USE OF JUICE CONDUCTIVITY TO CONTROL DIFFUSER OPERATION

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Abstract

Preliminary tests on the feasibility of using conductivity measurements for diffuser control have shown that brix and conductivity profiles along a diffuser are very similar in shape. The influence of temperature, concentration, pH-value, non-solubles and sulphated ash on conductivity of cane juice was investigated and simultaneous on-line measurements were carried out to establish short- and long-term variations of conductivity, due to changes in cane quality, at four adjacent diffuser stages. The results indicate that conductivity may be a useful control variable for diffuser performance.

Introduction

It is generally accepted that brix profiles along a diffuser give a good indication of the progress of the extraction process and the performance of the plant. However, as the recording of reliable brix profiles is time-consuming and labour-intensive, it is not often carried out in factories and the actual performance of the plant cannot be controlled sufficiently for optimum operation. An automatic measuring device to overcome this particular problem is not a practical proposition under factory conditions, therefore the possibility of obtaining information on diffuser performance by replacing brix profiles by conductivity profiles, which can be measured and monitored continuously in the factory at low instrumentation and labour costs, was investigated. The results of these preliminary investigations are reported below.

Conductivity profile versus brix profile

The conductivity of aqueous solutions is due to the partial dissociation of the molecules into positive and negative ions which in an electric field will become the carriers of an electric current, and this can be measured and calibrated in units of conductivity. Since the degree of dissociation is high in dilute solutions, the particular concentration of the solution can be ascertained by measuring the specific conductivity.

Problems concerning the measurements of cane juice conductivity are:

(1) The relationship between conductivity and concentration is proportional at low dilution, but with increasing concentration, the ions start hindering each other resulting in a decrease of conductivity and the initial proportionality ceases to exist from a certain point of concentration.

(2) The conductivity of solutions increases with increasing temperature because less resistance is offered to the migrating ions.

(3) Cane juice is a solution of sucrose and non-sucrose. Because the conductivity of sucrose is negligible in comparison with that of the ionised non-sucrose, any measurement of juice conductivity determines mainly the concentration of ionised non-sucrose. It must be assumed, at least at the beginning of the extraction process, that sucrose and ionised non-sucrose are extracted at a constant ratio.

(4) Non-sucrose in juice depends not only on cane quality, but also on cane cleanliness, both of which are subject to rapid changes. Unfortunately, these two factors are outside factory control and therefore the conductivity of the juice will also change.

Before extensive laboratory and factory tests were carried out, brix and conductivity profiles along an efficient diffuser were compared. Juice samples were taken along the De Smet diffuser at TSB, Malelane and the brix and conductivity were determined in the laboratory at 20° C and plotted against the sample points. An average brix and conductivity profile along the diffuser is shown in Fig. 1 and it can be seen that the two curves are very similar in shape, having the same steep decline over the first 4 to 5 stages and tailing off towards the discharge end. Measurements carried out at AK, GH and UC confirmed this similarity and also showed that operational problems were reflected by conductivity profiles in the same way as by brix profiles. This indicated that it might be feasible to replace brix by conductivity profiles to control diffuser operation.

Conductivity of cane juice

Greater knowledge of the measurement of juice conductivity was needed in order to develop a suitable data acquisition system. Some problems concerning on-line measurements were

