TRACER TESTING IN CLARIFIERS

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Abstract

Two methods of tracer testing on clarifiers have been investigated, and both have been found to be useful. The methods are described and results of tests presented. The method using sodium chloride, monitored as conductivity, is a useful qualitative tool, whilst the method using lithium chloride, monitored as lithium, can yield quantitative information. In instances of high mud levels and of high throughputs large quantities of juice bypassing have been found, resulting in mean juice residence times significantly shorter than the theoretical value.

Introduction

Problems at Empangeni mill with clarifier carry-over and suspected mud build up in the trays led to the investigation of tracer testing for evaluating clarifier performance.

The juice residence time is an important factor affecting the performance of a clarifier. The ideal condition is the existence of plug flow, where any juice entering the clarifier eventually leaves one mean residence time later (determined as the volume of the clarifier divided by the volumetric flowrate of juice).

There are two basic types of deviation from this ideal situation which determine the approach of the clarifier to ideal conditions, viz.

(i) the presence of stagnant pockets of juice (dead volume) in the clarifier, resulting in inefficient utilisation of the installed clarifier capacity.

(ii) a distribution in residence times about the mean (dispersion) with some juice having residence times significantly shorter than the mean, resulting in solids carry-over in the clear juice.

Experimental

Sodium Chloride Tracer.

During the 1978/79 season tracer tests were performed on clarifiers in the Huletts group using sodium chloride as a tracer, monitored by conductivity.

For the large clarifiers (460 m^3) at Darnall and Empangeni, 300 kg of salt were dissolved in hot water and then pumped into the clarifier, at the beginning of a test, over a period of about 5 minutes to simulate an ideal impulse to the system. On the smaller (252 m^3) clarifiers at Mount Edgecombe only 150 kg of salt were used for each test.

Samples were taken regularly from all of the clear juice outlets of the clarifier under test and analysed immediately for conductivity using temperature compensated conductivity probes.

Lithium Chloride Tracer.

To overcome the problems of base line drift experienced with the sodium chloride/conductivity method, the use of lithium chloride monitored as lithum measured by flame emission spectrocopy was investigated. The quantities of lithium required necessitated the use of a technical grade lithium compound. This was acquired in the form of lithium hydroxide monohydrate which was reacted with technical grade hydrochloric acid to form the highly soluble lithium chloride. The cost of lithium in this form works out at R25,41/kg which compares favourably with the price quoted by Wright[1] of $US 48,50/kg of lithium purchased as lithium chloride.

To ensure detectable tracer peaks, it is necessary only to add sufficient lithium chloride to result in a lithium concentration of approximately 1,5 ppm if the tracer were fully mixed with the total volume of the clarifier. The solution of lithium chloride was added to the clarifier by pouring it from a bucket into the mixing chamber on top of the clarifier.

All of the clear juice outlets were sampled during a test but, to reduce the analytical load, samples from the different outlets on each tray were composited to give only one set of samples for each tray.

To ensure that no rapid bypassing occurred undetected, the sampling rate for the first 30 minutes was every 5 minutes. The sampling rate was then progressively decreased for the rest of the test as natural dispersion ensures that no sharp peaks can occur after longer periods of time.

The samples were analysed for lithium by flame emission spectrophotometry.

Flow Measurement and Control.

The flow into a clarifier from a common liming tank cannot be measured and controlled by the normal method of orifice plate and control valve as these devices place large shear forces on the juice which would damage the floc formed in the liming tank.

To overcome this problem for the lithium tracer tests done on the Mount Edgecombe clarifier, a system was devised whereby flow to the clarifier was from a rectangular weir on the liming tank, with the liquid level in the tank held constant by an adjustable weir feeding the other clarifier in operation. (See Appendix). The split in flow between the four trays of the clarifier was estimated from measurements of the height of liquid flowing over the weirs at the clear juice outlets from the clarifier.

Results

Sodium Chloride Tracer.

Figure 1 shows the basic construction of the Rapidorr 444 clarifier at Empangeni on which the following tests were performed.

