REMOVAL OF SUSPENDED SOLIDS FROM CLEAR JUICE BY DEEP BED FILTRATION

B GWEGWE, S C MKHIZE and S B DAVIS

Sugar Milling Research Institute, University of KwaZulu-Natal, Durban, 4041, South Africa.
E-mail: bgwegwe@smri.org

Abstract

Clarification of mixed juice in South African sugar factories is currently done using the clarifiers only. The removal of suspended matter when using clarifiers alone is not always sufficient, hence there was a need to investigate a device such as the Deep Bed Filter, which maintains good juice quality during clarification problems. This piece of equipment uses the readily accessible filtration media - magnetite, anthracite and silica sand - which have been selected according to their physical properties. These media require only water for regeneration.

A small pilot-scale deep bed filter was tested at the Sugar Milling Research Institute to determine the feasibility of using such a device for filtering clear juice.

The results for two different media size sets are compared and discussed. The media size selection and the efficiency of the equipment are evaluated by assessing the solid retention capacity of the bed.

Keywords: filtration, pilot plant, media, backwash, deep bed filtration

Introduction

The efficiency of clarifiers at the sugar mill factories is critically important in ensuring good juice quality, which in turn is necessary for good sugar quality (Mkhize, 2003). The South African sugar industry is currently faced with juice quality problems affected by, among others, mud carry-over. Thus there is a need for a device to assist in this regard. The Deep Bed Filter (DBF), a relatively simple piece of equipment, has become the most likely supplement. The filtration media is readily accessible and only water or juice is required for media regeneration. This equipment can be used when small amounts of suspended solids need to be removed from large amounts of liquid (Chetty and Moodley, 2002).

The calculation of the minimum fluidisation and settling velocities to obtain the required particle sizes was essential for the optimum filtration and backwash processes (Perry and Chilton, 1973). This was done so that the most probable media size for the given flow rates could be established with a minimum number of trials.

The packing of the media in the columns is in accordance with size - the largest on top and the smallest at the base. This ensures the removal of the largest particles by the top layer. The media is further differentiated by particle densities to assist in the settling of the media after regeneration - the lightest on top and the heaviest at the base. A laboratory investigation was undertaken to determine the potential for the use of a DBF after the clarifiers, to remove carried-over suspended solids and thus improve juice quality. A laboratory scale pilot plant was tested to determine sizes and materials of suitable media, and to investigate the degree of solids removal under various operating conditions.

Experiment method

Plant rig

The plant rig (Figure 1) consists of a 9.8 cm diameter column with a height of 84 cm, connected to feed and product tanks, a positive displacement pump and a rotameter to assist flow control.

Figure 1. The DBF pilot rig.

