash	1.98	0.77	0.73	0.71	0.02	1.8–21.7	206
GCV (MJ/kg)	0.41	0.2	0.83	0.81	0.07	6.2–11.0	156
NCV (MJ/kg)	0.47	0.23	0.83	0.75	−0.17	4.7–10.0	156

The regression correlations for all predicted parameters show the results to be suitable for process monitoring and limited process control.

Bagasse calorific value

A 24 hour trend of bagasse gross calorific value (GCV) predictions (Figure 3) shows significant variation between cane consignments and reasonable consistency within consignments. The variation in bagasse calorific value over 24 hours was approximately 4 MJ/kg with step changes of the same order.

This information can provide effective feedback on the contribution of cane quality to final mill performance and feed-forward to the boiler station with regard to the fuel quality

of the bagasse supply. Step changes in bagasse fuel quality adversely affect boiler operations and any advance warning to operators would allow preemptive corrections to be made. Further work is required to relate changes in bagasse GCV to boiler station performance before appropriate control schemes can be developed.

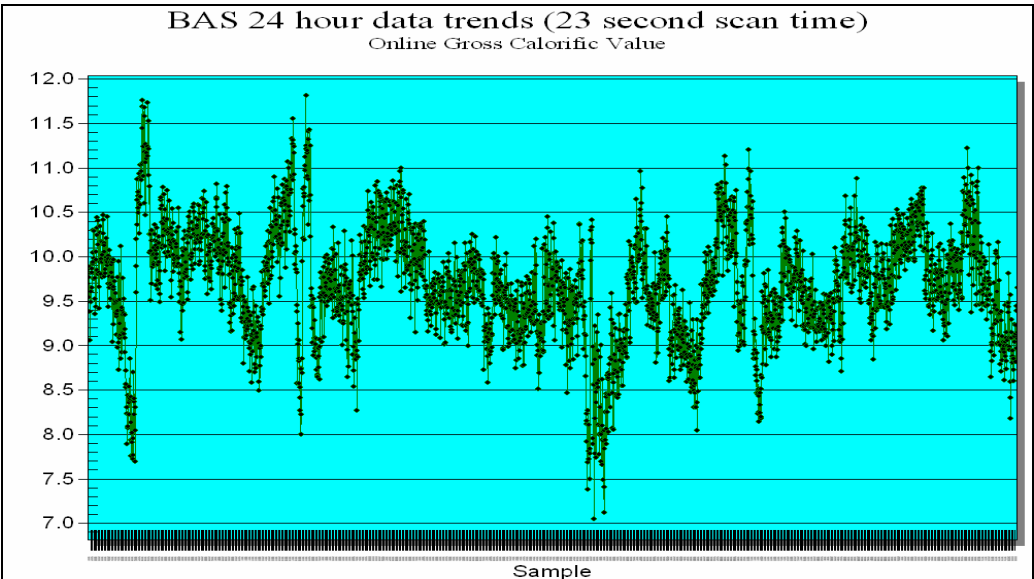


Fig 3—Online gross calorific value (MJ/kg) 24 hour trend (no units on graph).

The average predicted bagasse moisture and GCV for each consignment were plotted in an XY format (Figure 4) and a linear regression generated. As expected, bagasse moisture strongly influences GCV. The regression line shows for every unit increase in bagasse moisture, GCV decreases by approximately 0.3 MJ/kg through the dilution of combustible material present in bagasse. This result highlights the importance of final mill de-watering to boiler operations.

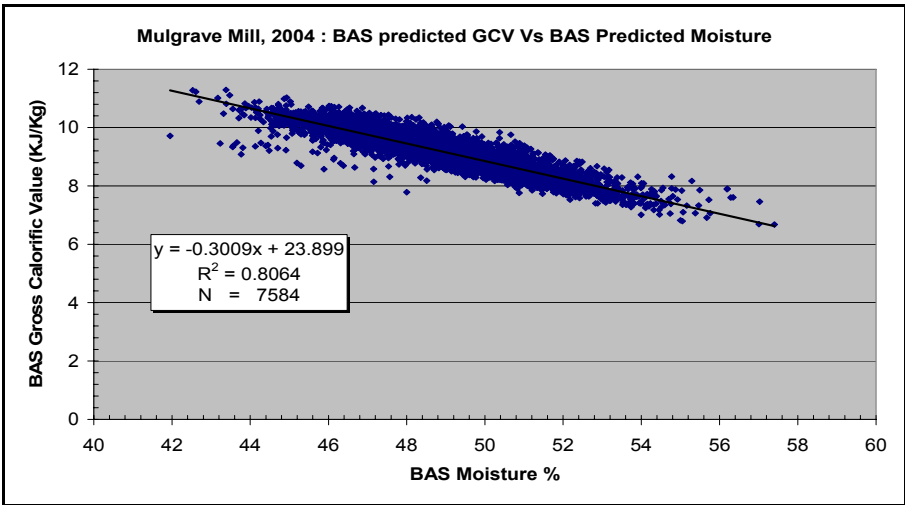


Fig. 4—BAS predicted moisture against BAS predicted GCV.

Extraction monitoring

The CAS repeater and extraction monitor software operated continuously with only one crash over the period of the trial. The software crash was tracked to a faulty digital input signal and once corrected did not occur again.