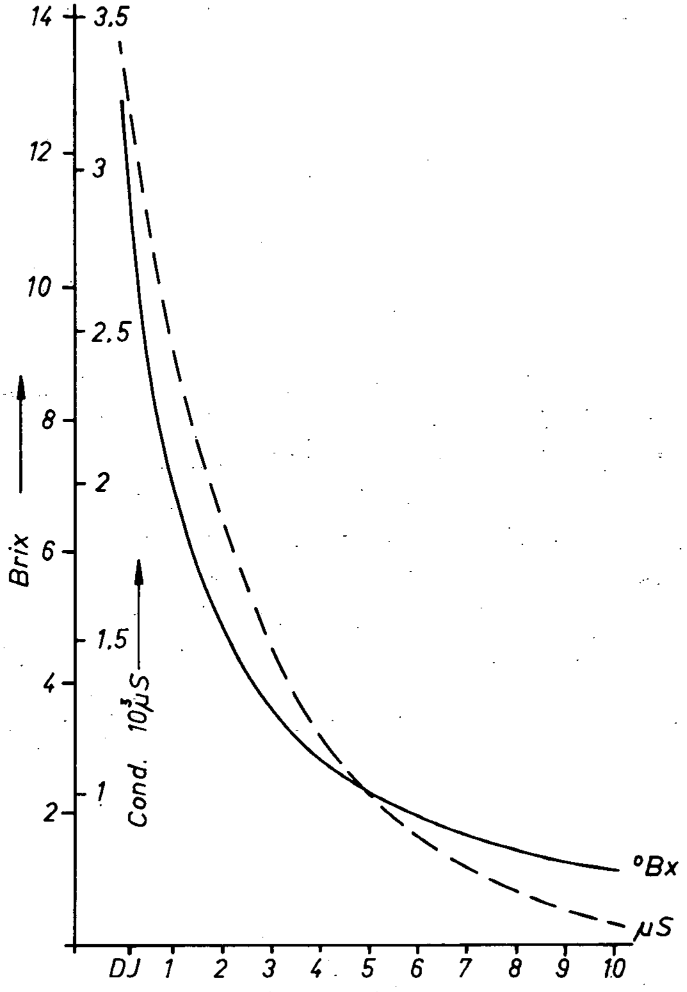

FIGURE 1 Average brix and conductivity profile along De Smet diffuser at ML.

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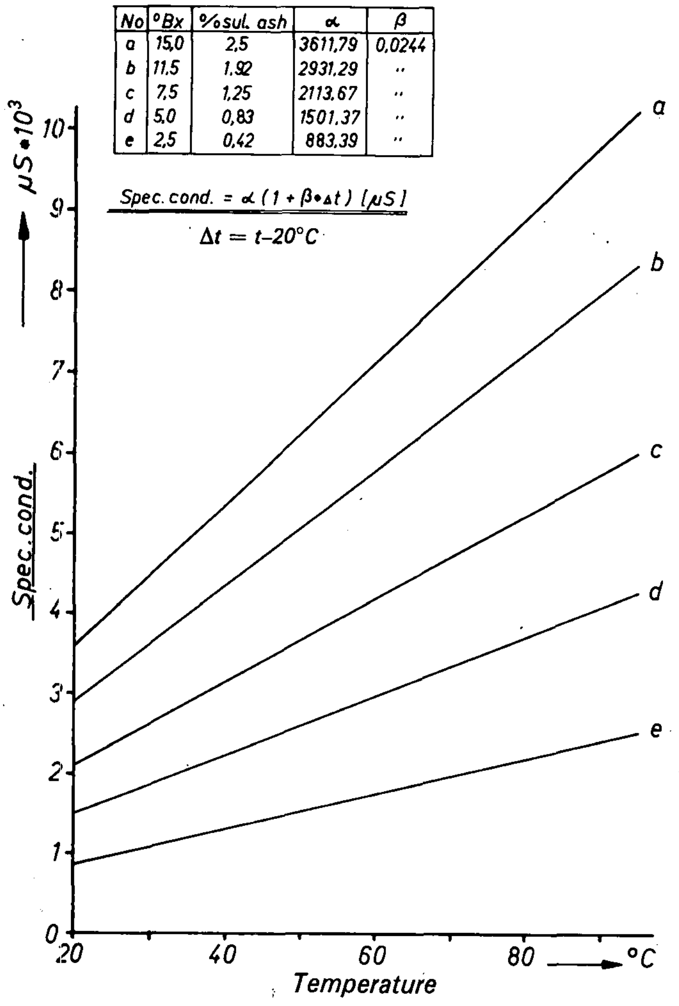
therefore investigated in the laboratory, viz. the influence on the conductivity of temperature, concentration, pH-value, non-solubles and sulphated ash content of the juice.

During the early stages of these investigations, samples were treated with a preservative, but the preservative influenced the results considerably; a 0,3 % concentration of $HgCl_2$ raised the conductivity by about 100 %. Due to the inaccurate addition of preservative in the factory, a correction for its influence was impossible. Subsequently, only untreated samples were investigated and these were deep-frozen during storage. However, replicate analyses were necessary to establish the experimental error for the investigation and it was found that repeated deep-freezing of a sample resulted in an increase of its conductivity value. Therefore, the original samples were sub-sampled before storage, defrosted only when ready to be examined, and afterwards destroyed.

(*a*) *Influence of temperature*

Samples of about 5 litres were taken from process juice of the diffuser, agitated carefully, and 5 sub-samples were made. Four of these were diluted with deionised water to lower concentrations, thus keeping the nature of the juice unchanged. These samples were stored in a deep-freezer after being further sub-sampled three times. Hence, a total of 15 samples had to be investigated for each test.