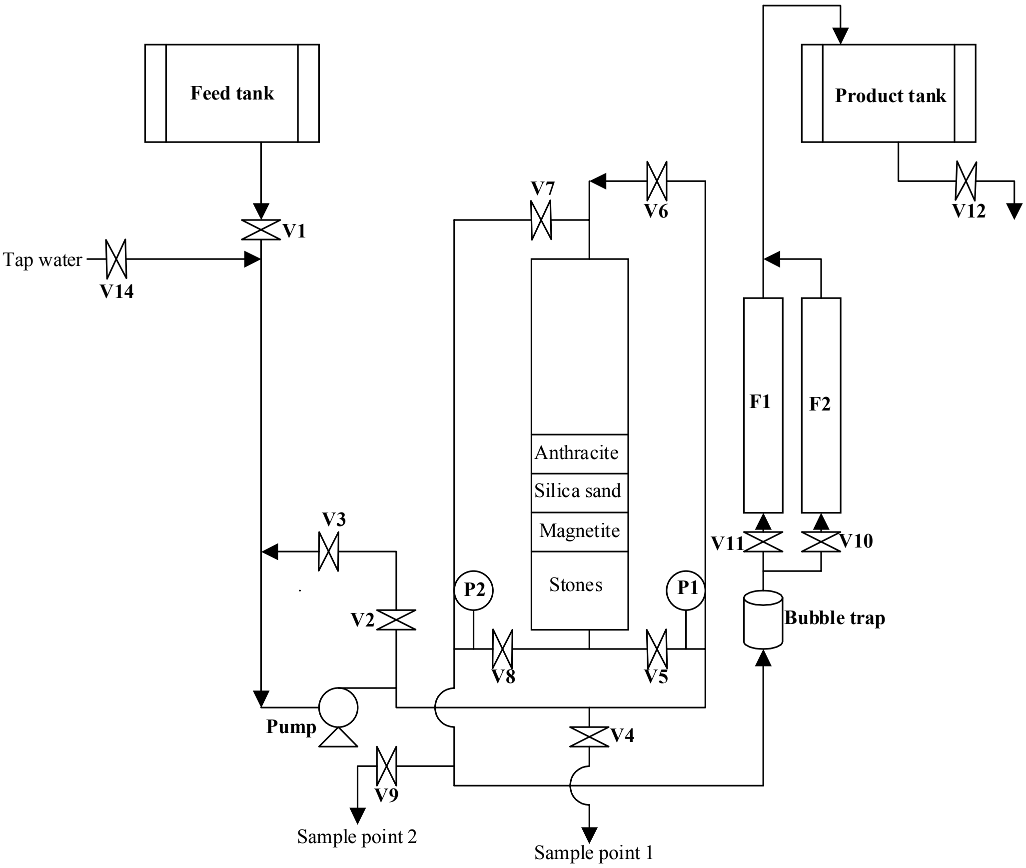

Figure 2. Schematic diagram of the DBF pilot plant.

A schematic diagram and the description of valve manipulation for filtration and backwash procedures are given in Figure 2 and the Appendix 1 respectively.

Details of the pilot plant and the operating conditions are given by Gwegwe and Moletsane (2003a). The filtration media characteristics are given in Table 1. The media used was divided into two fractions of the media available, the finer set and the coarser set.

Table 1. Characteristics of filtration media.

Media	Material	Size (mm)	Settling velocity (m/s)	Minimum fluidisation velocity (m/s)
Finer filtration media set	Magnetite	0.27 - 0.28	0.0755 - 0.0799	0.0199 - 0.0205
	Silica sand	0.43 - 0.60	0.0647 - 0.0936	0.0158 - 0.0188
	Anthracite	1.0 - 1.7	0.0619 - 0.1026	0.0119 - 0.0156
Coarser filtration media set	Magnetite	0.43 - 0.60	0.128 - 0.176	0.025 - 0.030
	Silica sand	0.60 - 0.85	0.094 - 0.130	0.018 - 0.022
	Anthracite	1.4 - 2.0	0.084 - 0.119	0.014 - 0.017

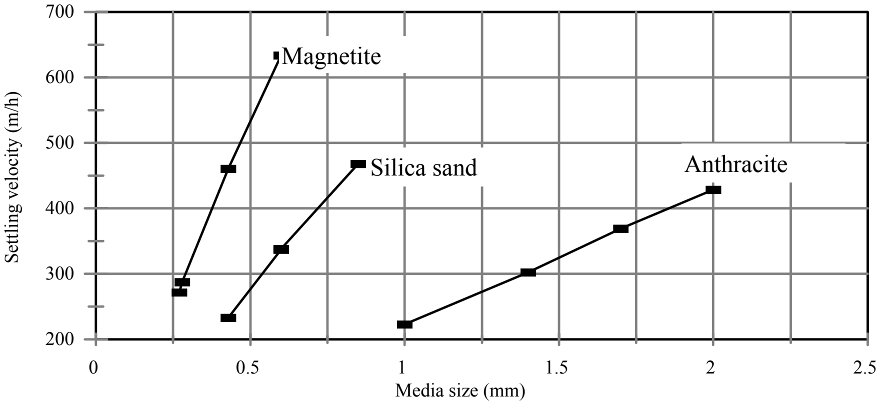

Figure 3. Settling velocity selection chart for different media used in the deep bed filter.

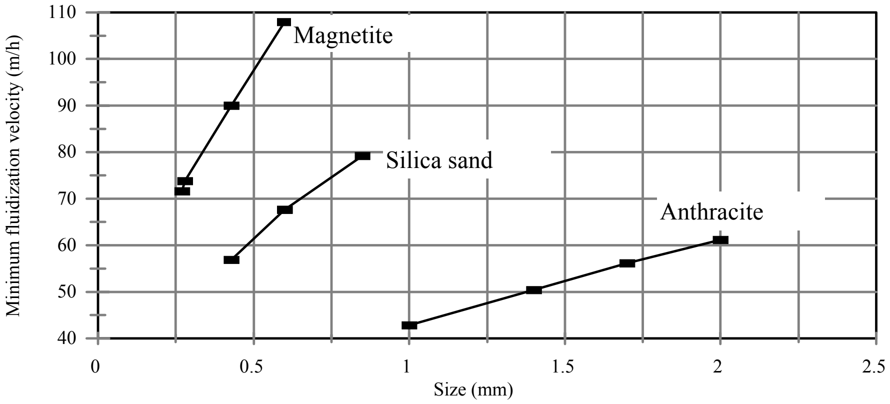

Figure 4. Minimum fluidisation velocity selection chart for different media used in the deep bed filter.

