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FIRST FULL-SCALE TRIALS OF PEBBLE MATRIX FILTRATION

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ABSTRACT

Protecting slow sand filters from high turbidity waters by pre-treatment using Pebble Matrix Filtration (PMF) has been studied in the laboratory at University College London followed by pilot field trials in Papua New Guinea and Serbia. Subsequently, the construction of two full-scale PMF units, one out of concrete (4.8m x4.8m x 3.0m high) and the other using pre-cast Ferro-cement panels (900mm x 1600mm x 20mm thick) with an effective diameter of 4.7m and 3m height, and the combined effective plan area of 40 m^2 was completed to protect an existing Slow Sand Filter system at the National Water Supply Drainage Board (NWSDB) in Sri Lanka. Although the plant was completed in April 2008 due to some major repairs to address some leaks and other construction defects in both filters, monitoring was intermittent until November 2008. The results on the plant performance are presented here along with some of the construction problems encountered during the project.

Keywords: Pebble matrix filtration; Full-scale trials; Sri Lanka; Slow sand filtration; Ferro-cement tank; World Bank Development Marketplace

INTRODUCTION

Filtration of drinking water by slow sand filters (SSFs) is an old and well known water treatment technique: the process percolates untreated water slowly through a bed of porous sand, with the raw water introduced over the top surface of the filter, and then treated water drained from the bottom. The filter consists of a tank, a bed of fine sand (typically d_{10} = 0.30 mm), a layer gravel to support the sand, a system of under drains to collect the filtered water, and a flow regulator to control the filtration rate (typically 0.1-0.2 m/h). No imported chemicals are required to aid the filtration process, and most construction materials are locally available in most developing countries. For all its advantages, SSF is highly recommended by the World Health Organization as a low cost, sustainable water treatment technique, suitable for developing countries.

However, the operation of slow sand filters deteriorates during periods of increased raw water turbidity during heavy rain periods, causing disruption to continual operations. To sustain slow sand filters' operation and therefore enable uninterrupted drinking water supply, adequate pretreatment before SSF is required. For rural areas, especially in the developing world, simplicity in the design and operation of the pretreatment together with low construction and operational costs is of crucial importance.

LOW TECHNOLOGY IMAGE*:* One of the major problems in the water industry (or any industry for that matter) is convincing decision makers to use simple and cheap technologies. There is always the misconception among decision makers that simple and cheap technologies are unreliable or does not produce a good image for the organization. The way forward to overcome such barriers is through positive information against such misconceptions. For example although very reliable in removing *E.coli*, slow sand filters are considered by many decision makers as inferior technology, particularly in many developing countries and very reluctant to adopt in new treatment plants. Yet one can argue in highly industrial countries like UK (London), USA, Belgium all use slow sand filters and find extremely effective in water treatment. It is the authors' view that the lack of knowledge on SSFs ability to produce very high quality water (when properly operated) and their simple operational procedures associated with low maintenance costs, make decision makers to go for inappropriate chemically assisted imported technologies.

KATARAGAMA WATER TREATMENT PLANT IN SRI LANKA

The town Kataragama (Lat $6^0$25' 0N, Long $81^0$19 60E) is a very important pilgrim site for people of all religions and overseas visitors throughout the year. The Kataragama Water Treatment Plant (WTP) is government owned and operated under the National Water Supply and Drainage Board (NWSDB) and located about 250 km away from the NWSDB head office in Colombo. The NWSDB of Sri Lanka is the principal authority providing safe drinking water and facilitating the provision of sanitation in Sri Lanka. Currently there are 290 water supply schemes operated by the NWSDB and about 200 treatment plants abstracting water from river sources. Fifteen plants use slow sand filtration as the main form of treatment and all fifteen plants including the Kataragama WTP suffer from occasional monsoonal high turbidity problems with turbidity reaching above 500 NTU. The plant abstracts water from the river "Menik Ganga" and supplies about 20,000 population as regular customers and a further about 2000 visitors from all over the country and abroad during weekends throughout the year. During Karatagama festival in July another staggering 10,000 pilgrims need to be served annually. The total output through the plant is 3500 m^3/day. The raw water is first pumped into a system of aerators and then goes through a horizontal flow plain sedimentation tank before being fed by gravity into the four slow sand filters (20m x 16m each).