Figure 2 shows the tracer response curves from a test performed when it was suspected that there was a large amount of solidified mud in the clarifier. The conditions during the test were :

Diameter	11 m (36 ft).
Volume	460 m^3
Juice inlets	0,27 m^2 per tray (trays 1, 2 & 3).
	0,10 m^2 (tray 4).
Juice outlets	0,065 m^2 per tray.
Juice flow	240 m^3/hr.
∴ Inlet velocity	3,7 m/min (trays 1, 2 & 3).
	9,0 m/min (tray 4).
Outlet velocity	15,4 m/min.
Theoretical residence time	115 min.

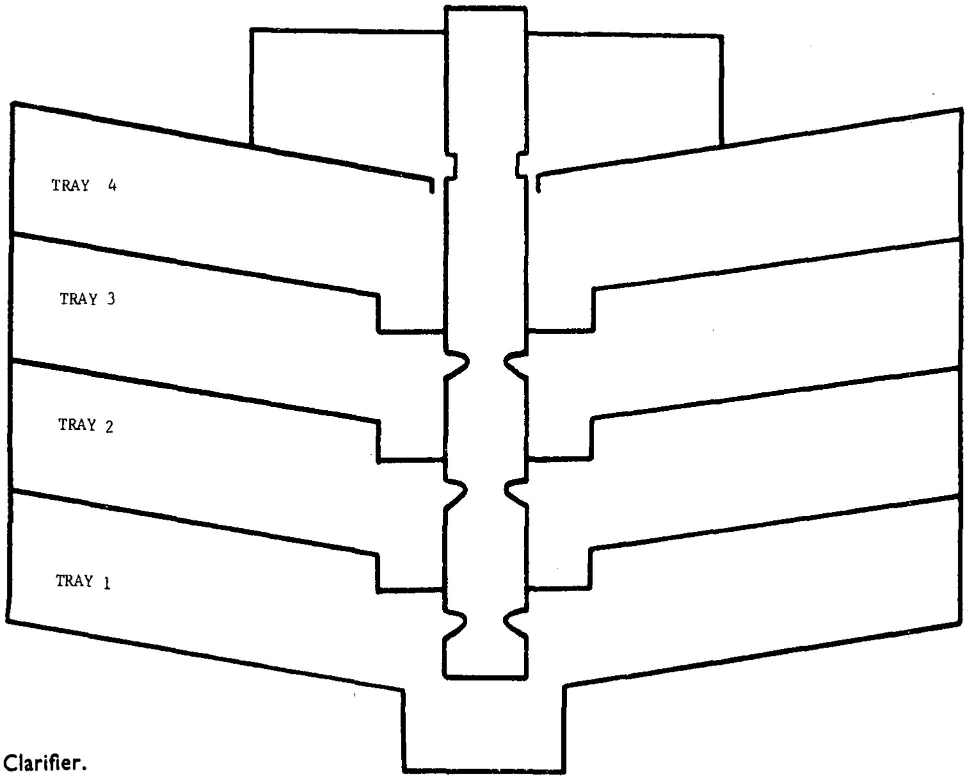


FIGURE 1 Rapidorr 444 Clarifier.