The theoretical settling and minimum fluidisation velocities given in Table 1 are presented graphically in Figures 3 and 4. A layered bed that obeys these selection charts does not need to be carefully put in place, since these layers quickly sort themselves out during backwashing. If the particle size range is too wide, inadequate separation of the media could be experienced (Purchas, 1981).

Filtration

For the laboratory trials done at the Sugar Milling Research Institute, a suspension of clarifier mud and water was used to simulate suspended solids in clear juice to guarantee a consistent feed for trial purposes. These trials were done at different concentrations of mud solids under similar conditions. Three mud concentration levels that typify the levels of suspended solids in clear juice were chosen. Moreover, the use of hot juice was prevented by the construction materials of the DBF pilot plant that was tested.

It was decided to run the tests at constant flow rates (see Tables 2 and 3) and varying pressure drops, as this is how the unit is likely to be run in practice. At a given flow rate, the pressure drop across the filter bed was recorded at 30 second intervals. The filtrate was sampled periodically, and samples were combined and analysed to determine the residual suspended solids in the product.

When the cut-off pressure drop was reached, the process was stopped and the media regeneration cycle began. The pressure drop referred to is the maximum pressure drop that could be achieved on the pressure gauges that were installed in the pilot plant.

Media regeneration

Suspended solids trapped in the filter bed were removed using the backwash process. Tap water was used to facilitate this process. The backwash flow rates (see Table 5) were gradually increased to the desired backwash flow rates to avoid media being carried over with backwash water as sufficient headspace was provided to allow expansion of the fluidised bed. The trapped solids, being generally smaller and less dense than the media, are discharged from the top of the filter (Coote *et al*., 1986). The backwash product was sampled and analysed for solids content using a high-pressure filter with a fine filter cloth (Gwegwe and Moletsane, 2003b).

Results

Filtration

The performance of different size media can best be explained by assessing the amount of solids removed at a specific concentration and flow rate and the residual solids in the filtrate. The overall removal of suspended solids for various conditions is given in Tables 2 and 3 and Figures 5 to 10.

Table 2. Results for various feed concentrations at different flow rates for finer media.

Feed conc. (g/L)	0.2			0.6			1.2		
Flow rate (L/min)	6	8	12	6	8	12	6	8	12
Flow rate (m/h)	47.8	63.7	95.5	47.8	63.7	95.5	47.8	63.7	95.5
Product volume (L)	88	99	90	68	46	39	40	34	21
Product conc. (g/L)	0.11	0.12	0.12	0.16	0.22	0.29	0.14	0.32	0.36
Run time (min)	12	9.5	5.5	8	3	2	5	2	1
Solids removed (%)	45.12	39.56	40.48	72.68	62.96	50.88	88.48	71.84	70.73

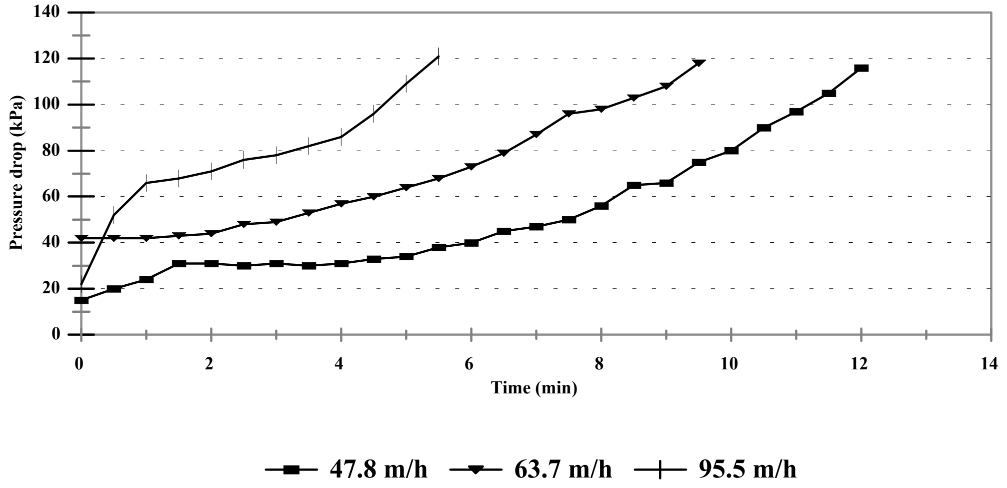

Figure 5. Effect of flow rate on 0.2 g/L feed for finer media.