The rainfall in the Menik Ganga basin is subjected to monsoonal variations and occasional high turbidity keeps the existing four SSFs out of operation several times a year, the most recent plant shut down occurred in October 2006 where river turbidity was recorded at 585 NTU. Such high turbidity events are taking place at the time of writing in November 2010. Yet, early research showed (Rajapakse, 1988) that the maximum turbidity / suspended solids loading that SSF can tolerate is about 25 mg/l (approx. 25-30 NTU) for preferred operation times (5-6 weeks and more) and about 50 mg/l (approx. 45-65 NTU) for shorter operation times (2-3 weeks). Samples collected by authors in December 2006 had a river turbidity of 137 NTU, plain sedimentation tank influent and effluent at 94 and 74 NTU and the SSF final at 36 NTU, which is much higher than the recommended Sri Lanka drinking water standards of 2 NTU. Therefore, it is necessary to use pretreatment before slow sand filtration and reduce suspended solids in high-turbid water to a concentration suitable for application to slow sand filtration (preferably less than 30 NTU) without the slow sand filter becoming rapidly clogged and failing to function biologically to produce potable water. These pretreatment methods have to meet the criteria of simplicity for application in rural areas of developing countries, and preferably should avoid the use of chemicals, due to their complexity of handling and dosing, with demands on foreign currency exchange. Kataragama water treatment plant itself is a good example where the recently (2008) imported "Dyna Filter" system needs to shut down when river turbidity exceeds 250 NTU.

PRETREATMENT WITH PEBBLE MATRIX FILTRATION

A novel pretreatment method called pebble matrix filtration developed at University College London was thought to be applicable to the problem of very high turbidity waters, to be used as pretreatment before slow sand filtration in tropical monsoon conditions (Rajapakse and Ives, 1990).

Both the PMF and SSF are sustainable systems suitable for rural settings since both filters use natural purification processes, can be constructed using local materials, do not require imported chemicals and their operation and maintenance can be carried out without highly qualified personnel in rural areas. Schematics of a PMF and a SSF are shown in Fig. 1 below.

The PMF can be described as a crude two-layer filter, where a turbid suspension approaching the filter flows downward, first through a layer of pebbles only (about 50 mm in diameter) and then through a matrix of pebbles and sand as shown in Fig. 1.

The upper part of pebbles only has some pre filtering effect, but the improvement in suspension solids concentration is dominated by the pebble-sand mixture which provides the secondary finer filtration. The PMF has proved satisfactory in addressing the high turbidity problem first in the laboratory in the UK (Rajapakse and Ives, 1990) and then in the field in Papua New Guinea (Rajapakse and Ives, 2003) and later in Serbia and Montenegro (Rajapakse et.al 2005). Construction of the first full-scale PMF test plant at Kataragama water treatment plant in Sri Lanka (Rajapakse and Sumanaweera, 2007) to protect one of their four slow sand filters was completed in April 2008 and monitoring performed intermittently between April and November 2008, and continuous monitoring was not possible due to serious leaks in both filter tanks caused due to construction defects. This paper will discuss the outcome of this project in relation to plant performance and several problems encountered during the project.

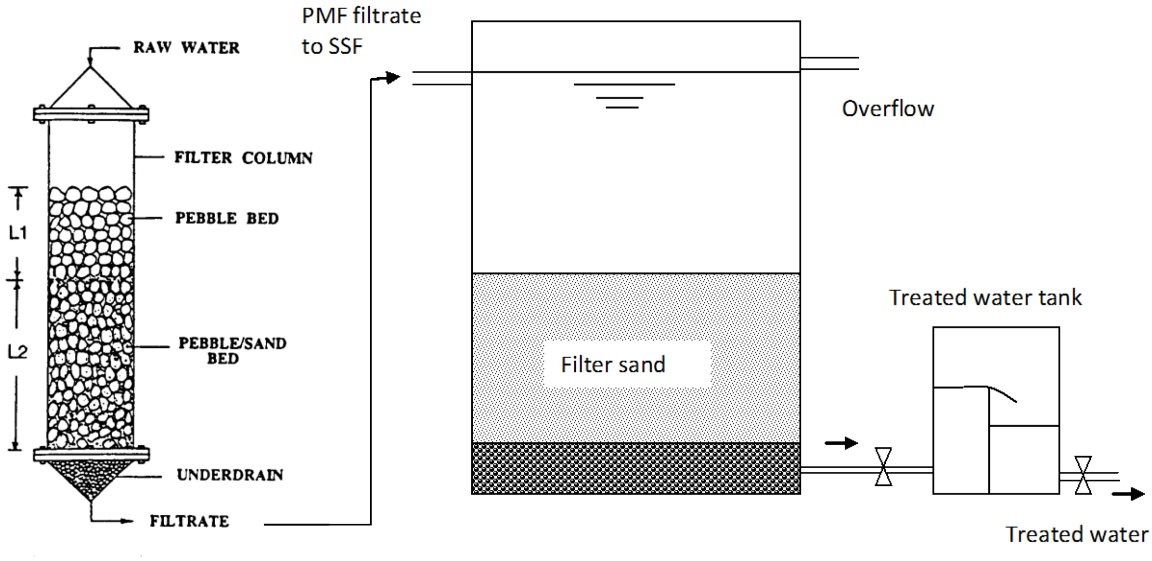
OBJECTIVE

There are four SSF's at Kataragama treatment plant troubled by high turbidity. The objective was to protect one of the four existing SSF units against high turbidity of the inlet raw water by constructing two PMF units ahead of SSF. A schematic diagram showing the four slow sand filters and the newly constructed pebble matrix filters is shown in Fig. 2 below.

