THE DEVELOPMENT OF AN INSTRUMENT TO MEASURE THE OPTICAL DENSITY OF JUICE FROM A CLARIFIER

VC STONE

Sugar Milling Research Institute, Durban

Abstract

An instrument was required to detect the presence of mud carry over in clear juice. This was subsequently extended to include the detection of mud level in clarifiers. Both these requirements were satisfied by the development of a multichannel instrument to measure the optical density of juice from several sources. By measuring the light absorbance of juice the quality of clear juice as well as the presence of mud at the clarifier sampling points can be monitored continuously. The mechanical and electronic aspects of the development of this instrument are described. The performance of the prototype installed at a mill is described as well as the design of a production model currently available.

Introduction

A good indication of the performance of a clarifier is the optical density of juice taken from different points of the clarifier. This is normally done manually at the various sampling points. Instruments exist for the on-line measurement of optical density but their prices preclude their use on the numerous points that would have to be monitored to evaluate the clarifier performance effectively. This instrument has been designed using readily available components with a very simple optical system making it economical for the above application. It may be produced in a single-channel version for a particular function such as monitoring clear juice, or in a four-channel version for monitoring clarity and/or mud level at points in the clarifier as well as clear juice.

The optical density of juice consists of two main components, one due to the colour of the juice and the other due to turbidity. Buchanan (1967) has shown that normal variations of juice colour have very little effect on the absorption of light from a tungsten lamp. This instrument, described in this paper, uses a light source with a wavelength of 640 nm which is close to that normally used to measure turbidity. Laboratory tests have shown that at this wavelength the suspended solids contribute about 98% of the light attenuation. Although the measuring principle used is that of a photometer and not the scattering technique of a turbidimeter, the results can be taken as a measure of turbidity because of the wavelength used. No attempt has been made to quantify the suspended solids because of the complex relationship between light absorbance and particle size and nature but the dynamic measurement range of four absorbance units is quite adequate to differentiate between normal clear juice, juice with carry over and mud.

An instrument based on the same principle of light measurement was developed by Buchanan (1967) of the SMRI but apparently no attempt was made to produce any more than the prototype instrument. The instrument described here has been taken through the development stage to a production model which can be supplied to the industry.

Design considerations

Optical system

One of the major costs in any light measuring instrument is the optical system because optical components such as lenses, filters and monochromators are expensive. Elimination of these components was therefore a main aim in this design. This was made possible by the availability of an ultra bright light emitting diode operating at 640 nm with a brightness of 4 candelas. This is about 1000 times brighter than the normal red indicating LEDs. This diode with its fairly narrow angle of emission of about 40° is a good approximation of a point source and its wavelength is close to the standard 720 nm used in turbidity measurements. An LED is a far more rugged and efficient light source than a filament lamp. It has an extremely long life so there should be no maintenance required for the light source.

Conventional optical sample cells are flat sided but a flow through cell of this shape is difficult to produce. A round glass tube was used as the cell and the curvature of the sides was used to form a cylindrical lens which helped to focus the light onto the photocell. Figure 1 shows the arrangement of LED, tube and photocell. An optical gain of 1,6 times was obtained in this way.

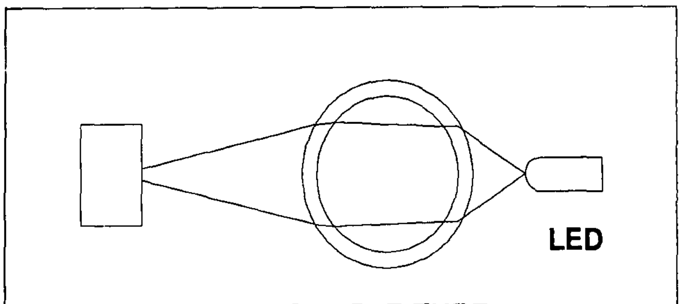

FIGURE 1 Optical system.

The photocell is a silicon photodiode integrated onto a chip together with a voltage-to- frequency convertor. This combination makes a light intensity-to-frequency convertor which has a linear dynamic range of six decades. The light intensity can then simply be determined by counting the frequency. The sensitive area is about two millimetres square and the band of light produced by the cylindrical lens of the cell is about five millimetres wide so that focusing is very simple.

Figure 2 shows the narrow bandwidth of the light available from the LED and its position relative to the spectral response of the photocell.

