THE EFFECT OF SELECTED FACTORS ON PERCOLATION IN PILOT DIFFUSION COLUMNS

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Abstract

Percolation through prepared cane beds has been investigated in both laboratory and pilot plant columns. The investigation has concentrated on the effects of cane packing density, flocculant, clarifier mud and soil on the percolation rate. At the levels usually found in sugar factories flocculant and clarifier mud have little impact on the percolation rate. Cane packing density has a marked effect, and the presence of soil in cane affects the percolation rate negatively. The use of lime to correct the pH of the percolating liquid is known to reduce percolation; this was confirmed and work with other alkaline agents is suggested. Further work is required and various areas for investigations are suggested.

Keywords: percolation, mud, flocculant, soil, lime, pH, diffuser, diffusion

Introduction

Diffusion is now well established in South Africa, with 16 diffusers in 2004 processing 91% of the cane. The progress of diffusion in this country is summarised in Table 1, based on data given in the Monthly Summary of Laboratory Reports from the Sugar Milling Research Institute (SMRI). Extractions achieved by diffusers have been excellent, with five units reporting values above 98.3 for the 2004-2005 season.

Table 1. Progress of diffusion in South Africa.

Season	Number of diffusers in South Africa	Percentage of the cane processed by diffusion
1969 – 1970	4	16
1979 – 1980	9	43
1989 – 1990	14	67
1999 – 2000	17	84
2004 – 2005	16	91

Pioneering work on cane diffusion (Love and Rein, 1980) identified percolation through the cane bed as being a most important operational parameter. Poor percolation can give rise to flooding which occurs when more liquid is sprayed on the top of the cane bed than is able to percolate downwards through the bed. Flooding results in serious drops in extraction; it can cause a number of operational problems such as the washing of cane out of the feed or discharge end of the diffuser, spillages of cane and juice with associated losses, downtime and reduced throughputs.

Percolation and the factors that affect it have been investigated, in both pilot plant and full-scale diffusers, by Love and Rein (1980) and by Rein and Ingham (1992). The degree of cane preparation, the bulk fibre density and the cane quality were found to be the factors that affect percolation most; the pH of the percolating liquid was also found to have a very significant effect.

The routing of clarifier mud to diffusers, thus eliminating the need for a filter station is a recent innovation. It was applied at Maidstone on a permanent basis from the beginning of the 1999 season. Meadows *et al.* (1998) and Jensen and Govender (2000) described this implementation and commented on steps taken to ensure that the performance of the diffuser was not affected negatively, particularly in terms of percolation. Apart from the impact of the mud itself, recycling can affect the diffuser in two other areas: firstly it can change the pH profile in the diffuser since mud will generally be at a pH similar to or slightly higher than that of clear juice and secondly mud can contain residual levels of the flocculant used at the clarification station, which could possibly reduce the percolation rate in the diffuser.

Recently, serious operational problems, resulting in an 11-hour stop, were encountered in diffuser B at Felixton, following which the factory staff gathered evidence showing that mud recycling and high levels of soil in cane could be associated with the problem.

Since the effects of mud and of soil in cane on percolation have not been investigated, it was decided to use pilot diffusion columns to look at the impacts of clarifier mud, soil, flocculant and pH on the percolation rate.

Equipment and experimental methods

Various small laboratory columns were used to compare selected factors, mostly pH and packing density. These tests were done at room temperature and with cane prepared by a Jeffco cutter-grinder, and are thus not representative of industrial diffusers but cane quality and preparation were well controlled.

A pilot column, shown schematically in Figure 1, was constructed and located at the Maidstone factory to allow experimental conditions to be as close as possible to industrial ones. The column was jacketed and condensate was used to keep the temperature around 75ºC; the bottom tank was filled with the same hot condensate that was then circulated through the cane bed. Shredded cane was obtained from the Cane Testing Services sampling point and manually fed into the column; between 25 and 35 kg of cane were used, with bed heights of 35 to 55 cm. The cane packing density varied between 300 and 450 kg/m^3; fibre % cane values at Maidstone were around 16 when the experiments were done, which yielded fibre packing densities of 48 to 72 kg/m^3. The pump delivered up to about 200 litres per minute. A sight glass was fitted, which allows the cane surface to be seen; the by-pass gate valve was then adjusted to keep the level of liquid at a fixed height above the cane surface. When the conditions were steady the flow rate was obtained by diverting the liquid to the bucket for a measured time, measuring its mass and converting to volume of liquid per unit time (m^3/min).