The river water quality was monitored mainly for turbidity and the performance of the new PMF units was assessed in terms of turbidity removal efficiency and filter run times with regard to headloss development in the filters.

CONSTRUCTION DETAILS OF PMF TANKS

The two PMF units at Kataragama WTP were constructed with total effective plan area of 39 m^2; one was built out of reinforced concrete (PMF1: 4.8 m x 4.8 m) and the other using Ferro-cement technology (PMF2: diameter 4.5 m) and both tanks with a height of 3m as shown in Fig. 3.



Pebble Matrix Filter (PMF) **matic of PMF** Slow Sand Filter (SSF) **s**

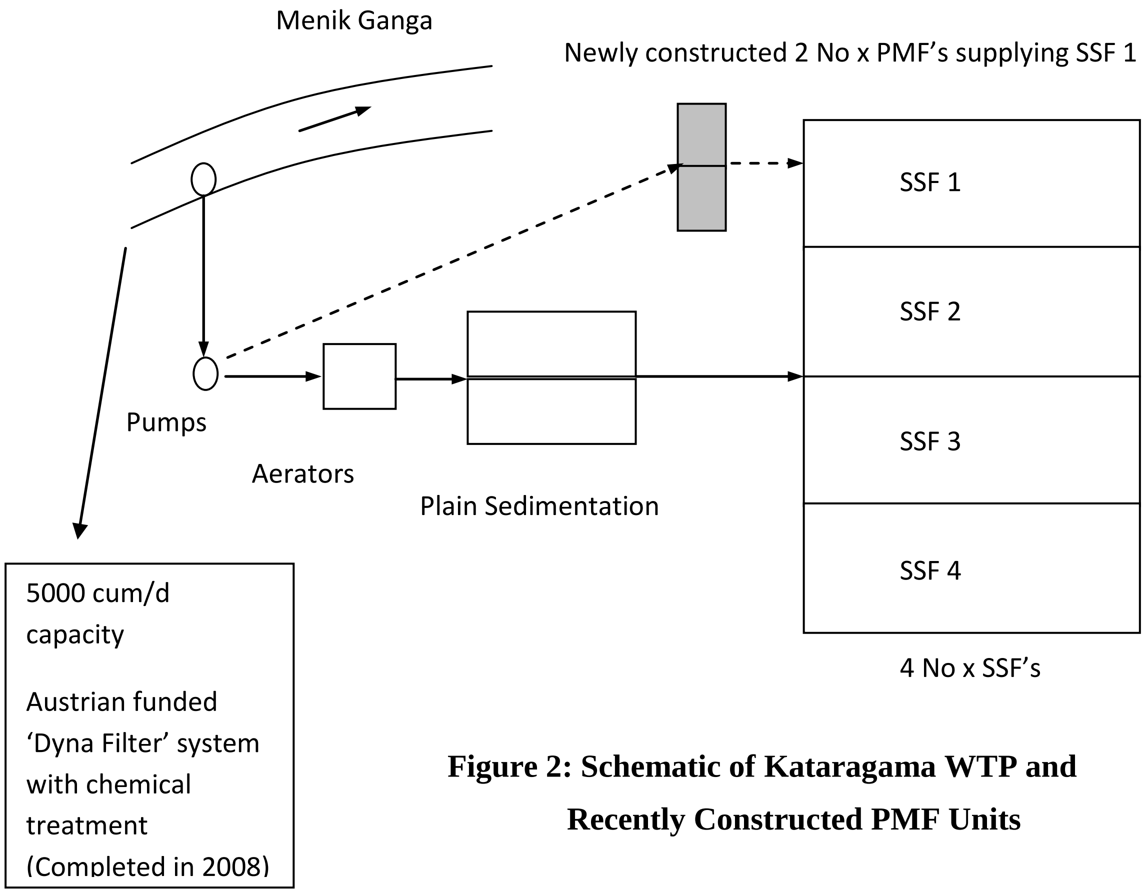


Figure 2: Schematic of Kataragama WTP and Recently Constructed PMF Units


Figure 3: Photos of 4.8 m x 4.8 m RC Tank and 4.5 m Diameter FC Tank

FILTER BOTTOM

As opposed to the backwash system used in laboratory and field trials (Rajapakse and Ives, 2003), a locally manufactured new nozzle system was used at Kataragama plant for better back wash water distribution, hence better cleaning of the filters. A filter model 1 m x 1 m x 3 m high was fitted with these nozzles and tested for establishing an effective backwash rate before placing the nozzles in the full-scale PMF units.

