ON-LINE ETHANOL DETECTOR FOR DETECTION OF DETERIORATED CANE

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Abstract

The deterioration of sugarcane produces substances that can cause difficulties in sugar factories because they increase viscosities resulting in poor exhaustion of molasses, and in certain cases interfere with clarification. The problematic substances produced are generally polysaccharides, the detection of which often involves the use of lengthy analyses in a laboratory. The online detection of deteriorated cane has to rely on a less direct indicator. Ethanol, which can be detected using near infrared absorption, has previously been shown to be one such indicator of deterioration.

A commercial unit was used to detect the amount of ethanol released during the knifing and shredding process. The use of the detector on the gases released from the cane presented its own set of challenges. The environment is extremely humid with a relative humidity approaching 100%. The process of rupturing the cane releases fine droplets of juice. These droplets contain dissolved sugar and other components. Once these droplets are deposited on the measuring equipment, fermentation can produce ethanol, which might obscure the real signal, or the water may evaporate leaving the sugar behind fouling lenses and mirrors.

Techniques had to be developed to ensure that moisture did not condense inside the detector and that sugar was not deposited on the optical surfaces. The most effective way to prevent condensation was found to be to heat the gas sample. The sugar crystals formed in the gas stream were removed using a cartridge filter. Once the gas conditioning techniques had been developed, the system was linked to the laboratory information system (LIMS). Readings were taken for each consignment, stamped with a tracker number and stored in a LIMS compatible format. Data could then be processed by LIMS to identify potentially stale consignments.

Keywords: ethanol, deterioration, detector, online, infrared, LIMS

Introduction

Many authors agree that introduction of deteriorated cane into the sugar factory has a detrimental effect on processing (Cuddihy JA Jr and Day DF (2005). The process and financial impact of dextran on a sugar factory. Midland Research Laboratories, Inc. www.midlandresearchlabsinc.com/doclib/dexfinan.pdf [accessed 17 Jan 2005]; Chavanan *et al*, 2002; Cuddihy JA Jr, Porro ME and Rauh JS (2005). The presence of total polysaccharides in sugar production and methods of reducing their negative effects. Midland Research Laboratories, Inc. www.midlandresearchlabsinc.com/doclib/polysach.pdf [accessed 17 Jan 2005]). Not only is some of the sucrose consumed by the deterioration process but also some of the products formed, such as dextran, cause the viscosity of the massecuites to increase. This reduces the scope for good boiling house recoveries. In other words, deterioration of cane between burning or harvesting and crushing has a negative impact on the profitability of the sugar production chain. It is not only the grower who is penalized for delivering cane of lower purity but the whole cane growing community suffers from a reduced output from the factory.

The detection of polysaccharides is not an easy process. Most methods require the addition of a reagent in the laboratory. One method is to precipitate the dextran, which is then analysed further; this is the principle of the Roberts Copper Method (Curtin and McCowage, 1986; Saska *et al*, 2002). Another procedure is a polarimetric method where the difference between an initial reading and a reading after the application of dextranase gives the quantity of dextran present. Polysaccharides can also be quantified using chromatographic separation techniques (Morel du Boil, 2000). These methods require that a sample of juice be treated with reagents in a laboratory in order to obtain a measurement. This approach is not suitable for online measurement. Consequently, other methods of detecting deteriorated cane need to be used for online detection systems.

One product that has shown to be an indicator is the production of ethanol (Lionnet and Pillay, 1987). Although ethanol itself is not a concern, it is generally produced as part of the deterioration process. It should be noted that certain deterioration processes do not have ethanol as an end product, and could thus escape detection using this method. In most cases, however, yeast infection does occur and ethanol is produced.

In the work of Lionnet and Pillay (1988), it was shown that despite a fair amount of scatter, ethanol could be used to indicate delays, especially when the delays were of the order of several days. For fresher cane, the correlation was not as significant. A commercial gas analyser was used to detect ethanol released from cane during the cane preparation process. The analyser, a Dräger Polytron Transmitter, uses infrared absorption for determining ethanol concentration. It is an optical device and is therefore susceptible to dirt accumulation on optical surfaces.