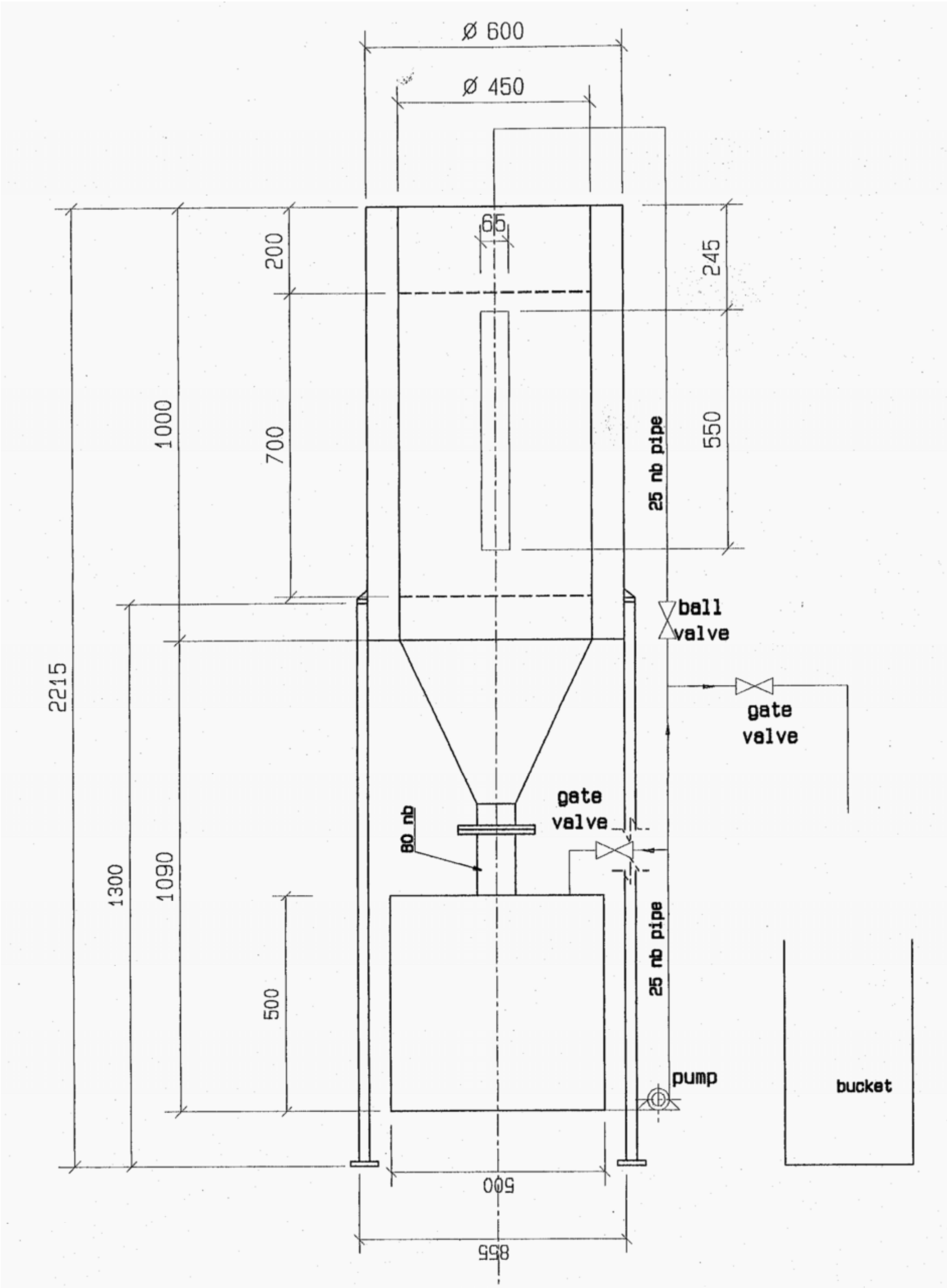

Figure 1. Schematic diagram of the pilot percolation column installed at Maidstone.