The influence of temperature on conductivity was measured as follows. The defrosted sample was poured into an insulated container, agitated by a magnetic stirrer, and electrically heated at a rate of 0,5° C/min from 20° C to 95° C. The conductivity was measured with a Beckman solu-meter, type SM and a Beckman conductivity cell, model 414 for each 5° increase in temperature. The results obtained for juice samples taken at GH are shown in Fig. 2. As expected, a linear relationship exists between temperature and conductivity of juice, but the lines for the different concentrations are not parallel. The reproducibility of the results was ± 3 % and interpolation between the lines is therefore permissible.



No	°Bx	% sul. ash	α	β
a	15,0	2,5	3611,79	0,0244
b	11,5	1,92	2931,29	··
c	7,5	1,25	2113,67	··
d	5,0	0,83	1501,37	··
e	2,5	0,42	883,39	··

$$\text{Spec. cond.} = \alpha\,(1 + \beta \cdot \Delta t)\ [\mu S]$$

$$\Delta t = t - 20°C$$

FIGURE 2 Conductivity versus temperature for different juice concentrations (GH samples).

(*b*) *Influence on concentration*

The data obtained for the conductivity versus temperature measurements were used to derive Fig. 3, which shows that the relationship between conductivity and concentration is not linear over the range investigated. These results were confirmed by measurements carried out at ML.

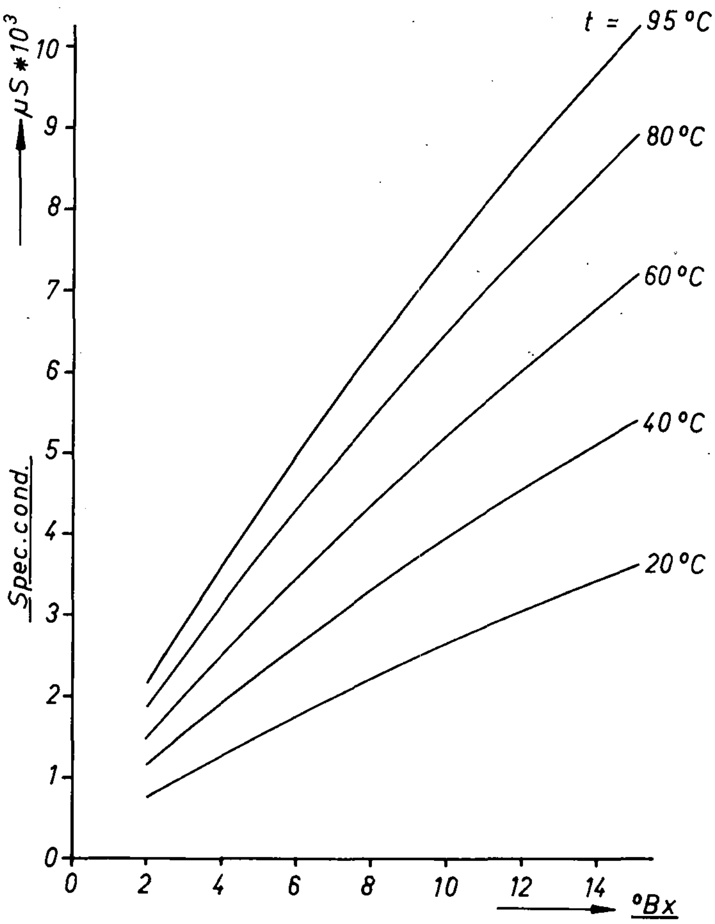


FIGURE 3 Conductivity versus concentration for different temperatures (GH samples).

(*c*) *Influence of pH*

As milk of lime is added only at certain stages along the diffuser, the pH of the juice in the diffuser is not constant. The influence of a change in the pH (within practical limits) on the conductivity at different temperatures was therefore examined under the conditions mentioned above. The results of the statistical analyses on the data obtained indicated that there is, with 95 % probability, no significant influence of pH on conductivity for a pH between 5 and 8 and for temperatures from 60° C to 90° C.

(*d*) *Influence of non-solubles*

Investigations on clean and dirty juices were carried out to establish if non-solubles (floating particles, dispersion, bagacillo, sand, etc.) influenced the conductivity of cane juice. No significant results were obtained on a 95 % probability level.

(*e*) *Influence of sulphated ash content*

The sulphated ash was determined on all the juice samples. However, this parameter does not characterise a juice sufficiently as it is a combination of unknown proportions of soluble and non-soluble ashes. In addition, the sulphated ash determination cannot be carried out on a routine or continuous basis and it is therefore unsuitable as a control variable.