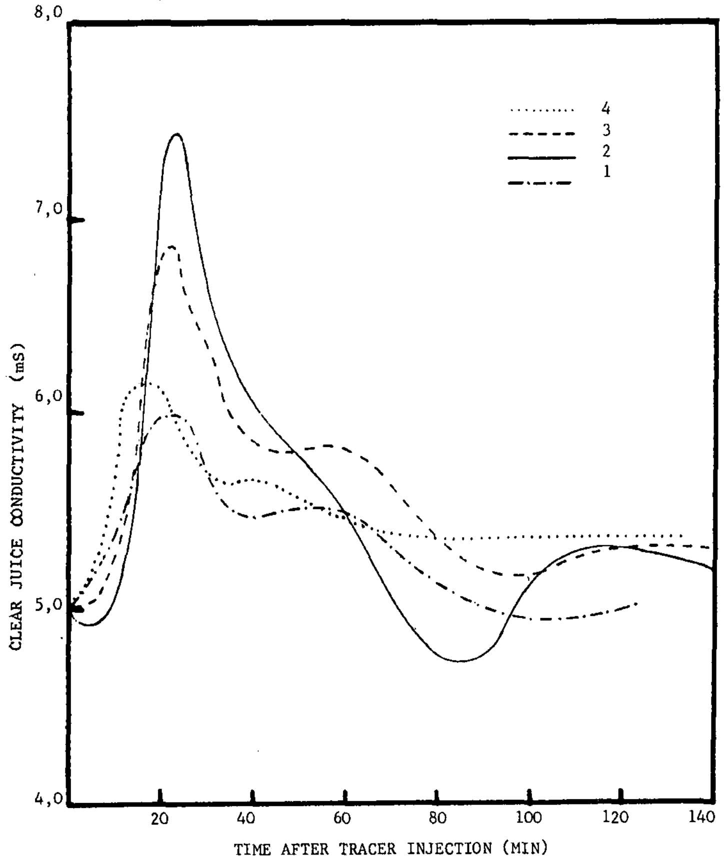


FIGURE 2 Conductivity tracer response curves for Empangeni Rapidorr 444.

(Clear juice flows adjusted to given even distribution of flow between trays.)

The inlet and outlet velocities quoted above have been calculated as the volumetric flow rate to a tray, divided by the total cross-sectional area of inlets and outlets respectively on each tray. These values are of significance as high local velocities, particularly at the inlets, can cause both short-circuiting and turbulence which disturbs the mud blanket.

Continuous conductivity measurement was used for this test.

All of the trays show peaks in the response curves after about 20 minutes and this indicates a large amount of bypassing and dead volume. The exact shape of the response curves is not clear because of the natural variations in the background conductivity of the juice. The sharpest peak occurred in the response from the lower-middle tray (2). This is consistent with it having the shortest residence time and highest dead volume. On liquidating the clarifier, tray 2 was found to contain large quantities of solidified mud.

After the clarifier had been cleaned modifications were made to the filter station to allow higher mud removal rates so that low mud levels could be maintained in the clarifier. The test was then repeated under the same conditions but with low mud levels in the trays. The tracer response curves are shown in Figure 3.

There was no significant difference between the responses of the individual trays. It is not possible to distinguish a response peak from the natural variations in background conductivity in this test but it is apparent that the serious bypassing previously observed is no longer occurring. The test was repeated to ensure that this was not simply a case of mislaid tracer but essentially identical results were obtained.

Tests were performed on clarifiers at Mount Edgecombe mill to compare clarifier operation at different flow rates. The clarifiers tested were Rapidorr clarifiers of the type shown in Figure 4.

The comparative tests involved a test on No. 2 clarifier operating on half of the juice flow and one with the total juice flow being fed to No. 1 clarifier. The No. 1 clarifier has an extra clear juice outlet pipe on each tray to allow it to accommodate the total flow. The clarifiers have the following specifications :

Diameter	7,3 m
Volume	252 m^3
Mud tray volume	76 m^3

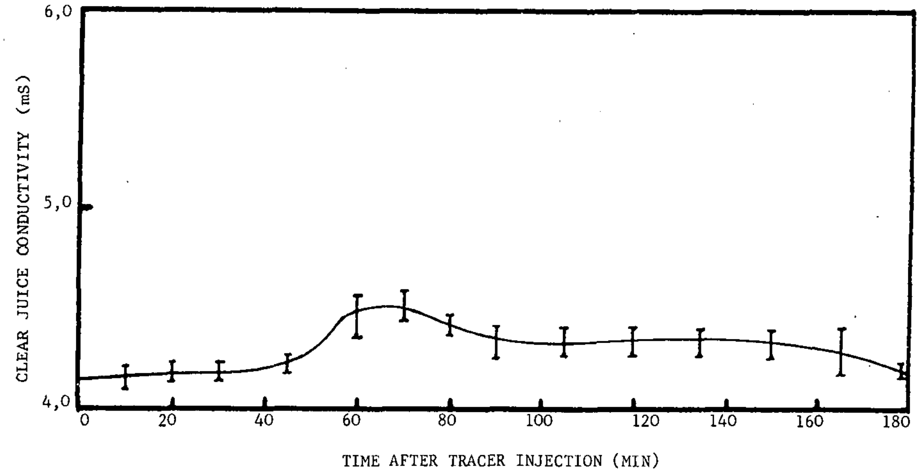


FIGURE 3 Conductivity tracer response curves for Empangeni Rapidorr 444 with low mud levels.