A nozzle deck constructed at 400 mm height from the base of the tank facilitated the collection of filtered water and at the same time provided an even distribution of water in up flow direction during backwashing. The nozzle deck consisted of 50 nozzles per square meter and the slot area of each nozzle was 10 mm x 0.6 mm and there were 12 slots per nozzle. A photograph of the nozzle deck is shown in Fig. 4.

FILTER MEDIA

The filter media was placed manually on top of the deck. First, a 50 mm layer of 2-10 mm chips were placed and then 75 mm thick 10 -20mm chips were placed as the support media for the pebble and sand mixed bed of 800mm depth. Finally, a 300 mm deep pebbles only layer was placed above the 800 mm pebble and sand mixed bed, giving a total filtration media depth of 1100 mm. The effective diameter of sand (d_{10}) in the reinforced concrete tank (PMF1) and Ferro-cement tank (PMF2) was 0.52 mm and 0.38 mm respectively. The pebbles and sand mixed bed was placed on the support media manually in layers of 150 mm pebbles then sprinkling sand to fill all the pore spaces as shown in Fig. 5.

Figure 4: Nozzle Deck

Figure 5: Placing the Pebbles & Sand Mixed Bed Manually

During construction it was found that due to scarcity of pebbles, and the difficulty of securing supply of requisite quantities of uniform size pebbles, sourcing from one site was not possible. Pebbles need to be bought in a variety of mixed sizes and sorted on site manually as shown in Fig. 6 (a). Pebbles were supposed to be of uniform size approximately 50 mm size, however, due to the difficulty in finding such material even after handpicking a non-uniform bed of pebbles ranging from as small as 20-25 mm to large as 60-70 mm (see Fig. 6, b &c) were placed in both filters, PMF1 and PMF2.

(a) Hand picking pebbles

(b) Non-uniform pebble media

(c) pebbles 20-25mm to 60-70mm

Figure 6: Difficulty in Obtaining Uniform Size Pebbles

FILTER CLEANING

As in the laboratory and field trials mentioned earlier, the cleaning of the PMF was performed by two drainage cycles followed by backwashing. Water for drainage and backwash was taken from the sedimentation tank as can be seen in Fig. 7. In order to avoid the common problem of getting spare parts for imported pumps, we have made every effort in finding a suitable pump manufactured locally and finally found a close match by connecting two locally manufactured pumps in parallel.

Figure 7: Backwash Water Supply from Sedimentation Tank

MONITORING

The two pebble matrix filters were operated at filtration rates between 0.60 m/h to 1.20 m/h (mostly around 0.70-0.80 m/h) and the backwash flow of the two combined pumps was 800 m^3/h, with backwash rates of 35 m/h and 47 m/h for PMF1 and PMF2 respectively. The turbidity measurement was carried out using a HACH-2100P portable turbidimeter. Headloss in both filters were monitored using piezometers and pressure gauges connected to the filtrate pipes.

RESULTS AND DISCUSSION

Except for a few days, the May 2008 monsoon period produced unexpectedly low turbidity for a short duration in the river 'Menik Ganga' at Kataragama area, while other parts of the country were inundated with floods causing severe damage to property and life. A graph showing the turbidity removal in the Ferro-cement tank (PMF2) is sown in Fig. 8. During the monitoring period of 2 April to 7 May 2008, the river turbidity varied between 22 - 264 NTU with an average value of 67 NTU, while the treated turbidity varied between 1.8 and 142 NTU with an average value of 28 NTU, which is quite acceptable as the input into slow sand filters. Turbidity removal in the RC tank (PMF1) for the period 27 May to 12 June is shown in Fig. 9. During the PMF1 monitoring period of 27 May to 12 June 2008, the river turbidity varied between 5 - 77 NTU with an average value of 17 NTU, while the treated turbidity varied between 1.2 and 18.7 NTU with an average value of 5.2 NTU. It should be noted that throughout these periods both filters were backwashed using raw water from the sedimentation tank.

During 9th to 29th of November 2008, the river water turbidity varied from 35-444 NTU with an average value of 173 NTU. The treated water quality of PMF1 varied between 6-246 NTU with an average value of 95 NTU, while filtrate of PMF2 fluctuated between 4-262 NTU with an average value of 95 NTU, similar to PMF1 in the same period. Filtration rates were between 0.68-0.78 m/h for PMF1 and 0.64-0.80 m/h for PMF2. Headloss in the PMF1 was below 10 cm throughout November operating period, while the plant operator has recorded zero headloss in the PMF2 throughout this period. A graph showing the turbidity removal in both PMF1 (d_{10}=0.52 mm) and PMF2 (d_{10}=0.38 mm) during November 2008 is shown in Fig. 10. It is interesting to note that although both filters operated under similar conditions except for the sand size, both filters produced almost identical filtrate graphs, whereas one would expect to see better filtrate quality in the filter with finer sand size (PMF2).