An attempt was made by means of a statistical evaluation to analyse all the data obtained. Multilinear regressions were carried out for conductivity as a function of brix, temperature, and percent sulphated ash and the following formula was derived from $n = 300$ data, measured on juice samples from GH:

$$\text{Specific Conductivity } (\mu S) = -1940{,}86 - 1190{,}15(°Bx) + 9419{,}57(\%\text{ sulphated ash}) + 51{,}26(°C);\ r = 0{,}964.$$

This empirical formula is valid for the range:

$$2 \leq °Bx \leq 13,$$
$$0{,}3 \leq \%\text{ sulphated ash} \leq 2{,}5,$$
$$20 \leq °C \leq 95.$$

Although the coefficient of multiple correlation, 0,964, is very good and conductivity values calculated by this formula were ± 6% of the measured data, this equation should not be used generally, as sulphated ash values do not characterise a juice sufficiently.

Variations in conductivity levels in a diffuser compartment

As the quality of the cane fed to the extraction plant changes continuously, an investigation was made to determine whether these changes influence the conductivity levels to such an extent that on-line measurements become meaningless. Some tests were carried out to establish short- and long-term variations of conductivity in a diffuser compartment.

Short-term variations

At UC, 20 juice samples were taken every 30 seconds over a 10-minute period and analysed in the laboratory for brix, specific conductivity, and percent sulphated ash. The results of the statistical evaluations, based on 95% probability, are shown in Table 1 together with their confidence intervals. The variation of the conductivity was about 10% of the mean, while the brix changed by about 5% and the sulphated ash by about 9%.

TABLE 1
Mean and confidence interval for data from juice samples taken at UC

Variable	Mean	Confidence interval (% mean)
Brix	3,23°	± 5,3
Specific conductivity	1534 μS	± 10,3
Sulphated ash	0,29%	± 8,8

Long-term variations

A continuous conductivity recording device (Beckman solumeter, type SM; Beckman conductivity cell, model 414; and Philips two-point recorder) was installed by Huletts R&D at the AK diffuser. The conductivities were measured and monitored over a period of four days at two different stages and an evaluation of the charts resulted in the following average and confidence interval, based on 95% probability:

$$\text{Specific conductivity} = (2500 \pm 10\%)\ \mu S.$$

Extreme values of about 1900 μS and 3500 μS were observed, but these levels persisted only over short periods.

On-line conductivity measurements were also carried out at GH at different diffuser stages. An example of a conductivity recording over an eight-hour period at stage 13 is given in Fig. 4 and as can be seen, the conductivity level was fairly stable throughout the test period with an average of about 540 μS and a maximum variation of ± 10%. Further tests have been carried out at stages 1, 3, 5 and 7 and all resulted in a variation of ± 10% of the mean.

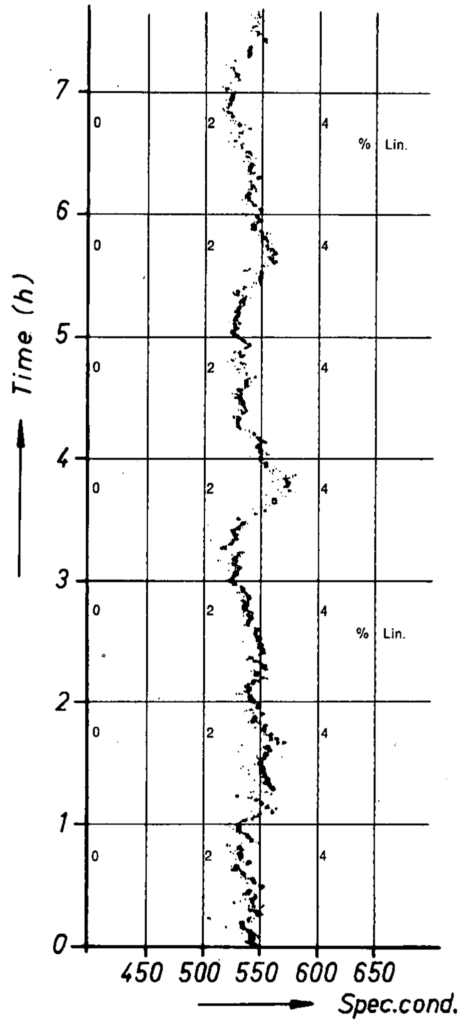


FIGURE 4 Changes of conductivity level at stage 13 of diffuser at GH.