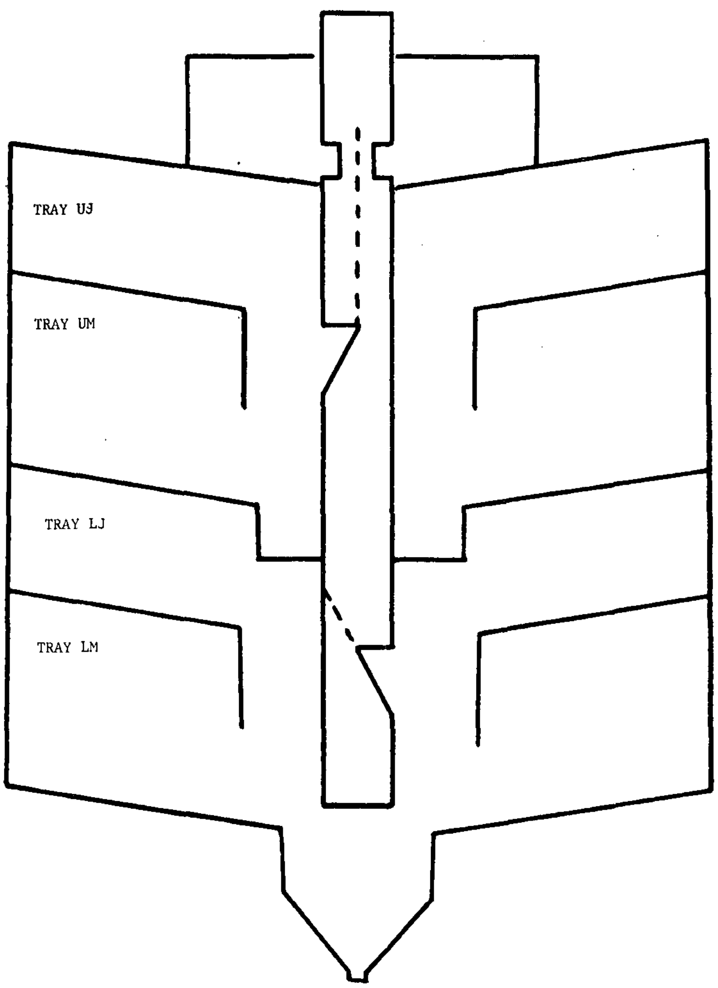


FIGURE 4 7,3 m diameter Rapidorr clarifier.

Juice tray volume	50 m^3
Juice inlets	0,91 m^2
Juice outlets :	
No. 1 clarifier	0,074 m^2/tray
No. 2 clarifier	0,037 m^2/tray

The conditions during the low flow test were as follows :

Juice flow	120 m^3/h
Inlet velocity	2,2 m/min
Outlet velocity	13,5 m/min
Theoretical residence time	126 min

The tracer response curves are shown in Figure 5.

This test shows a good approach to the theoretical mean residence time. Whilst there is a fair amount of dispersion, there is no rapid bypassing of juice as evidenced by the fact that no tracer could be detected during the first 45 minutes of the test.

The conditions during the total flow test on No. 1 clarifier were as follows :

Juice flow	260 m^3
Inlet velocity	4,8 m/min
Outlet velocity	14,6 m/min
Theoretical residence time	62 min

The tracer response curves are shown in Figure 6.

The response curve for the lower mud tray (LM) shows good performance of that tray whilst the other three trays show bypassing indicated by the sharp conductivity peaks during the first 20 minutes of the test.

These two tests indicate that the approach to ideal flow conditions is much better at the lower flow rate.

Lithium Chloride Tracer.

The tests using lithium chloride tracer were performed on clarifiers at Mount Edgecombe and Amatikulu, both of which were Rapidorr clarifiers of the type described above.