The output from the detector was a 4-20 mA signal, which had to be converted for interpretation by a digital computer. Cane with high ethanol levels could be identified and appropriate action taken. In a time where savings need to be made on labour, an implicit requirement for the system is that it must not increase the existing workload. Preferably a reduction in workload must be enjoyed. With this in mind, links were made between the ethanol detection system and the existing systems in place, namely the cane tracker and the LIMS systems. A PIC micro controller was chosen to handle the analogue to digital conversion, to schedule the air blasts for removing fibre from the gas cleaning devices and to capture belt position information.

The brief for producing an acceptable system therefore had three main elements:

- Gas collection and preparation to ensure long term operation with minimum maintenance interventions required
- System controller with cleaning schedule and data collection, analysis and transmission
- Data interpretation.

System overview

The cane preparation equipment ruptures the cane releasing various components. Ethanol is the component that is of primary interest for detection of deteriorated cane. A sample of the gas must be drawn out of the enclosure around the preparation plant, and pumped through the analyser. Before the sample enters the analyser, all components that might contaminate the detector need to be removed.

The analyser generates a 4-20 mA signal corresponding to the ethanol concentration in the gas sample. This signal is converted to a digital value for transfer to a computer workstation.

A method of identification of the source of deteriorated cane was required. The consignment start and end signals from the cane tracker were used for this function. Additional information had to be transferred to the workstation to compensate for the position of the gas sample point relative to the cane sample station (DAC station).

A program running on the tracker workstation collated the data and prepared it in a format that was compatible for the laboratory information system (LIMS).

Timer functions were added to the system to activate solenoids to clean the separators with compressed air at regular intervals.

Figure 1 shows the general layout of the system that was implemented.

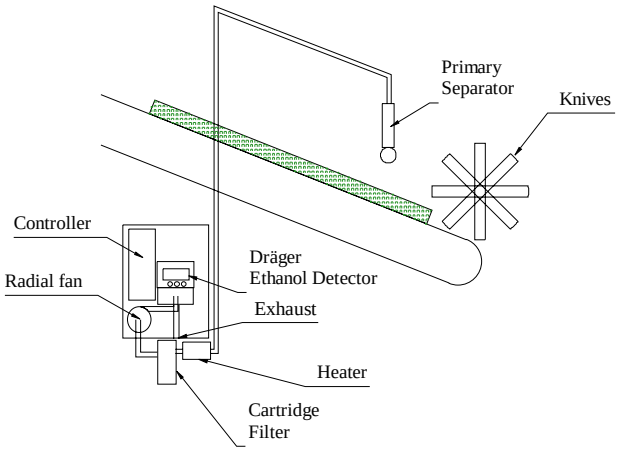

Figure 1. General layout.

The cane was ruptured by the knives. The liberated gas was collected and passed through the primary separator. A pipe conducted the sample to the detector box where it was heated. This caused the evaporation of the water in the droplets, which resulted in crystallisation of the dissolved solids. A cartridge filter was used to remove the sugar crystals and other solids. The sample was then pumped through the gas analyser. The signal from the detector was digitised by the controller and transmitted to a computer workstation for compilation and formatting for LIMS. A photograph of the system is shown in Figure 2.

Figure 2. Ethanol detector mounted just after knives.

Gas collection

Overview

The object of the gas collection system is to move gas from the area where it is liberated through the detector and remove any contaminants that may harm the detector.

As the cane sticks pass through the knives, various components are released into the air in the enclosure. These components include ethanol, which is the component to be measured, water vapour, fibre, water droplets and dissolved solids.

The gas sample was first drawn through a primary separator to remove the fibre and as much of the water as possible. The air was then conducted along a 32 mm pipe to the analyser-controller. The sample was heated to lower the relative humidity to prevent condensation and evaporate entrained water droplets. A five-micron cartridge filter was used to remove fibre from the sample and trap sugar crystals that form when the water droplets evaporate.

A DC radial fan was used to draw the gas sample from the sampling point through the cleaning stages and inject it into the detector.

Insoluble solids removal

The windage and mechanical effects of the preparation process cause pith and fines to be entrained in the air mass above the conveyor.

Figure 3 shows the arrangement of the trap. The movement of the sample is directed upwards. The pipe diameter increases from 25 to 40 mm resulting in a decrease in the gas velocity. This reduction in the velocity reduces the solids carrying capacity of the gas stream. The length chosen for the 40 mm section of pipe was 400 mm to allow time for the particles to lose momentum and start falling back. The solids accumulate at the bottom of the pipe and are blown back into the conveyor air space with compressed air blasts lasting five seconds at twenty-minute intervals. This also clears the cane that bridges the sample point inlet.