Compared to laboratory and field tests, the turbidity removal efficiency was not as expected, although, the plant was able to protect the SSF for short periods during high turbidity in the river. However, a smaller scale model (1.0 mx1.0 m x 3.0 m high) using stirred muddy river water at the inlet operated at the site produced removal efficiency of above 90%, as high as laboratory tests (Fig.11). The mixed bed depth was 800 mm (total bed depth 1100 mm) with sand size of 0.38 mm effective diameter and the filter was operated at a filtration rate of 0.70 m/h.

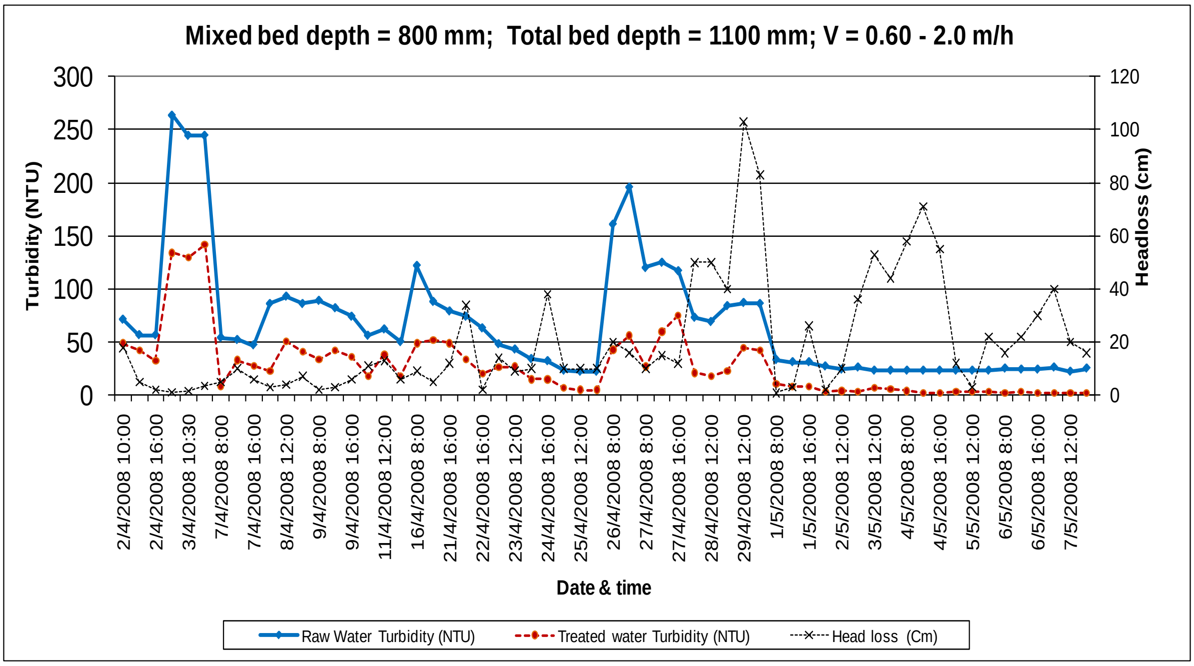


Figure 8: Turbidity Removal in the Ferro-Cement (PMF2) Tank from 2 April to 7 May 2008

PROBLEMS ENCOUNTERED

There were some delays in starting the project due to changes in senior management at the NWSDB. Delay in completion of construction was mainly due to security problems in the area, bad weather and late delivery of materials due to delays in funds transfer. Both tanks were completed by April 2008 and put into operation, however, after several weeks of operation some leaks appeared in both tanks and the operation of the Ferro-cement tank (PMF2) was seized on the 23rd June 2008 due to severity of the leaks until 27 September 2008 when the PMF2 was put back into operation after fixing the leaks. However the operation of Reinforced Concrete tank continued as there was no such serious threat observed by the site staff, although, after an inspection by a senior structural engineer cracks in the bottom of both slabs were observed (Fig. 12) and recommendations were made to provide additional beam and central supports as shown in Fig. 13. These remedial measures to PMF1 were carried out during 27 September and 09 of November 2008 by jacking the centrally supported column under the slab prior to concreting as shown in Fig. 14.

ALTERNATIVE MEDIA TO PEBBLES AND SAND

Undoubtedly, one of the main reasons for poor removal efficiency was the poor cleaning of the filter beds due to use of high turbidity water from the sedimentation tank for backwashing. For example during November 2008 operations when sedimentation tank water had a turbidity of 160 NTU, the initial effluent turbidity of backwashed water in the PMF1 and PMF2 were 934 NTU and 769 NTU respectively, and after 15 minutes of backwashing, the effluent water turbidity was settled around at 300 NTU in each filter, clearly indicating the poor cleaning of the filter media.