A preliminary test (without flow measurement or control) was performed on the clarifier at Amatikulu, both to test the experimental method, and to check the performance of an unmodified Rapidorr under normal operating conditions.

The details pertaining to the test are as follows :

Type of clarifier	Rapidorr	
Diameter	7,3 m	(24 ft.)
Volume	252 m^3	
Flow through clarifier	145 m^3/h	

(assume one third of measured total flow).

∴ Theoretical residence time : 104 min.

The results of the test are presented in Figure 7.

If the tracer is split between the trays of the clarifier in the same proportion as the flow (as would be expected), it can be shown that the areas under the tracer response curves will be equal. Although sampling in the above test was stopped before all tracer had passed through the clarifier, it is clear that there are large differences between the areas under the tracer peaks for the different trays. This is most likely the result of very rapid addition of the tracer to the clarifier resulting in the tracer being concentrated in a small pocket of juice which is not split proportionately between the trays.

The oscillations in the tracer concentration observed on trays LM and UM are unusual, the traces for trays UJ and

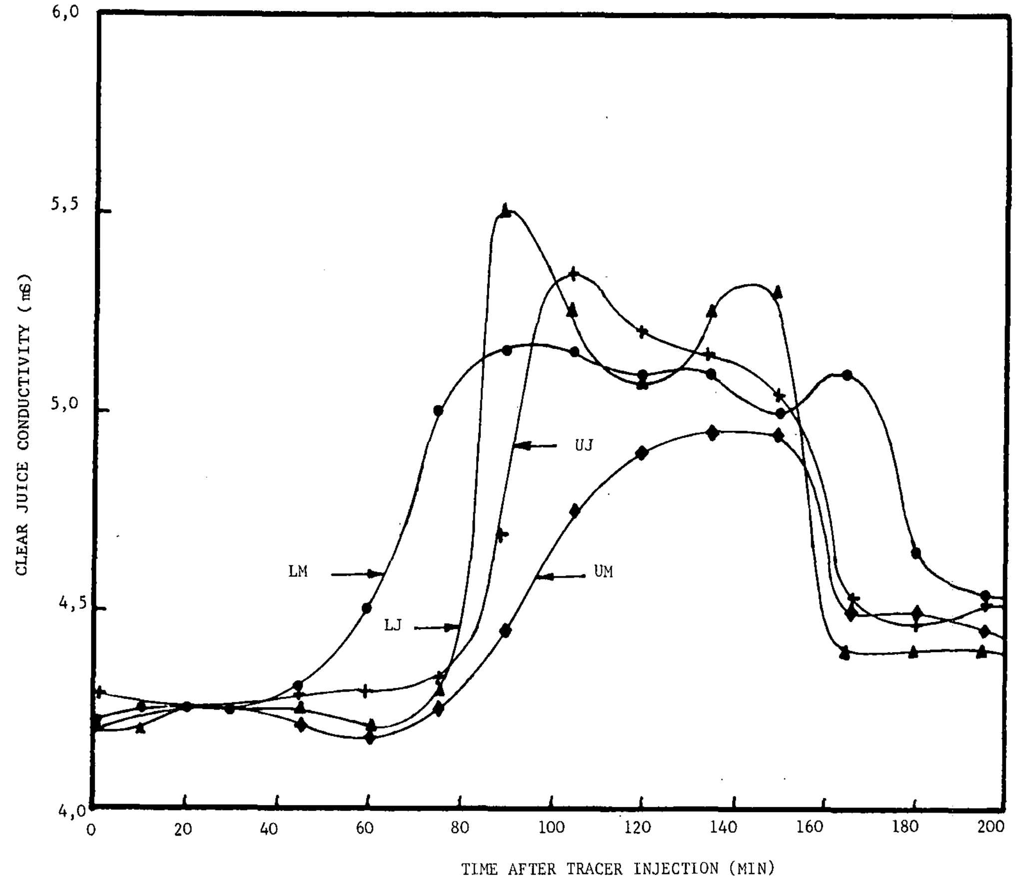


FIGURE 5 Conductivity tracer response curves for Mount Edgecombe Rapidorr clarifier with juice throughput of 120 m³/h.