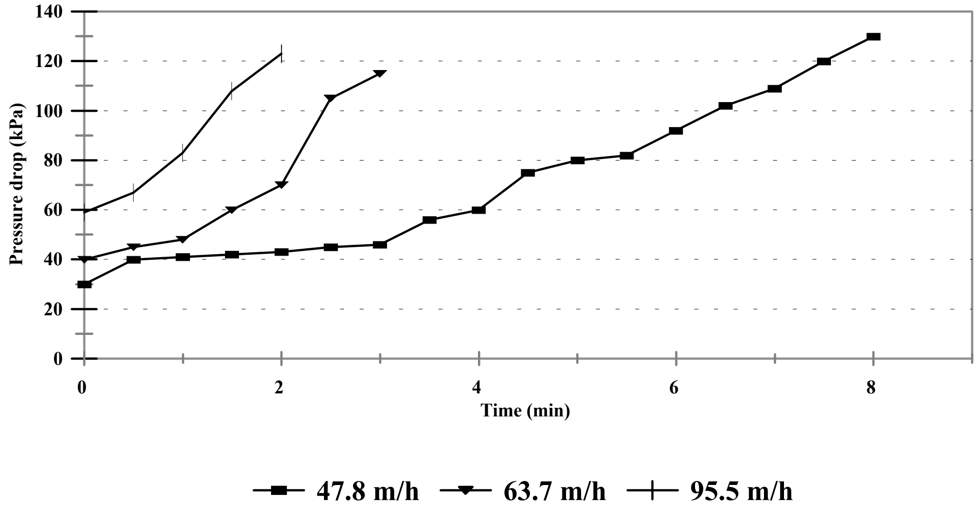

Figure 6. Effect of flow rate on 0.6 g/L feed for finer media.

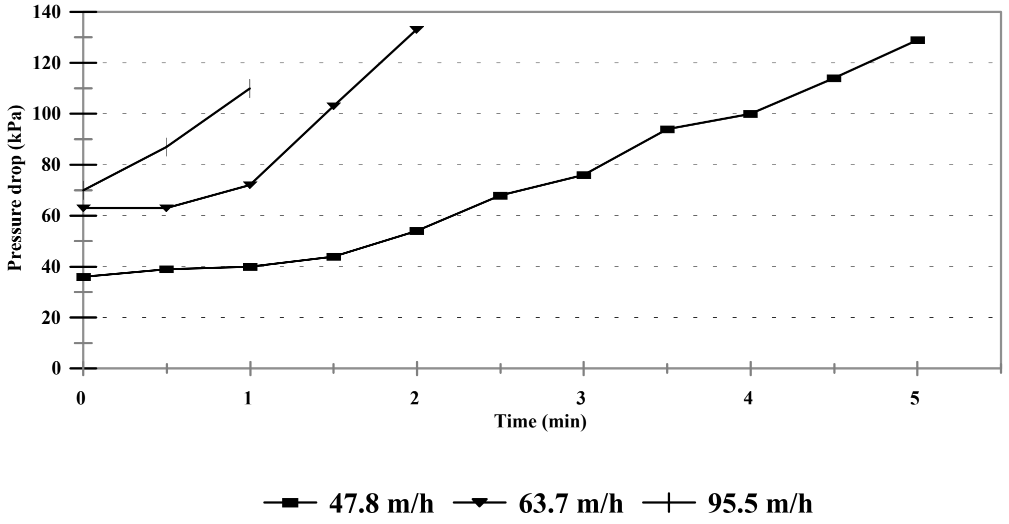

Figure 7. Effect of flow rate on 1.2 g/L feed for finer media.

Table 3. Results for various feed concentrations at different flow rates for coarser media.

Feed conc. (g/L)	0.2			0.6			1.2		
Flow rate (L/min)	6	8	12	6	8	12	6	8	12
Flow rate (m/h)	47.8	63.7	95.5	47.8	63.7	95.5	47.8	63.7	95.5
Product volume (L)	173	174	122	70	61	51	39	32	25
Product conc. (g/L)	0.11	0.10	0.11	0.13	0.09	0.37	0.23	0.23	0.14
Run time (min)	23	17	8	10	5	3	4.5	2.8	1.5
Solids removed (%)	45	50	44	78	85	38	80	81	88