Figure 3. Solids trap.

Liquid component

Although some of the moisture content remains behind in the solids trap, the gas still contains both water droplets and water vapour. Since some of this is deposited on the walls of the pipe, a high volume flow was chosen so that absorption and fermentation effects of the water on the walls would be small in comparison with the actual ethanol released.

Any water reaching the mirrors of the detector would foul the mirrors. A small 220 V heating element (500 W) was wound around a section of steel pipe through which the sample passed. An on/off control algorithm was implemented in the controller to heat the pipe to 70°C. This elevated the exhaust temperature to about 40°C, which was above the dew point of the moisture in the sample. This prevented moisture from contaminating the mirror. Any water droplets in the sample would also evaporate causing the dissolved solids to crystallise. These solids would then have to be removed.

Dissolved solids

fter the heater was introduced into the system a light coloured powder was observed to form on the downstream surfaces. This powder was analysed and found to contain predominantly sucrose. It was therefore clear that sugar crystals had to be removed from the sample stream.

Figure 4. Commercial filter cartridge.

Figure 4 shows the commercial filter cartridge that was chosen to filter the sample. The flow rate was monitored and it was estimated that the cartridge would have a life of about one month. Despite many attempts, no method of cleaning the filter was found. It was also found that the plastic core in the centre of the filter cartridge tended to collapse leading to bypassing of the filter. The cartridge should therefore be considered a consumable item to be replaced monthly.

Sample transport

To minimise the effects of ethanol dissolving in moisture on the pipe walls it was decided that the highest possible flow rate through the detector should be used. An instrument fan was

identified as a candidate for this purpose. Rudimentary tests with a plastic pipe set up as a water manometer showed that the pressure drop in the filter would be in the order of 150 mm H_2O. Additional allowance had to be made for the pressure drop in the inlet and the solids trap. This led to the estimate that the fan would have to be able to provide a pressure in the order of 600-900 mm H_2O. A plastic fan with sleeve bearings was chosen for the test. The fan had an estimated life of two seasons according to the manufacturer's specifications. A die-cast aluminium model with ball bearings could be obtained and this would have a life of the order of eight seasons according to the specifications.

Controller and data collection

Overview

Figure 5 shows the general layout of the communications system. The tracker PC and tracker workstation were housed in the tracker cabin and were linked by a serial data cable. The workstation was also linked to the controller in the 'sniffer box' with a serial cable. A current loop was used for the position pulse signal. An analogue current loop linked the ethanol detector to the controller.

The tracker workstation was used to collate the information from the system and store it ready for import into LIMS. The identification of the sample came from the tracker PC. When a consignment reached the DAC sample point the tracker PC would transmit a string containing an 'a' followed by the tracker number. At the end of the consignment at the tracker station, a 'b' followed by the tracker number was transmitted. The time when the consignment reached the DAC station at the end of the conveyor had to be related to the reading from the ethanol detector where the consignment passed some time earlier. This was done using the signal from the shaft encoder attached to the belt for the tracker system. The pulses from the encoder were counted as a measure of the distance that the belt had moved since start-up. This value, together with digitised current from the ethanol detector, was transmitted, on demand, to the workstation. A program running on the workstation kept track of the ethanol value, which it synchronised with the belt movement. When the start-of-consignment signal was received, the ethanol reading of the cane leaving the conveyor could then be retrieved, and averaged to match the actual consignment.