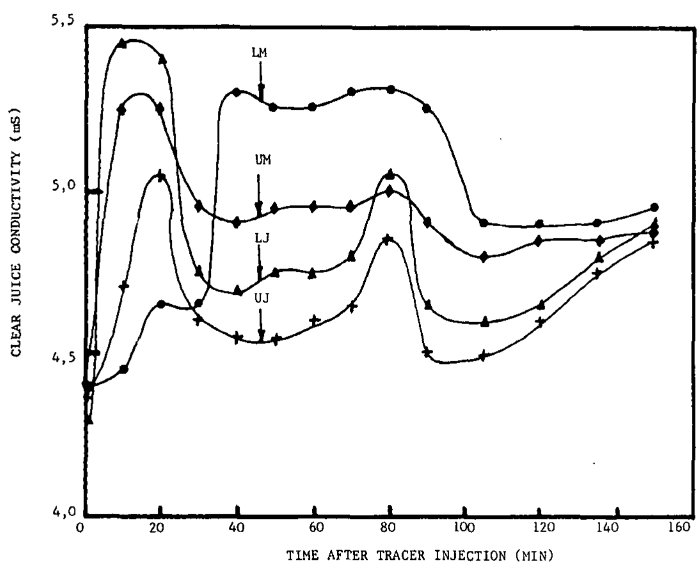


FIGURE 6 Conductivity tracer response curves for Mount Edgecombe Rapidorr clarifier with juice throughput of 260 m³/h.

LJ being more normal. This is probably also due to insufficient mixing of the tracer with the juice at the time of tracer addition.

The tests done at Mount Edgecombe were performed on the No. 1 clarifier described above.

Table 1 gives the details of a test performed on this clarifier, with the flow controlled by the system installed on the liming tank.

The actual mean residence times are determined by the method of moments as described by Himmelblau[2].

The figures in brackets are based on the assumption that the split in tracer between the trays is in the same proportion as the split in flow beween the trays.

The tracer response curves are shown in Figure 8.

TABLE 1

	Tray LM	Tray LJ	Tray UM	Tray UJ	Total
MJ flow to clarifier (m³/h)	—	—	—	—	155
CJ flow from clarifier (m³/h)	26	47	29	37	139
Flow split between trays (%)	19	34	21	26	100
Mud level	1	—	2	—	—
Areas under tracer peaks (ppm min) ..	188	121	245	130	—
Tracer added (kg Li)	(0,080)	(0,143)	(0,088)	(0,109)	0,421
Tracer recovered (kg Li)	0,092	0,106	0,133	0,087	0,418
Recovery (%)	(115)	(74)	(151)	(80)	99
Theoretical residence time (min)	155	57	141	74	98
Actual mean residence time (min)	94	130	86	119	111

The tracer recoveries for individual trays based on the assumption that tracer split between the trays is in proportion to the flow split show a large variation with values significantly above 100% recovery. The overall tracer recovery of 99% gives confidence in the test and indicates that the assumption of the tracer split is not correct. As mentioned previously this could be due to too rapid addition of the tracer.

The tracer response curves show a distinct similarity between the two mud trays (trays LM and UM) and between the two juice trays (trays LJ and UJ). The juice trays show a closer approach to plug flow (i.e. less dispersion) than the mud trays and have actual residence times which are longer