The pol extraction validation results are shown in Figure 5. Linear regression slope and correlation coefficients are considered to be very good when extraction range and population size are taken into account. The standard error of prediction obtained for the online calculated pol extraction was 0.17, which compares favourably to the laboratory precision obtained from shift composite samples. With real-time extraction results of this order, the BAS will prove very useful in determining optimum mill settings and maceration rates for any given cane supply.

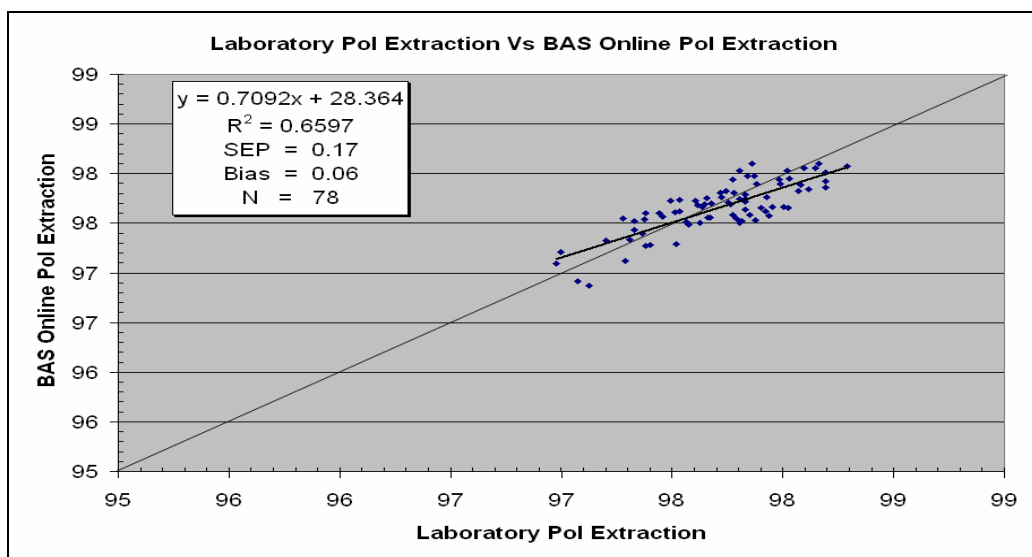


Fig. 5—Pol extraction validation plot.

A 24 hour trend of calculated Pol extraction (Figure 6) shows significant variation between cane consignments and reasonable consistency within consignments. The variation in Pol extraction over 24 hours was approximately 4% with step changes of the same order.

This information can be used to determine the relative contributions of cane quality, mill settings and maceration rates to milling train pol extraction. These relationships must be determined before effective control schemes can be generated.

Conclusions

An online NIR-based bagasse analysis system was successfully developed and installed at the Mulgrave Central Mill using an inclined, diverging exit chute. The system successfully analysed between 90 and 100% of the factory's daily bagasse production.

The NIR calibrations required for the online calculation of pol extraction and bagasse calorific value were successfully developed. The calibrations would benefit from the inclusion of more data, but their current performance was shown to be more than adequate in providing bagasse quality information and outputs for process control.

An online extraction monitor using the combined outputs of the CAS and BAS units was also successfully developed. The extraction monitor software delivered real-time results

that will prove useful in determining optimum mill settings and maceration rates for any given cane supply.

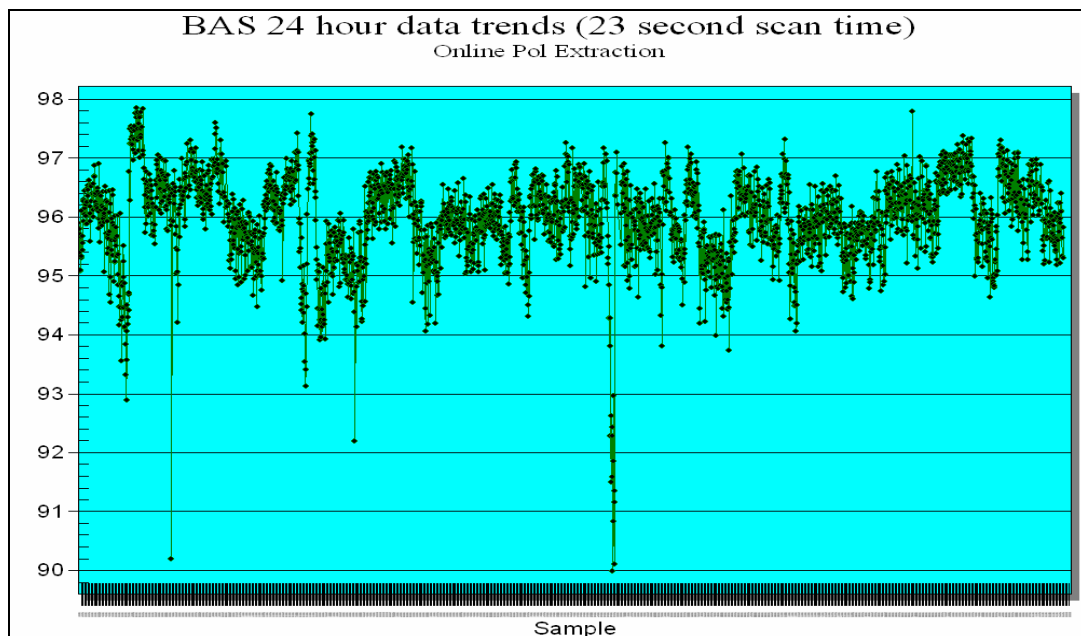


Fig. 6—Online pol extraction 24 hour trend (no units on graph).

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