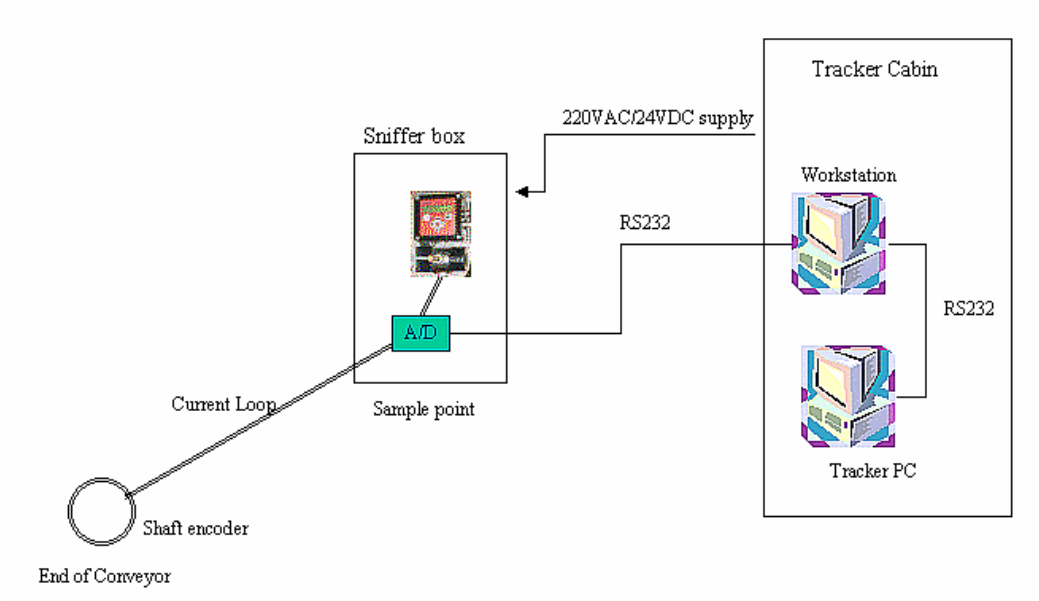

Figure 5. Communication layout.

Workstation

The software to keep track of the position of the conveyor and the associated ethanol did not require much computing power and could be performed adequately by a system that supported Windows 95. Two serial ports were required: one for the tracker signal and one for communicating with the controller. A software timer was used to initiate a request for data from the controller. If the returned data was not in the prescribed format, it was considered to be erroneous and was rejected.

A set of bins was defined in the software to correspond with imaginary packages of cane on the belt. The ethanol readings were averaged while the package was passing the ethanol detector. Once the package had passed the detector the average ethanol value in the bin was held and tracked with the belt until the cane left the belt. The second belt was also divided into bins and a similar process employed.

When a start of consignment signal was received, the values in the bins leaving the belt were averaged to give the final ethanol reading for the consignment. This value, together with the time and tracker number, were written into a text file which LIMS could import and match with consignment details.

Parameters such as the heater temperature and cleaning cycle frequency and duration were modified from the program running on the workstation. Once the program had verified the validity of the new parameter, it was transmitted to the controller using the RS232 data link.

Controller

The controller was based on a PIC micro-controller. The PIC not only offers flexible analogue to digital conversion but also presents the opportunity to count pulses from the conveyor position indicators, control the temperature of the sample heater, and act as a timer for the cleaning cycle of the sample collector. The controller responded with the ethanol detector output and the pulse counter value when a request for data was received or one of the control parameters was updated.

A serial, RS232, transmission was used. The data were sent in a format such that if any data were lost the packet could be rejected. The data was requested at approximately 500 ms intervals so sufficient data would be transmitted even if some of it were lost.

Data interpretation

Lionnet and Pillay (1988) suggested that ethanol could be used as an indicator of cane deterioration. The results shown in their work did, however, show a fair amount of scatter. Although recent developments by Kim and Day (2005) have opened possible fast, low cost methods for determining the dextran content of cane juice, the accepted methods currently commercially available remain lengthy and expensive. The detection of ethanol, despite the variability, remains a viable option.

Trials were performed at Sezela Sugar Mill where extensive gas chromatograph (GC) testing is already in place. This has already had a positive effect on the quality of cane that is delivered to the mill. Consequently, very little severely deteriorated cane is received at the mill as can be deduced from the results shown in Figure 6, where very little cane is received with ethanol above 336 ppm on extract or 2585 ppm on brix assuming a brix of 13%.

The correlation between ethanol and delay improves with older cane. By the time a well-correlated relationship exists, the cane is stale and no longer desirable for processing. Consequently, for fresher cane, an acceptance threshold would be more useful, than to try to deduce actual ethanol levels in ppm on brix from the detector measurement.