Simultaneous on-line conductivity measurements along the diffuser

Since the total variations of conductivity levels were ± 10% of the mean, it was felt that these would be suitable indicators for diffuser control. Four simple electrodes without temperature compensation were installed at the first four juice delivery pipes of the diffuser at GH. These electrodes were scanned every 6 minutes and the conductivity was measured with a Beckman solu-meter type SM and, at the same time, juice samples were taken and analysed for their conductivity in the laboratory to calibrate the installed electrodes. In Fig. 5, in which a chart with continuous conductivity recordings of the first four diffuser stages is reproduced, all 4 lines change their directions with time, but they remain almost parellel. Although the cane quality varied over this time period and resulted in a continuous decrease in juice conductivity, these changes were transmitted along the diffuser stages with very little delay. No rapid changes in conductivities were observed, probably because any effect of change in conductivity due to cane quality is smoothed out by the continuous dilution of the scalding juice in the circulation trough of the diffuser. A further dampening of any rapid changes will be due to juice recirculation in the diffuser, which is inevitable even under optimum operational conditions.

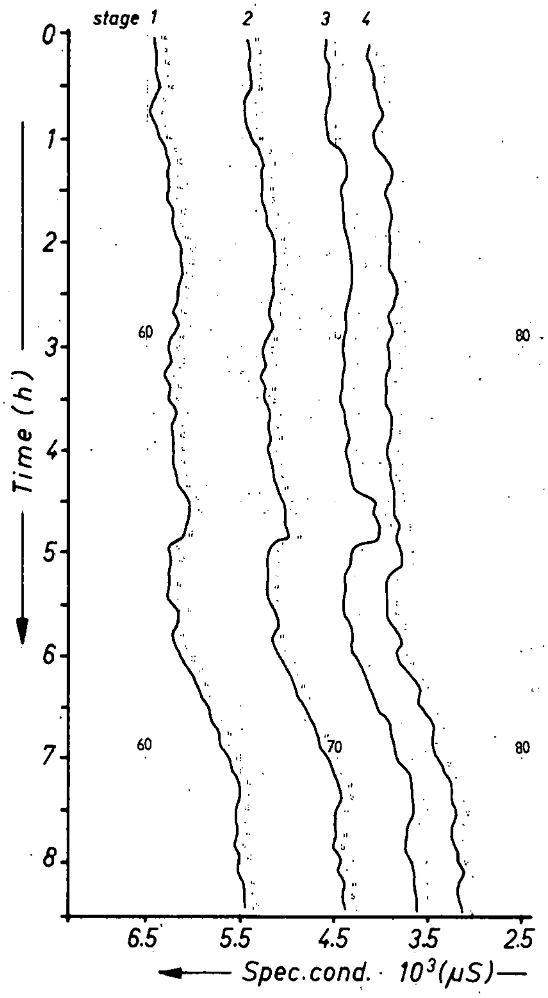


FIGURE 5 Conductivity recordings at stages 1, 2, 3 and 4 of diffuser at GH.

Conclusions

The results obtained to date indicate that it appears possible and practical to judge diffuser performance by means of a change of juice conductivity between two adjacent stages in the same way as can be done with changes in concentration expressed by brix.

Because of financial problems and lack of time, it was not possible to complete these investigations and further experimental work should be performed. The next step in the continuation of this work should be the installation of temperature compensating electrodes in all juice delivery pipes of the diffuser. It will then be possible to compare "on-line" conductivity profiles with brix profiles based on spot samples taken along the diffuser. It is expected that a good correlation between these profiles will be found, but should no statistically significant correlation be ascertained, the investigation would have to be abandoned. If, however, these comparisons are satisfactory and all conductivity measurements are within the ± 10% range, it should be possible to use these data directly for a comparison of actual plant performance against a standard conductivity profile. Because of rapid changes in cane quality and cleanliness, variations might exceed this 10% range. This is likely to occur in the process and scalding juice pipes before the damping of the conductivity measurements due to recycling, mixing, and dilution becomes too severe and in this case, the starting point for conductivity profiles might vary by even more than ± 50% (as indicated by some sample measurements). Under such conditions it will be difficult to compare actual performance against a standard, but this problem might be overcome by using the measured data relative to each other instead of absolute values. The highest value (e.g. process juice) can be taken as 100% and all the other measurements would be expressed as a percentage of this value. The comparison of such an "actual" conductivity profile with an "ideal" curve, which gives "ideal" percentage decreases in conductivity between any two stages, will then indicate the performance situation. Some kind of logic circuitry would be necessary to enable the comparisons on a percentage basis to be made, and it is felt that a microprocessor with a video-screen would be very suitable for this task.

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