In all experiments the percolation rate, U, was obtained as follows. The flow rate (Q) of the percolating liquid, in $m^3.min^{-1}$, was measured; the area (A), in m^2, of the top surface of the cane bed was also measured; percolation rate is then given by:

$$U = \frac{Q}{A}$$

U has been expressed in metres per minute in the paper.

Results

Love and Rein (1980) found that the percolation rate decreased with time as a run was progressing in their pilot column; this was caused by the compaction of the cane bed with time. When the bed had stabilised, the percolation rate and column height were measured. The same effects were found in the pilot column installed at Maidstone; in addition however, a marked increase in percolation rate was apparent during the last part of the series of tests. The results obtained for 11 runs done over the period September to November 2004 are shown in Figure 2. In all cases the first bar represents the first measurement after stabilisation, while the second bar represents a value measured 15 to 30 minutes later. The results given in Figure 2 show that percolation rate was around 0.5 m/min for the first eight runs, with some random variability between the first and second measurements. In November, however, a marked increase in percolation rate was evident and the time taken to reach stabilisation appeared much longer. Except for cane quality there were no obvious reasons for these changes.

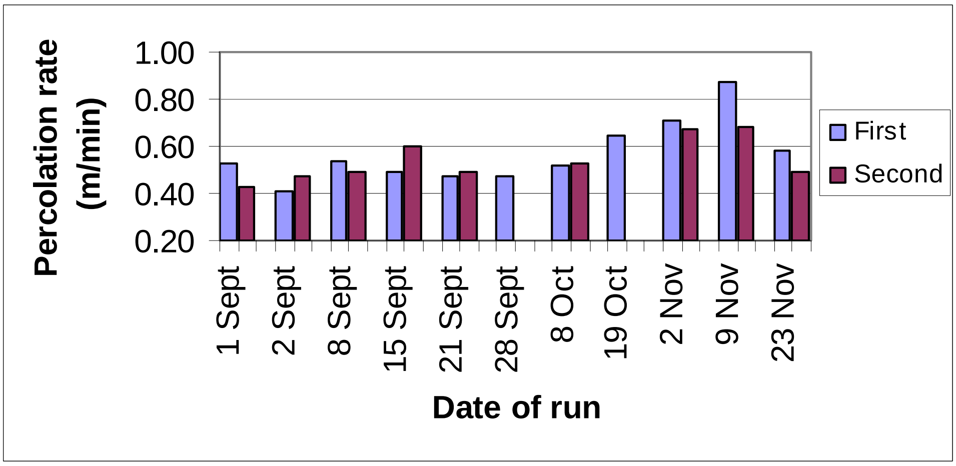

Figure 2. Percolation rates for prepared cane samples at Maidstone: first two consecutive measurements.

Effect of packing density

Love and Rein (1980) found that the bulk fibre density in the bed correlated inversely with percolation rate; bulk fibre density can be converted to cane density in the bed if fibre % cane is known. These authors worked with cane densities of 430 to 560 kg/m^3, bed heights of around 150 cm, and percolation rates of 0.15 to 0.32 m/min.

Tests[1] were done in the laboratory column using a Jeffco cutter-grinder to prepare the cane, and the runs were done at room temperature. The column was packed with known masses of the same prepared cane, compressed manually to a predetermined height, before starting the

[1] Unpublished data, Sugar Milling Research Institute, Durban, South Africa.

percolation. In this way the cane density could be set to approximately the desired value. In these tests cane densities ranged from 480 to 600 kg/m^3, bed heights from 30 to 50 cm, and percolation rates from 0.06 to 0.26 m/min. Percolation rates correlated with cane bulk density (D) as shown by Equation 1:

$$U = -0.0017D + 1.04 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

with an R^2 value of 0.86 for six pairs of observations.