Electronics

With a frequency output from the optical system the task of the electronics is simply to convert this frequency to an absorbance value and display the result. A microprocessor

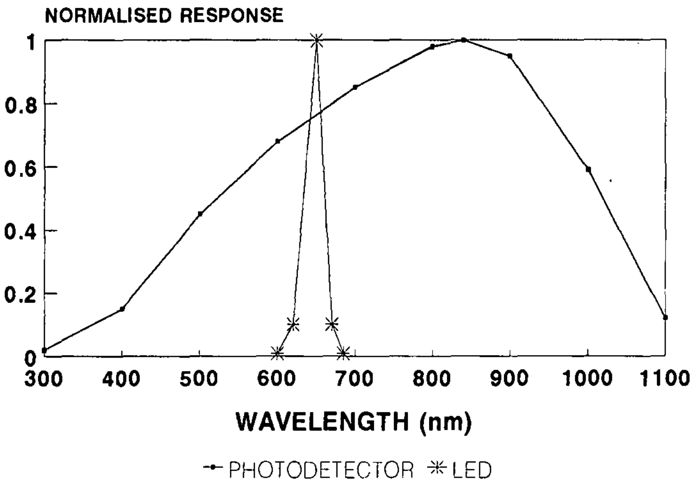

FIGURE 2 Spectral response of photodetector and LED.

was used to do the calculation and provide added features such as self calibration and self checking. A 4-20 mA current loop output was required to provide remote indication or connection to a control system

Mechanical

The main mechanical considerations were the nature of the juice and the temperature at which it leaves the clarifier. Juice out of the clarifier can be very dirty at times with considerable amounts of fibre and sand. This can cause problems with piping and valves. The smallest pipe size that can be used without causing blocking is 13 mm, which determines the size of all the other components. The dirt in the juice makes it impossible to use solenoid valves for control so ball valves with pneumatic actuators had to be used.

The temperature of the juice entering the instrument is about 80°C. The optical system must be closed off from light as much as possible which means there are conflicting requirements for ventilation of the photocell and exclusion of light.

Description of the instrument

The three main components of the instrument, the optical system, the electronics and the control valves are mounted on a metal frame. The single-channel version is shown in Figure 3. The four-channel version is very similar except that it has three additional valves to select the juice streams and the electronics has a larger display to accommodate the additional information.

Optical system

A diagramatic sketch of the equipment is shown in Figure 4.

The juice from the selector valves passes vertically upwards through a glass tube inside the outer light shield. The LED and photo cell are mounted on an aluminium carrier clamped to the glass tube by Tufnol brackets. Another light shield is attached to the cell carrier. A piece of heat absorbing glass is attached to the inside of this cover so that when it is in place the glass is positioned between the sample tube and the photo cell. All the inner surfaces of the cell carrier are insulated and the whole aluminium assembly acts as a heat sink to radiate what heat does get through the insulation. This together with the fan mounted on the outer light shield results in a temperature rise of only 8°C above ambient at the sensor. The photo cell like all silicon photodiodes has a temperature coefficient which results in a 5% change in sensitivity over the temperature range from 20 to 70°C. The abovementioned attention to cooling and the self calibration facility results in an instrument that is practically insensitive to the heat of the juice.