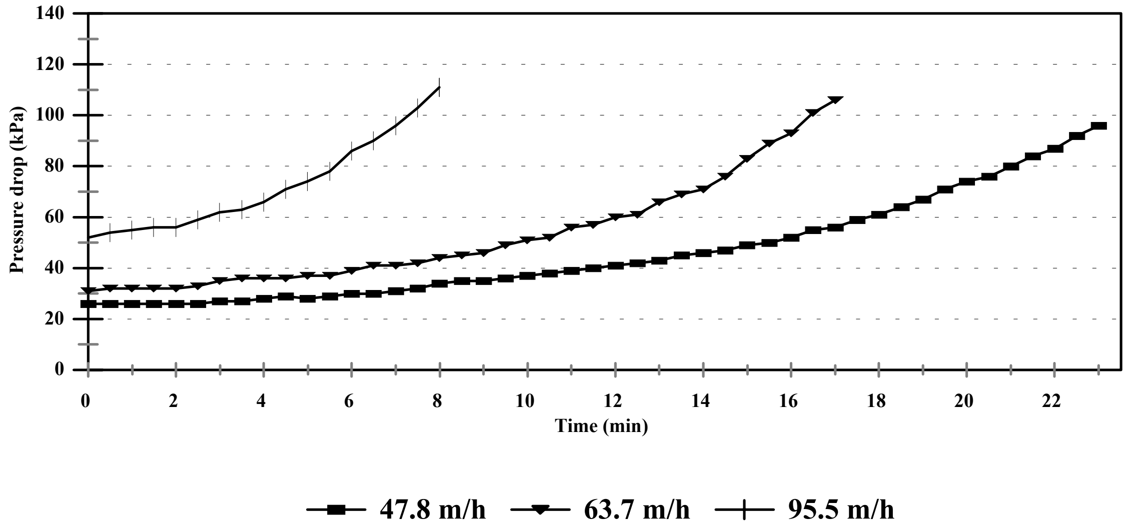

Figure 8. Effect of flow rate on 0.2 g/L feed for coarser media.

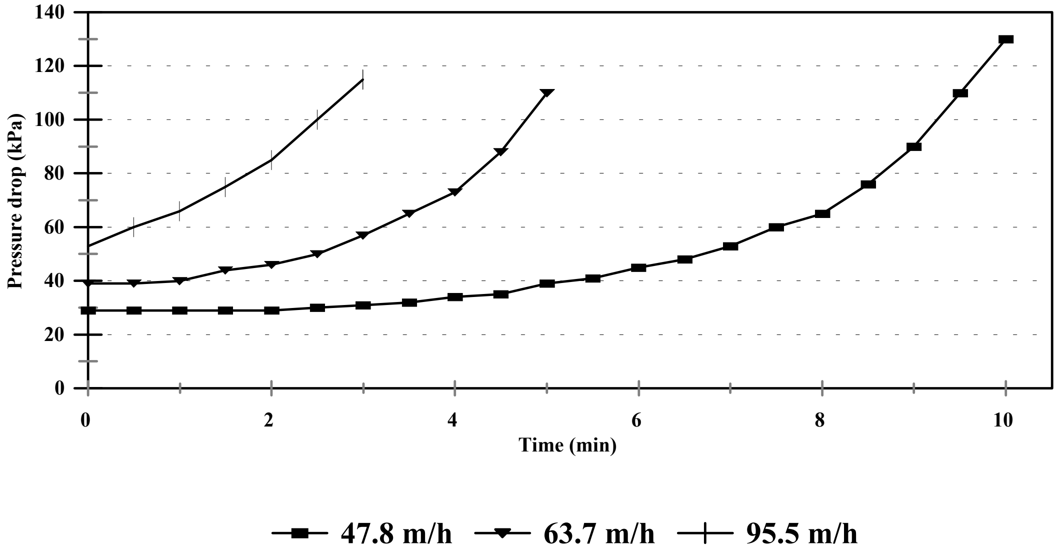

Figure 9. Effect of flow rate on 0.6 g/L feed for coarser media.

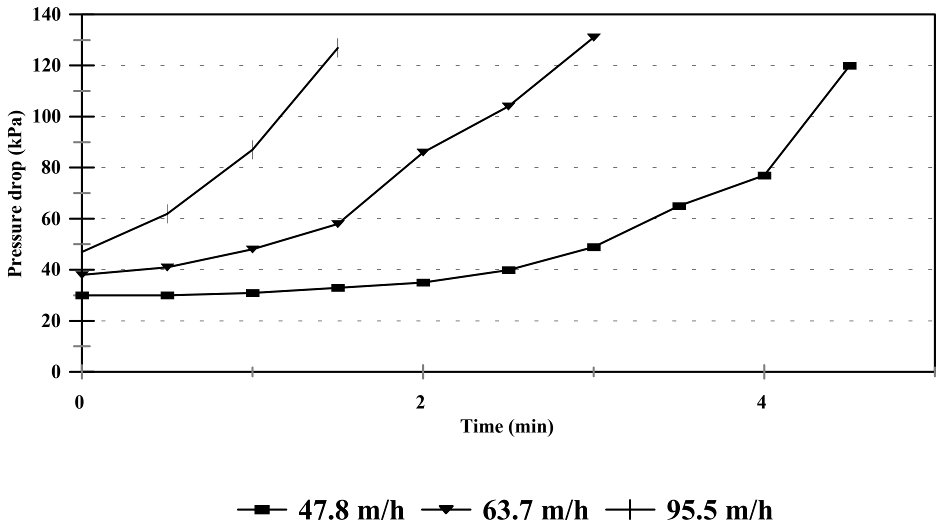

Figure 10. Effect of flow rate on 1.2 g/L feed for coarser media.