The severe structural damage to the filter slab due to under design may also have led to cracks in the filter bottom creating preferential flow paths of untreated water through the filter bed leading to higher filtrate turbidity. The zero headloss in PMF1 and constantly below 10 cm headloss in PMF2 also indicate such a possibility. During the first two days (9-11 Nov 2008) of operation of PMF1, there has been some 64% - 95% turbidity removal efficiency in the filter; however, the headloss constantly showed a zero reading. One would expect to have some initial headloss in the filter bed and to increase it with time as particles are removed from suspension and accumulated within the filter bed. Although digging the filter bed in two locations did not reveal such damage, to come to a definitive conclusion the whole bed need to be removed and inspected properly in both filters.

It was also suspected that the non-uniformity of pebbles has detrimental effects on the efficiency of the filtration process and cleaning of the filter. When a pebble bed of larger size is mixed with smaller size pebbles, it appears that sand does not return to its original position after backwashing, hence leading to poor filtration performance once filter resumes its operation after backwashing. Also it was observed that due to environmental concerns extraction of pebbles may be restricted in some countries, including Sri Lanka, therefore, the use of alternative media to pebbles will be explored and performance monitored in the laboratory.

Taking into account all these factors the National Water Supply and Drainage Board of Sri Lanka has shown interest in developing a new alternative to pebble media. If this can be produced cheaply, then it is always possible to make them to any required size, shape and with desired surface properties. Furthermore, previous research (Rajapakse, 1988) has shown that pebble matrix filtration technology can be used in many parts of the world with high turbidity problems during tropical monsoon periods, and it is possible that pebbles may not be readily available or too expensive in some of these countries as in the case of Sri Lanka.

Clay-balls and recycled glass as an alternative media to pebbles and sand has been explored at Cambridge University in the laboratory in 2009 by operating a series of filtration column studies and these results will be published in due course. These column tests also produced removal efficiencies well over 95% with a kaolin suspension containing 80-590 NTU in the inlet water.