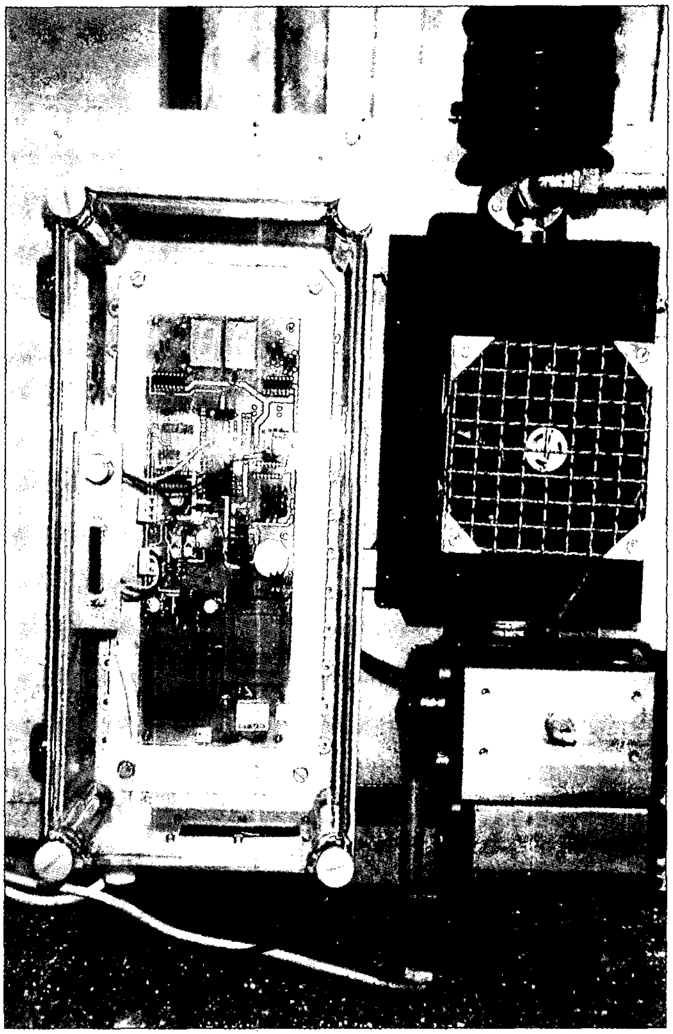

FIGURE 3 Photograph of single channel instrument.

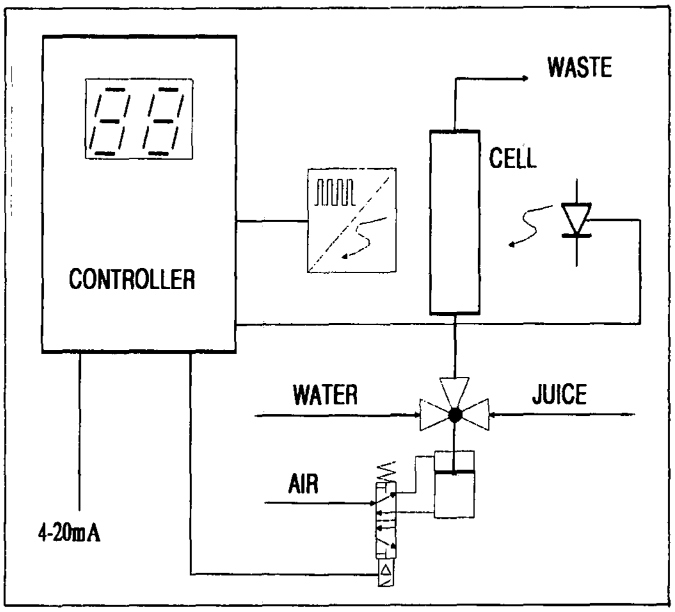

FIGURE 4 Diagram of the instrument.

. Both light shields are not completely light proof due to the need to provide ventilation. The amount of stray light is only significant above two absorbance units where accurate readings are not required because juice producing readings of this magnitude is very dirty and indicates that urgent attention is required.

Electronic system

There are different microprocessor systems for the single- and four-channel instruments. They differ mainly in the display and controls available. The single channel system is based on the Dallas DS5000 microprocessor and has a single two-digit display for the absorbance value. A single control button is available to initiate a calibration cycle when the cell has been manually cleaned. Fault conditions are indicated by flashing the display with an appropriate code number. The four-channel machine based on an 8031 microprocessor module has a four-line by twenty-character display for displaying the four absorbance readings as well as any messages in plain language. A keyboard is used for indicating to the instrument that the cell has been cleaned as well as for programming various parameters that affect the operation of the instrument.

When the instrument is started with a clean cell filled with water, a calibration cycle is initiated. The frequency corresponding to the light intensity at the photo cell is recorded in non-volatile memory and used as a reference for future calculations. When juice is flowing through the cell the frequency from the sensor is read and the absorbance is calculated as follows:

Absorbance = log (reference frequency/measured frequency)

The absorbance value is displayed locally and is also transmitted over the 4-20 mA output. The local display can cover a range of zero to four absorbance units. Four absorbance units means that only 1/10000 of the light passes through the cell and is fairly meaningless for practical purposes. The 4-20 mA loop sensitivity can be programmed to represent any desired range. The default full scale value is two absorbance units. This is suitable for monitoring clear juice which normally produces a reading of about 0,5-0,7. Readings higher than two units can be regarded as approaching mud.

Every hour the instrument starts a self calibration routine. The juice is switched off and clean water is passed through the cell. The reading is monitored by the microprocessor until it has been stable for a period of time indicating that all juice has been flushed out, after which this reading is taken as the new reference in the above calculation. The original start up reading is still kept for comparison with later calibrations so that when the new reference reaches a certain proportion of the start up reference it may be assumed that the cell is dirty and a message to this effect is displayed.

Mechanical

The valves for selecting the juice streams and flushing water are ball valves operated by double acting pneumatic actuators. The air supply for the actuators is controlled by solenoid valves close coupled to the actuators.