The tests done in the pilot column at Maidstone involved different samples of cane prepared by the factory and the runs were done at 70 to 75ºC. Cane densities could not be varied as widely as was the case in the laboratory column and ranged from 250 to 425 kg/m^3, while bed heights ranged from 40 to 60 cm and percolation rates from 0.44 to 0.78 m/min. Percolation rates correlated with cane bulk density as shown by Equation 2:

$$U = -0.0018D + 1.18 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

with an R^2 value of 0.67 for seven pairs of observations.

Although the experimental conditions were very different for these two sets of experiments, Equations 1 and 2 are remarkably similar. The combined results are plotted in Figure 3, and percolation rate now correlated with cane density as shown by Equation 3:

$$U = -0.0020D + 1.24 \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

with an R^2 value of 0.94 for 13 pairs of observations.

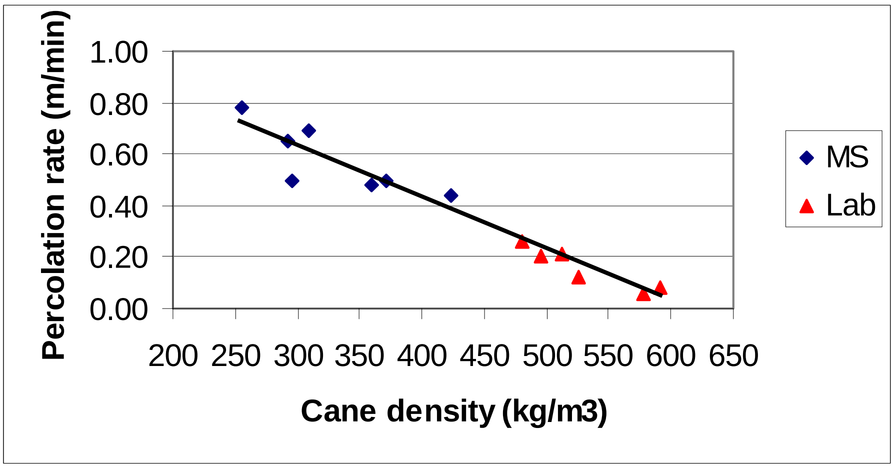

Figure 3. The relationship between percolation rate and cane density in laboratory and pilot plant diffusion columns.

The results in Figure 3 indicate that cane-packing density can be an overriding factor under experimental conditions.

Effect of flocculant

The effect of flocculant was investigated in the pilot column at Maidstone; the flocculant was that used at the clarification station of this factory and it was added as required to the circulating liquid. No impact on percolation rate was detected with concentrations up to about three times higher than normal (4 ppm on mixed juice), as shown in Figure 4. A catastrophic contamination was, however, not investigated.

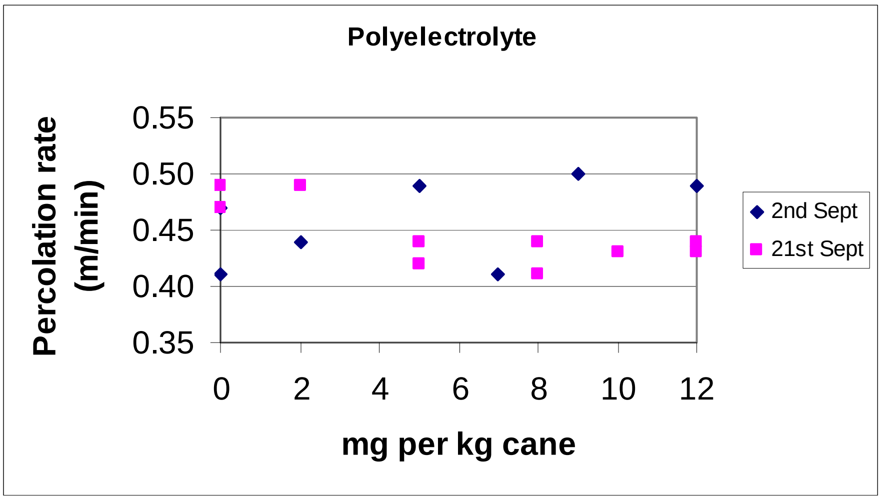

Figure 4. The effect of flocculant on the percolation rate in the pilot column at Maidstone.