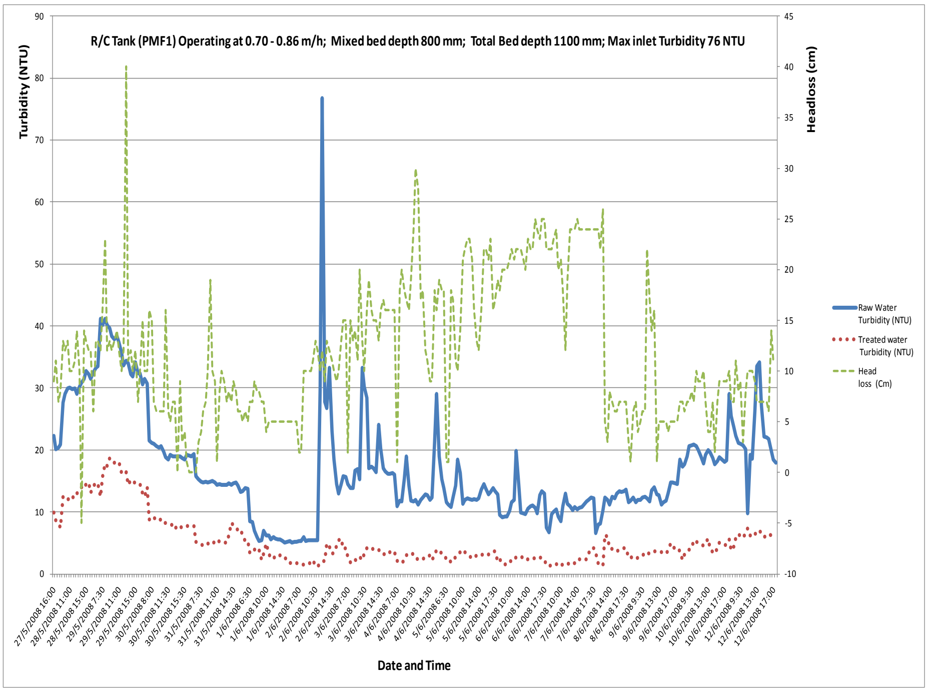


Figure 9: Turbidity Removal in the RC (PMF1) Tank from 27 May to 12 June 2008

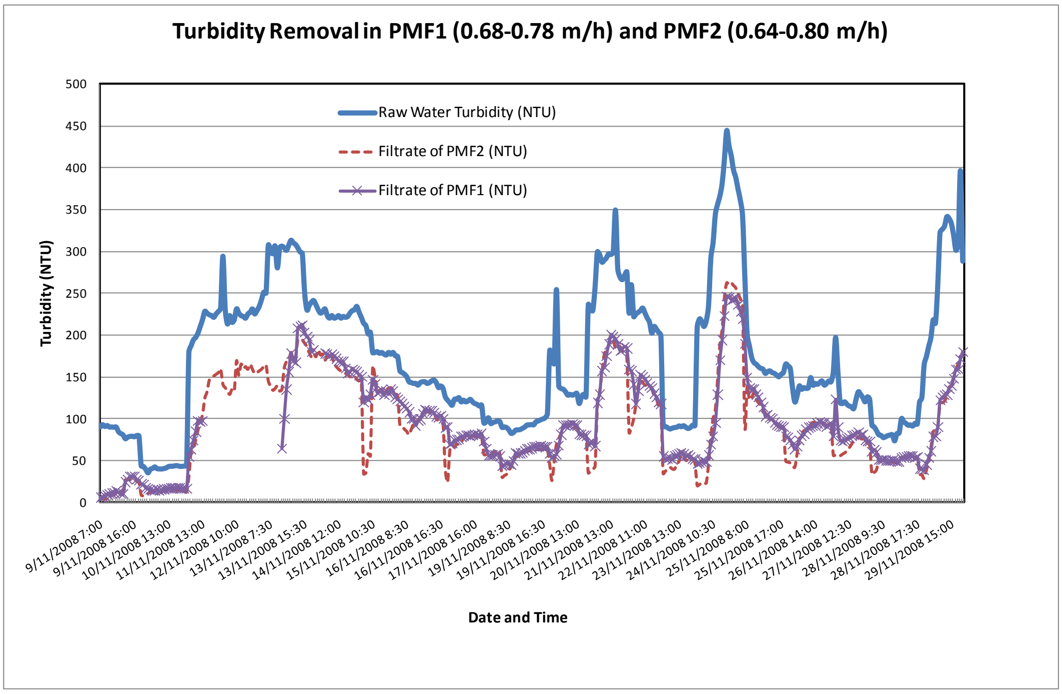


Figure 10: Turbidity Removal in PMF1 (RC) and PMF2 (FC) Tanks from 9 to 29 Nov 2008

(Mixed bed depth 800 mm and total depth 1100 mm in each tank)