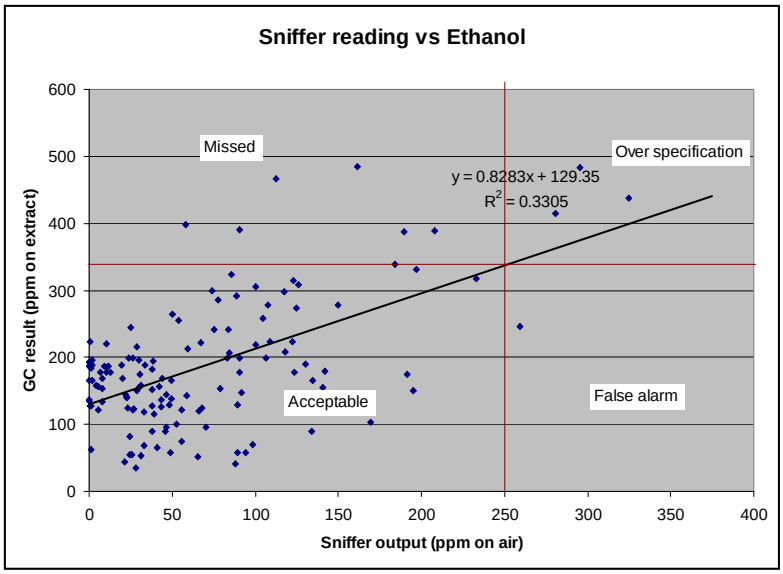

Figure 6. Comparison of ethanol detector and GC results.

Over a period of two weeks 185 consignments were analysed both by GC and the ethanol detector. These results are plotted in Figure 6 together with a regression analysis. A threshold in the detector output needs to be set to flag consignments where GC analysis must be performed. If it is decided to set this threshold to 250 ppm on air, then, according to the regression, this would equate to 2585 ppm ethanol on brix (assuming 13% brix).

The readings fell into one of four categories as shown in Table 1. The majority of the cane was acceptable and would have been allowed into the factory without GC analysis. Four of the 185 readings would have been flagged for GC analysis of which one would have been a false alarm. Five consignments would have entered the factory with high ethanol on brix without being detected.

Table 1. Number of cases threshold to 250 ppm on air.

Acceptable cane	Stale cane detected	False alarms	Missed stale cane
176	3	1	5

It can be seen that only the small number of consignments flagged for having high ethanol would have to be analysed further. The approach of random GC analysis requires a large number of samples. Consequently, the introduction of an ethanol detector can substantially reduce the cost of analysing for stale cane.

Maintenance

If a good quality fan with ball bearings is used the fan would only have to be replaced after more than six seasons.

A small amount of contamination on the mirrors can be tolerated. The contamination causes the baseline or ‘zero’ to move upwards. Compensation has to be made by manually resetting

the zero on the detector. This involves removing the sample feed pipe and waiting for the detector to settle to its zero value. The value is accepted at the push of a button and the system is then ready to run. The process takes less than ten minutes, and would preferably be performed on a weekly basis. The relationship between ethanol reading and current output is preset in a laboratory with gases of known concentration. The six-month stability of the detector is quoted as better than 2%, which is much less than the variability of the detector-GC relationship. Consequently, it is unnecessary to recalibrate the range of the detector.

It may be necessary to wash the mirrors in the detector about twice a season. To do this the detector needs to be removed from the cabinet. The cavity is then filled with water and wiped out gently. Compressed air is then used to dry out the cavity. This process generally takes approximately 40 minutes.

Experience at Sezela showed that the filter cartridge would need to be replaced at approximately monthly intervals. No suitable washing process for the filter was devised so replacement is recommended.

Conclusion

The ethanol detector can be used as an online detector for deteriorated cane. It is an optical device, which uses mirrors and lenses. Moisture, solids and biological growth can coat the mirrors and cause false signals. It is therefore critical that the gas sample must be cleaned before it is passed through the detector. Solids could be removed using a trap and cartridge filter. The effects of moisture can be removed by heating the sample so that dew point is never reached within the detector. This causes crystal formation, which must be removed by the filter.

A computer system was developed so that ethanol data could be matched with tracker number and exported to LIMS. A module had to be written within LIMS to import the data and attach grower information. If the threshold was exceeded, then a flag needed to be set so that a GC analysis could be performed to confirm the ethanol content. It might even be viable to perform polysaccharide analysis on the reduced number of samples.

Acknowledgements

The authors would like to thank the management and staff at Sezela Mill for their assistance during the test and development of the system.

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