The best flow rates for specific concentrations can be decided upon by considering the filter load (amount of solids removed per run) and the removal rate (amount of solids removed per unit time). These comparisons are given in Table 4 and Figures 11 to 14.

Table 4. Comparison of finer and coarser media.

Feed conc. (g/L)	0.2			0.6			1.2		
Flow rate (L/min)	6	8	12	6	8	12	6	8	12
Flow rate (m/h)	47.8	63.7	95.5	47.8	63.7	95.5	47.8	63.7	95.5
Filter load (g/run)[1]	7.95	7.83	7.28	29.65	17.37	11.90	42.45	29.31	17.82
Filter load (g/run)[2]	15.57	17.40	10.98	32.90	30.93	11.73	37.83	31.04	26.50
Removal rate (g/min)[1]	0.66	0.82	1.32	3.70	5.80	5.90	8.49	14.60	17.82
Removal rate (g/min)[2]	0.68	1.02	1.37	3.29	6.19	3.91	8.41	11.29	17.67

[1] Results for finer media
[2] Results for coarser media

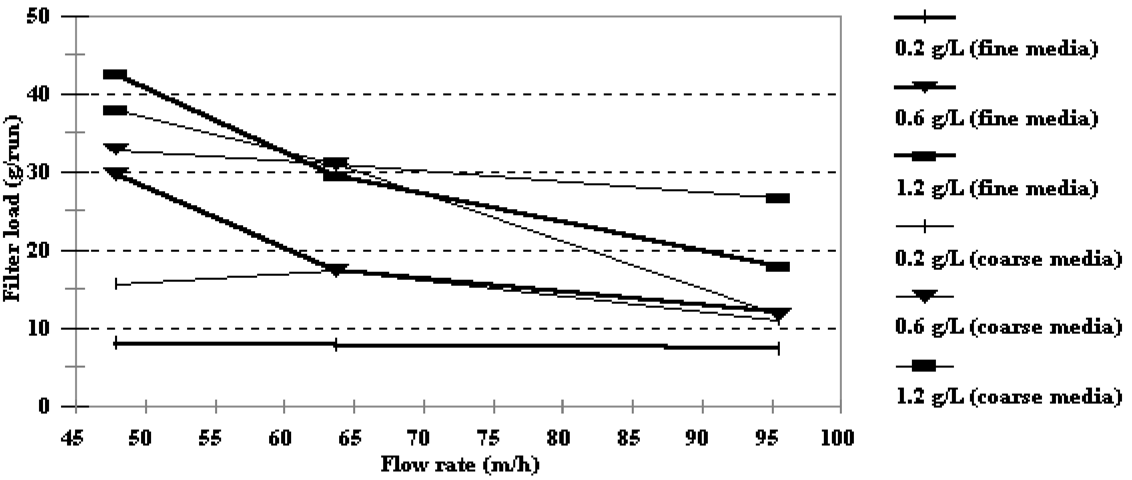

Figure 11. Effect of flow rate on filter load at varying feed concentrations.

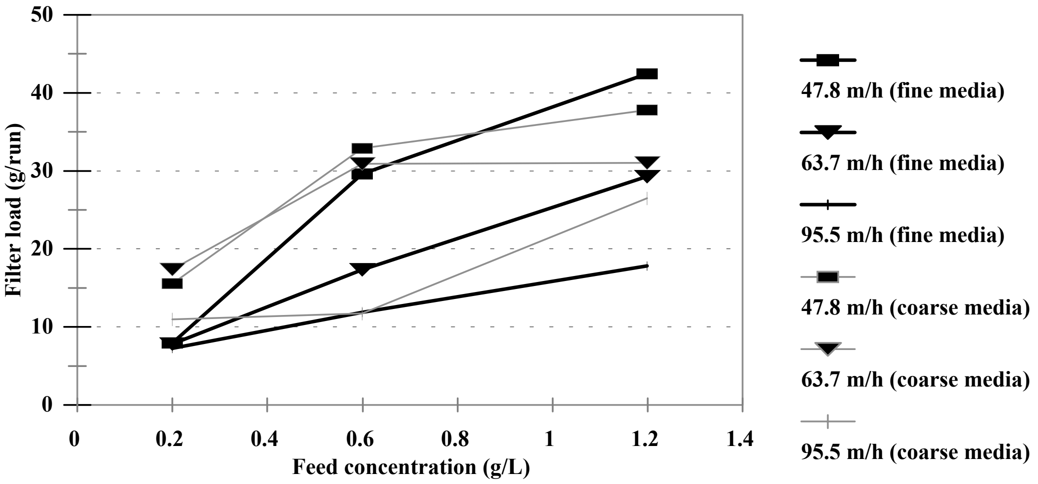

Figure 12. Effect of feed concentration on filter load at varying flow rates.