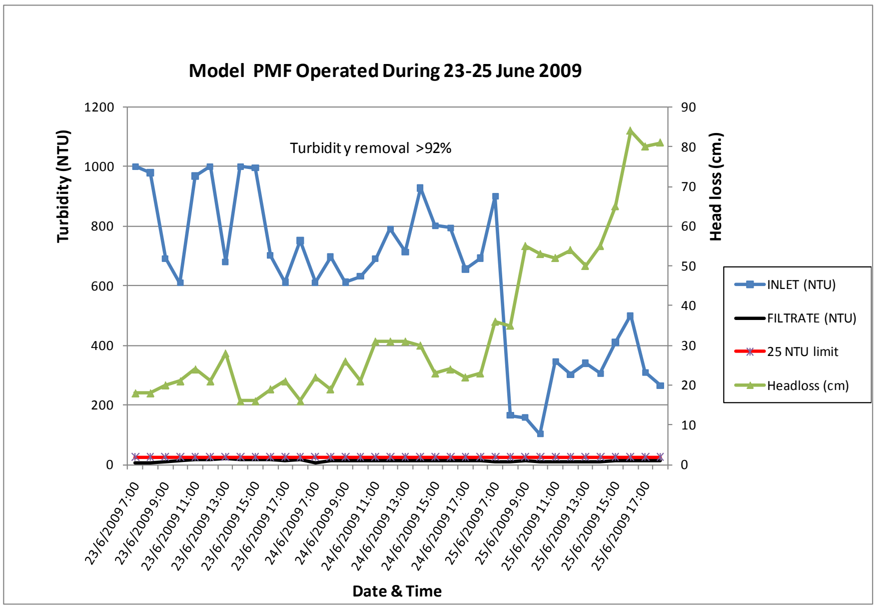


Figure 11: High Turbidity Removal Efficiency in the 1 m x 1 m x 3 m Model PMF

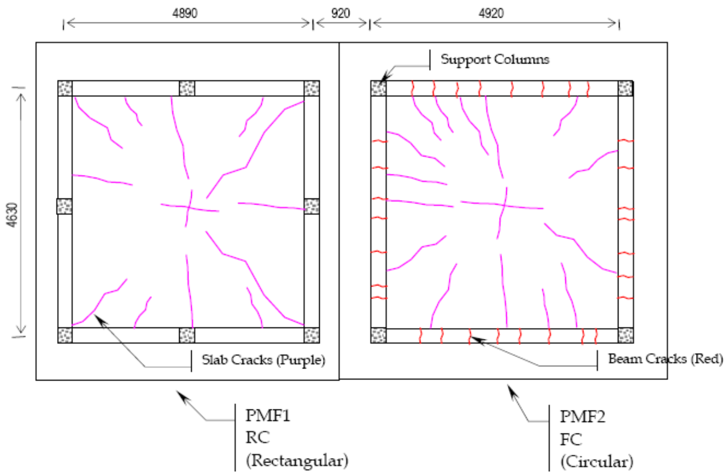


Figure 12: Cracks Observed at the Bottom Outer Surface of the Slabs

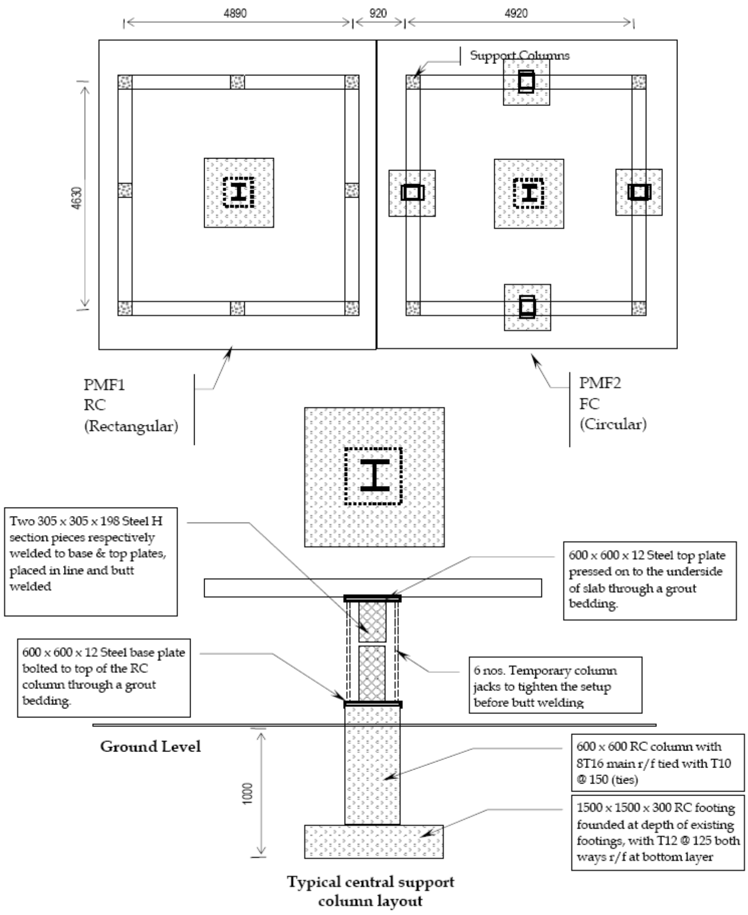


Figure 13: Remedial Measures Carried Out to both PMF Tanks

Figure 14: Centre Column H Iron Support Jacked Under the Slab Prior to Concreting.

CONCLUSIONS

There have been many challenges during the construction and operation of the first-full-scale Pebble Matrix Filter plant at Kataragama Water Treatment Plant in Sri Lanka. The use of Ferro-cement tanks instead of reinforced concrete tanks for filter construction can reduce costs by about 50%. The turbidity removal efficiency in the filters was lower than expected (above 90%). The reasons for low removal efficiency in the full-scale plant compared to very high removal efficiency (above 95%) in both laboratory and field trials need further investigation. The plant was able protect an existing slow sand filter without any chemicals addition during monsoon period when the other three SSFs (without prereatment), and the newly constructed 'Dyna Sand' system had to shut down for short periods. The cleaning of the PMFs was performed using raw water of high turbidity and no product water was utilized throughout the project. The headloss in the pebble matrix filters are generally small, therefore, there is room for reduction in sand size to below 0.38 mm and further improve turbidity removal efficiency. It is possible that this new non-chemical pre-treatment technology can be scaled-up in many other tropical developing countries for high turbidity problems, not necessarily associated with slow sand filters, but also in general to combat high turbidity at low maintenance cost.

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REFERENCES

Rajapakse, J.P., (1988) Pre-filtration of high turbidity waters, PhD Thesis, University of London, 1988.

Rajapakse. J.P. and Ives. K.J., (1990) Prefiltration of very highly turbid waters using pebble matrix filtration, *Journal of IWEM*, Vol 4, No 2, April 1990.

Rajapakse, J.P and Ives, K.J., (2003), Field Trials of a Simple Surface Water Treatment Package for Rural Supply, *J. Env.Eng. Soc, IEAust, The Environmental Engineer*, Vol.4, No.1, pp.16-20, ISSN 1447-943.

Rajapakse, J.P., Jovanović, B. & Ljubisavljević, D., (2005) Field trails of a simple surface water treatment package for rural supply (Part II), Pebble Matrix Filtration Field Trials in Serbia and Montenegro, *The Environment Engineer, Journal of the Society of Sustainability and Environmental Engineering*, Institution of Engineers Australia, Vol 6 No 3, pp.17 – 19, ISSN 1447-9435, Spring 2005.

Rajapakse. J.P.and Sumanaweera.S ,(2007) Pre treatment before slow sand filtration with pebble Matrix filtration at KataragamaWater Treatment works, Sri Lanka, *Journal of IESL*, Vol XXXX, No 2, pp 53-57.