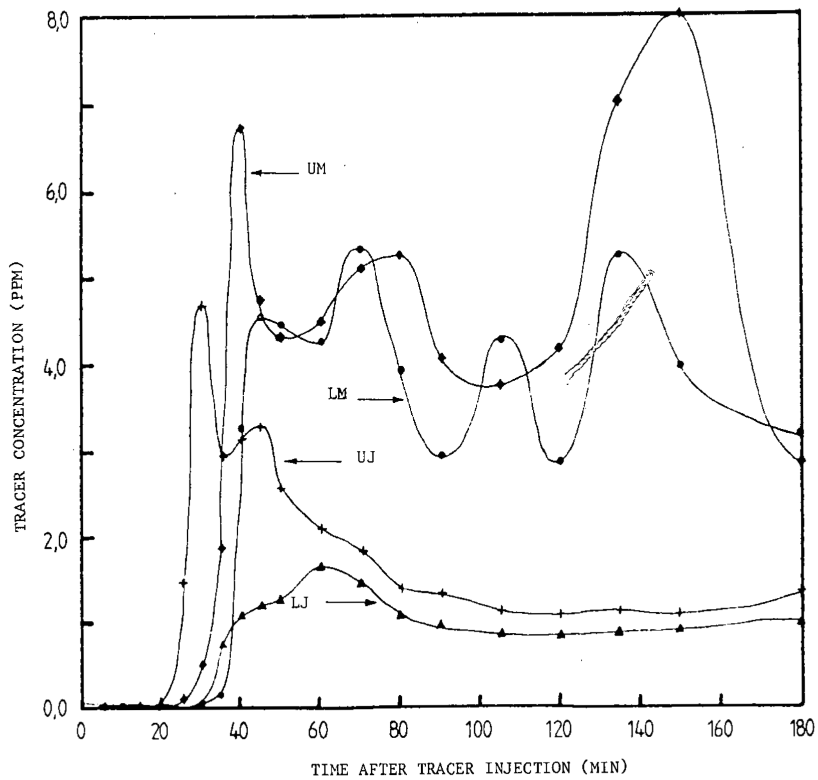


FIGURE 7 Lithium tracer response curves for Amatikulu Rapidorr clarifier.

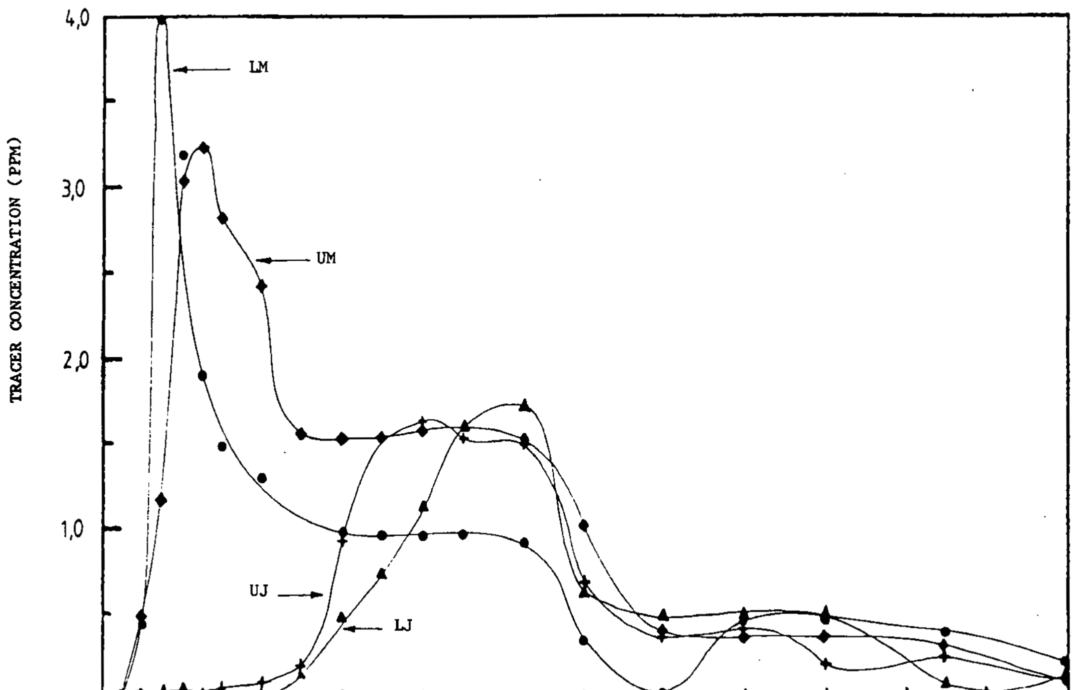


FIGURE 8 Lithium tracer response curves for Mount Edgecombe Rapidorr clarifier.

than the theoretical residence times. This places some doubt on the flow split measurement. The response curves for the mud trays show a sharp peak after 20 minutes combined with a more dispersed peak similar to that obtained for the juice trays. This indicates that there is a short flow path operating in parallel with the main flow of juice through the tray. A possible explanation would be a small layer of clear juice at the top of the tray through which some juice would pass rapidly whilst the rest of the juice moved more slowly, and with more dispersion, through a low density mud blanket occupying the rest of the tray. The actual residence times are about 60% of the theoretical residence times.