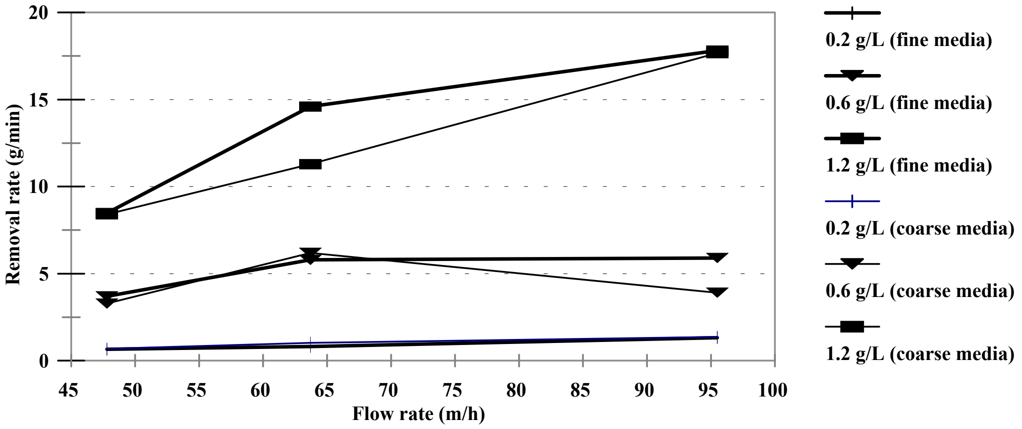

Figure 13. Effect of flow rate on solids removal rate at varying feed concentrations.

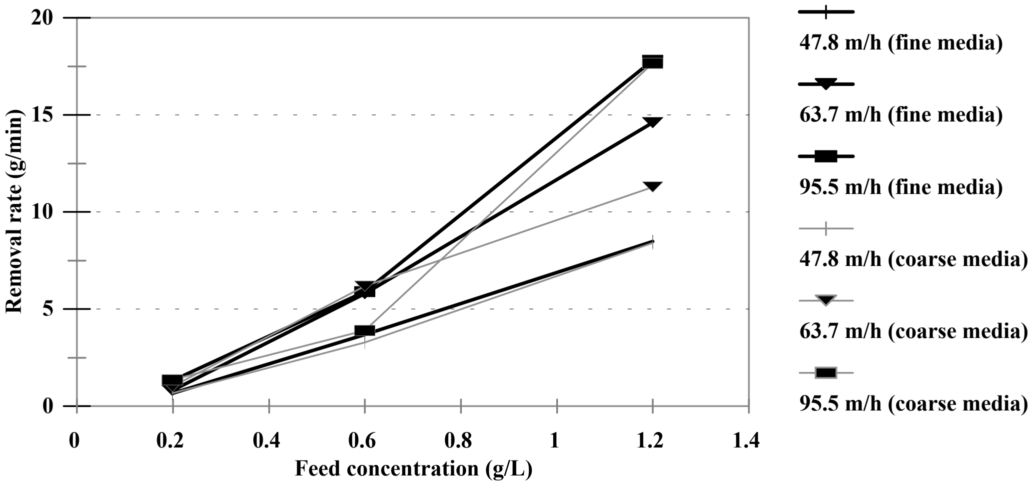

Figure 14. Effect of feed concentration on solids removal rate at varying flow rates.

Backwash

During the backwash process, 45% bed expansion was targeted and achieved with a backwash flow rate ranging between 6.5 L/min (51.74 m/h) and 13.3 L/min (105.5 m/h). A constant pressure drop was observed during the backwash.

Table 5. The backwash effect on media regeneration.

Run	1	2
Feed concentration (g/L)	1.2	1.2
Solids trapped (g)	38	36
Pressure drop (kPa)	29	26
Solids recovered (g)	29	26
Regeneration (%)	76	72

Factory carry-over characterisation

A survey of clear juice quality and carry-over frequency was undertaken at selected South African mills (Mkhize *et al.*, 2003). The carry-over was analysed to contain from 2 to 259 mg/L suspended matter concentration, with sizes ranging from 34 to 786 microns in width and from 43 to 1193 microns in length. The suspended solids were made up principally of bagacillo, of the order of 80% of the total solids volume. The balance of the contents were fine particulate matter and flocculated clarifier muds. These findings will be used to better understand future DBF trials.