The plumbing of the sample lines needs careful consideration. The design of the installation depends on where the sample points and waste disposal point are situated and the pressure at these points. It is not acceptable to have flow in the sample lines controlled by half open valves because this is certain to cause a blockage. Assuming then that all valves will be either fully open or fully closed, the flow through the instrument is determined by the pressure head in the sampling lines, usually the difference between the head height in the clarifier and the pressure of the waste disposal point. These pressures can be adjusted by the choice of the installation site of the instrument.

Choice of the waste disposal point depends on whether clear juice only is being monitored or if there is a chance of a large proportion of mud being passed through the instrument. In the case of clear juice the waste can go to the suction side of the pump delivering clear juice to the juice heaters. When measuring mud level the waste can be fed to the mud mixer or filtrate receiver depending on the location of the instrument. Whatever the destination, if there are long vertical lengths of piping a strong siphon effect can be built up so it may be desirable to insert a vacuum breaking vent at the outlet of the instrument. The vent pipe must be extended above the juice level in the clarifier to avoid overflows.

A supply of clean water at a pressure of at least 100 kPa is required to flush the cell and perform calibrations. Manual cleaning may simply be carried out by removing a screwed plug and inserting a bottle brush into the cell.

Performance

The optical cell was tested by measuring the absorbance of various dilutions of molasses with the instrument and comparing the results with those obtained from a laboratory spectrophotometer at the same wavelength. Figure 5 shows the results obtained.

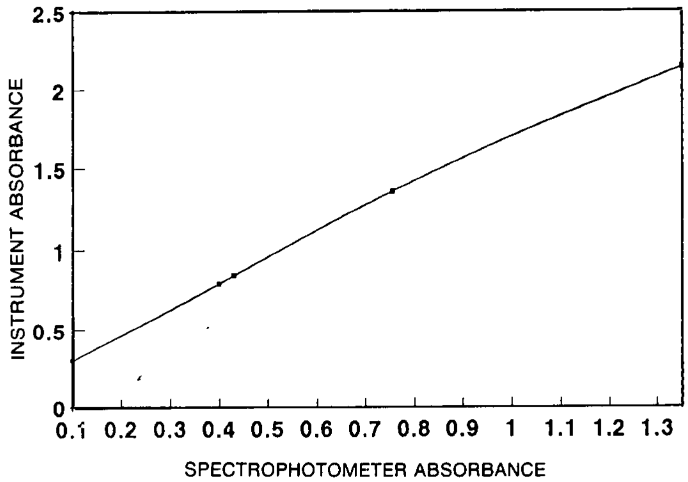

FIGURE 5 Comparison of readings taken with instrument and spectrophotometer.

Over the range normally covered by clear juice the correlation with the spectrophotometer is very good. The absorbance values are not numerically equal because the cell constants are different.

A prototype machine with six measuring cells was first installed at ME for two weeks in 1992 to determine the feasibility of the whole measuring principle. Juice was drawn from the sampling points of the clarifier and measured by the instrument. All the sampling points produced readings of roughly the same value (0,5 unit) with no trace of mud. The mud pumps were then stopped and the mud level was allowed to rise. As soon as the first specks of mud became visible the absorbance value went up to about two units. This showed that the instrument was sensitive to the presence of mud. During this trial any fouling of the glass tubes was carefully observed and over a period of two weeks without any cleaning an error due to fouling of only 1% was measured.

The next version of the instrument was a single-channel fully automated one which was installed on the clear juice line at ME for six weeks in 1993. The instrument ran successfully for this period providing a useful indication of the quality of the clear juice. During this time at the end of the drought the cane quality was extremely poor and the clarifier could not cope with very high loads of suspended matter. Recordings were made of the instrument reading which regularly ran at above one absorbance unit and often peaked above two. Under normal circumstances this would have indicated the need for immediate attention to the clarifier.

During this time the glass tube was found to be visibly fouled within a few days but the instrument compensated for this for a week and was still able to produce good readings. The cell was not left longer than a week before cleaning because it was feared that the dynamic range might have been reduced if the cell became too dirty. It appears that weekly cleaning would be quite adequate in most cases under normal juice conditions.

In this version of the instrument the optical components were cooled by convection which proved to be inadequate. A fan was therefore incorporated in the outer light shield and it reduced the operating temperature to a safe value.

Conclusions

An instrument has been produced which can successfully measure the clarity of juice from various sources. It has been taken through the development stage to a finished product ready for production. It can be used for checking the quality of clear juice or detecting the presence of mud at sampling points on the clarifier. A four-channel version is being developed for production in 1994.

Acknowledgments

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