Overall the clarifier shows good performance in terms of its approach to the theoretical residence time of 98 min.

Conclusions

Two methods of tracer testing have been investigated and their usefulness has been shown. The sodium chloride/conductivity method has the advantage of easily available tracer and sample analysis that does not require elaborate equipment. The disadvantages are that the response curves can be obscured by variations in background conductivity and that the large quantity of tracer needed results in handling problems. The lithium method has the advantages of low background concentrations which do not interfere with the results and the comparatively small quantity of tracer required makes tracer addition exceedingly simple. The disadvantages are that lithium is not readily available in the form required and that sample analysis requires a flame emission spectrophotometer. The conductivity method is a useful qualitative tool whilst the lithium method yields good quantitative information.

It has been shown that the actual residence times in a clarifier can be considerably shorter than the theoretical value resulting in highly inefficient use of clarifier volume. In instances of both high mud levels and high juice throughputs rapid bypassing of juice through the clarifier has been found.

Acknowledgements

The assistance of Messrs. Corts and Prince and their staff at Mount Edgecombe and Empangeni factories respectively is gratefully acknowledged.

Thanks are also due to Miss Morel du Boil for her work in refining the analytical technique and performing the analysis for the lithium samples.

REFERENCES

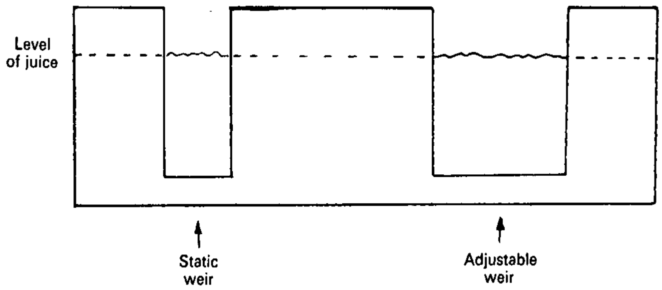
1. Wright, P. G. and Broadfoot, R. (1977). The application of a lithium tracer method to residence time studies in a sugar factory. *ISSCT Proc* 16, 3, Page 2569.
2. Himmelblau, D. M. and Bischoff, K. B. (1968). Process Analysis and Simulation: deterministic systems, John Wiley, New York, Page 114.

Appendix

Flow Control System for Clarifier

The flow control system devised for maintaining a constant flow to the clarifier under test is best illustrated diagramatically.

The figure below shows a development of the cylindrical wall of the liming tank.



Juice flowing over the static weir is fed to the clarifier under test. The flow may be determined from the height of the crest over the weir, using the Francis formula for rectangular weirs:

$$q = 0{,}415\,(L - 0{,}2\,h)\,h^{1{,}5}\,\sqrt{2g}$$

where q = volumetric flow rate (ft³/sec)
L = width of weir (ft)
h = height of liquid over weir (ft)
g = gravitational acceleration (ft/sec²)

or in metric units.

$$q = 1{,}83 \times 10^{-5}\,(L - 0{,}2h)\,h^{1{,}5}$$

where $[q] = m^3/sec$
$[L] = cm$
$[h] = cm$

To maintain a constant flow to the clarifier under test, the level of juice in the liming tank is held constant. This is achieved by raising or lowering the bottom of the adjustable weir, thus causing the other clarifier, which it feeds, to absorb all the fluctuations in flow.

Since the juice level in the liming tank cannot be varied substantially, to cater for different flows to the clarifier under test the static weir was made interchangeable and three different sized weirs have been provided viz. 15 cm, 20 cm and 25 cm wide.