Discussion

It is evident from the results that higher flow rates during the filtration process produce higher solids removal rates (g/min) but lower percentage removal than the rest of the tested flow rates. Some inconsistent figures may be due to a longer waiting time for the steady state to be reached before recording the pressure readings. High flow rates proved to require more frequent backwashing than low flow rates. In the factory trials that have been recommended, cycle times and throughputs will be investigated to choose the best flow rates that need to be employed in the DBF. Given the fact that the backwash was done with cold water, higher percentage regeneration is expected at the factories, as hot water or juice will be used for backwashing.

During the backwash, 45% bed expansion was achieved without mixing of different materials. This is due to proper selection media by minimum fluidisation and settling velocities of these materials. The uppermost layer (anthracite) has a very low density, hence it was essential to avoid very high flow rates of backwash that would elute it from the column.

Media selection

The same concentrations of feed were tested with two sizes of media - fine and coarse - under similar conditions. The results show that the two media sizes produced similar percentage solids removal at the same flow rates (as the media size ranges overlap), but the coarser media permitted longer run times. This may be due to the fact that there is more solid penetration and distribution in the media than just forming a filter cake on the top layer, hence the coarser media performed better.

Conclusion

- Deep bed filters have proved capable of removing between 38 and 88% of mud solids suspended in water.
- The extent of removal was influenced by initial solids concentration and flow rate.
- An acceptable media regeneration was achieved, but care must be taken to ramp backwash liquid to the desired flow rate to avoid carry-over of the top layer.
- The coarser media size was found to be better due to the longer time that it takes to clog compared with the finer media. This is justified by the fact that the removal rate of both sizes is almost the same, therefore the longer it takes to clog, the higher the filter load per run.

Further work

A pilot plant consisting of three columns has been designed and will be tested at three factories during the 2004 season, to determine the performance and optimal conditions for operation under factory conditions.

This will include:
- Determination of the optimal fluid flow rate, taking into account present factory conditions.
- Individual analysis of the filtrate samples to assess the filter breakthrough. This could be achieved by plotting the filtrate concentration (expressed as ratio C/C_0) with time of the filter run.
- Reduction of filtration flow rates, which seem to be excessively high. This should increase residence time and produce better results. These flow rates should be expressed in m/h for comparison.

Acknowledgements

The authors wish to thank the University of KwaZulu-Natal for the rig supply, African Pegmatite for sponsoring the filtration media, Ruth Moletsane and Samuel Maleka for their valuable input in running the tests and Dave Joseph (SMRI workshop) for refurbishment and instrument modifications.

REFERENCES

Chetty J and Moodley R (2002). Deep Bed Filtration. Final year Chemical Engineering Thesis, University of KwaZulu-Natal, Durban, South Africa. 23 pp.

Coote N, Carroll C and Leavins NP (1986). Deep bed filtration in the sugar industry. *Proc int Soc Sug Cane Technol* 19: 733-734.

Gwegwe B and Moletsane R (2003a). Removal of suspended solids from clear juice via Deep Bed Filtration: Progress Report 1. Technical Report No. 1905, Sugar Milling Research Institute, University of KwaZulu-Natal, Durban, South Africa. 12 pp.

Gwegwe B and Moletsane R (2003b). Removal of suspended solids from clear juice via Deep Bed Filtration: Progress Report 2. Technical Report No. 1928, Sugar Milling Research Institute, University of KwaZulu-Natal, Durban, South Africa. 10 pp.

Mkhize SC (2003). Clear juice turbidity monitoring for sugar quality. *Proc S Afr Sug Technol Ass* 77: 414-422.

Mkhize SC, Gwegwe B and Moletsane R (2003). Characterisation of clear juice carry-over for clear juice filtration. Technical Report No. 1922, Sugar Milling Research Institute, University of KwaZulu-Natal, Durban, South Africa. 6 pp.

Perry HR and Chilton CH (1973). *Chemical Engineers' Handbook.* 5th Edition, McGraw-Hill Kogakusha, New York, USA. pp 5-61, 5-62, 5-64.

Purchas DB (1981). *Solid Liquid Separation Technology.* Uplands Press. pp 436-447.

APPENDIX 1

Process control during the tests

Valve position	Filtration	Backwash
Fully open	V_1, V_6, V_8	V_5, V_7, V_{14}
Half open	V_3, V_{11}	V_3, V_{11}
Fully closed	V_4, V_5, V_7, V_9, V_{10}, V_{12}, V_{14}	V_1, V_4, V_6, V_8, V_9, V_{10}, V_{12}
Flow control	V_2	V_2