Effect of clarifier mud

The effect of mud was tested on the Maidstone pilot column by adding the required masses of mud to the circulating liquid. The results are shown in Figure 5. The usual levels of mud found in diffusion factories, namely 6 to 7% on cane, show little to no impact on the percolation rate although it is evident that higher levels do reduce percolation. It should be noted that the results shown in Figure 5 include extremely high quantities of mud that are unlikely to be reached in factories.

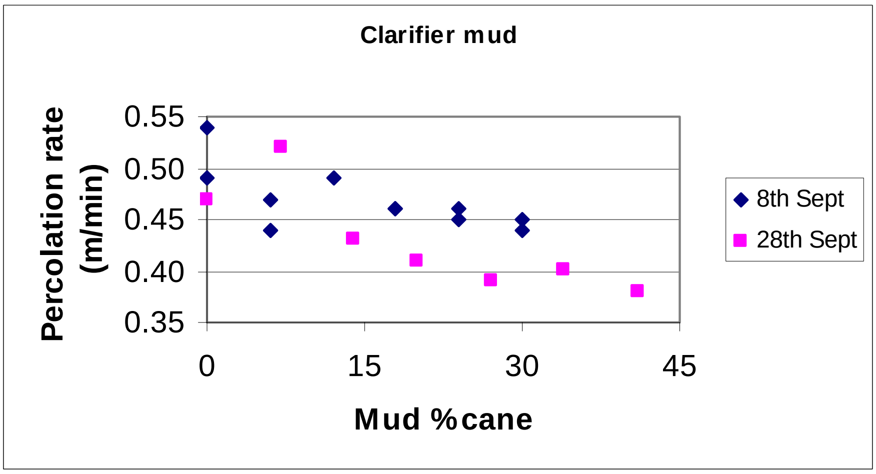

Figure 5. The effect of clarifier mud on the percolation rate in the pilot column at Maidstone.

Effect of soil

A high clay content (34%) soil was used in the Maidstone column. The procedure used to introduce the soil into the column was to mix the required mass of soil with a small quantity of the prepared cane sample; this mixture was then spread on the top of the cane bed in the column. Liquid circulation had to be stopped to carry out this procedure and there was thus some disruption to the percolation process. The results obtained show that the high clay content soil did decrease the percolation rate, even when the soil was present at relatively low concentrations, as shown in Figure 6. The results of another run where soil was added once only are given in Table 2.

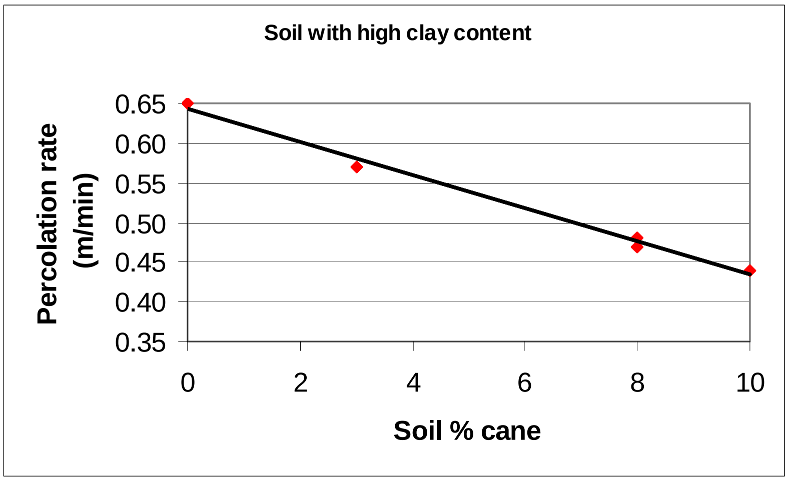

Figure 6. The effect of a high clay content soil on the percolation rate in the pilot column at Maidstone.

Table 2. Effect of the high clay content soil on percolation rate in the pilot column.

Soil % cane	Percolation rate (m/min)
0	0.49
5	0.40
5	0.36

Clearly, the presence of a high clay content soil reduced percolation rate; in both runs 1% of the soil in cane reduced percolation by 3 to 4%. It should be noted that the soil content was quantified by using the mass of soil as is; this soil showed a moisture content of 17% and an organic matter content of 4%. At mills the soil content is quantified by ashing prepared cane samples, and on this basis 1% ash from soil in cane would reduce percolation by about 5%.

Effect of pH

Love and Rein (1980) added milk of lime to the circulating liquid of a pilot plant column filled with industrially prepared cane, to increase the pH from 5.2 to 7.6. This resulted in the percolation rate decreasing from 0.20 to 0.13 m/min, which is equivalent to a decrease of about 15% per unit of pH over the range found here. These authors noted that the addition of lime caused some compaction to take place in the cane bed; the decrease in percolation rate could, however, not be attributed to the compaction only.

The investigation of pH effects in the Maidstone column was affected by the changes in cane quality mentioned earlier in the paper; preliminary results with milk of lime are shown in Figure 7. Here pH was increased from 4.7 to 8.2 and the percolation rate decreased from about 0.48 to 0.37 m/min, equivalent to a decrease of about 8% per unit of pH over that range of pH. This drop is lower than the one found by Love and Rein (1980), and the relation does not seem to be linear but there is too much scatter to confirm this statistically.

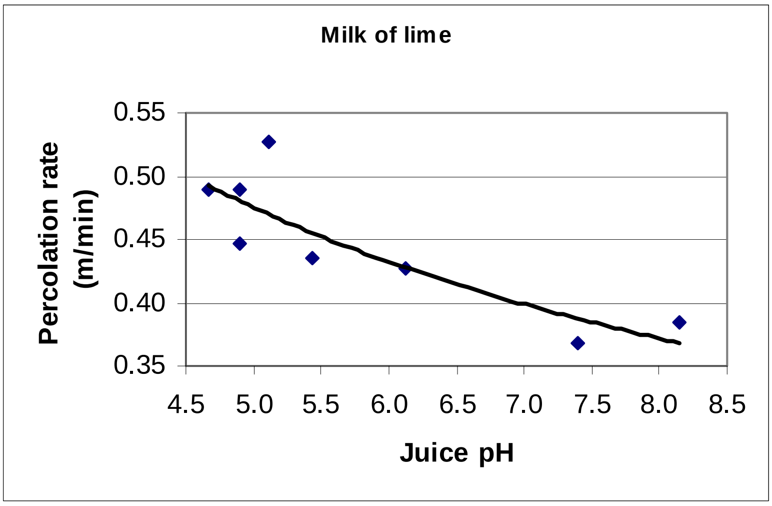

Figure 7. The effect of pH measured at room temperature on the percolation rate in the pilot column at Maidstone.

Conclusions

This work shows that relatively simple pilot equipment and experimental procedures can be used to study the effect of various factors on percolation. More particularly, it is possible to investigate the effects of mud recycling, of flocculants and of soil in cane on percolation rate.

Although cane-packing densities in the Maidstone pilot column were lower than those achieved during pioneering work on percolation by Love and Rein, a strong linear relationship was found between percolation rate and cane density over a wide range of packing density. This result indicates that cane-packing density may be overriding in affecting percolation rates in pilot diffusion columns. It will be necessary, however, to confirm that the results obtained with mud, flocculant and soil also apply at higher packing densities, and thus at lower percolation rates.

Generally the presence of flocculant at the normal levels used in the factory, and mud recycling with normal levels of mud % cane did not affect the percolation rate significantly. The effects of instantaneous and extremely high flocculant contamination, and of abnormally high quantities of mud were not investigated.

Soils with high clay contents on the other hand measurably reduced percolation when present in cane at concentrations found in industry. At values of 5% ash in cane percolation rate would be reduced by 25% if the ash originated from a high clay content soil.

The experimental work showed that the use of milk of lime to increase the pH of the percolation liquid reduced the percolation rate; this reduction ranged from 8 to 15% per unit of pH, over a pH range of 5 to 8. There are indications that the reduction in percolation rate was not due only to the compaction of the cane bed, through softening of fibre occurring at higher pH values. It is therefore necessary to investigate the effects of using sodium carbonate or sodium hydroxide to increase the pH.

Another aspect needing investigation is to establish whether the effects of flocculant, of clarifier mud and of soil are additive. If this is the case then the presence of these three materials at relatively low concentrations could result in operational problems in diffusers.

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