ENGINEER - Vol. XXXX, No. 02, pp. 53-57, 2007

Pre-treatment before Slow Sand Filtration with Pebble Matrix Filtration at Kataragama Water Treatment Works, Sri Lanka

J.P. Rajapakse and S. Sumanaweera

Abstract: The Kataragama water treatment plant (WTP) currently abstracts water from the river 'Menik Ganga' and seasonal high turbidity exceeding 500 NTU put the existing four slow sand filters (SSF) out of operation several times a year. The proposed use of Pebble Matrix Filtration (PMF) ahead of SSF as a pretreatment is an attractive option as the PMF itself is a simple and sustainable solution to the problem in the developing country context. The proposal to conduct first, full-scale trials at Kataragama WTP has been submitted to the World Bank's Development Marketplace competition (with partial funding from UNESCO-DaimlerChrysler Mondialogo Engineering Award 2005), and has won the DM-2006 Award out of 2500 proposals worldwide. The background and concept of PMF technology and its proposed use at Kataragama WTP to overcome high turbidity problems associated with SSF is explained in this paper.

Keywords: Pre-treatment, high turbidity, slow sand filtration, pebble matrix filtration, Kataragama, Sri Lanka, World Bank, Development Marketplace, Mondialogo

1. Introduction

The National Water Supply and Drainage Board (NWSDB) of Sri Lanka functions under the Ministry of Water Supply and Drainage and it is the principal authority providing safe drinking water and facilitating the provision of sanitation in Sri Lanka. Currently there are 287 water supply schemes operated by the NWSDB and about 200 treatment plants abstracting water from river sources. Fifteen plants out of the 200 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. Therefore, it is desirable to use pretreatment ahead of slow sand filtration and reduce suspended solids in high-turbidity water to a concentration suitable for application to slow sand filtration without the latter 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. Although existing non-chemical pretreatment methods, such as horizontal and up-flow roughing filters can produce removal efficiencies of up to 68% and 86% respectively (Galvis et. al [1]; Clarke [2]), when the raw water exceeds 200 NTU, the filtrate from such prefilters is not suitable to be fed into slow sand filters.

The pebble matrix filter has been tested with 500-5000 mg/1 suspended solids loadings and produced filtrates below 25 mg/1 in the laboratory in London (Rajapakse and Ives[3]). These laboratory tests were followed by successful field trials in Papua New Guinea (Rajapakse and Ives[4]), Serbia and Montenegro (Rajapakse et. al [5]) and most recently a small-scale field trial was conducted in Mexico, but no results have been published yet from the Mexican experiments.

2. Objectives

The main objective of the study is to conduct full-scale pebble matrix filtration trials as a pretreatment method before existing slow sand filters at the Kataragama water treatment plant.

There are four SSFs at Kataragama troubled by high turbidity. However, initially, only one of

Eur.Ing. Rajapakse. J.P., PhD(Lond),MSc (Mow),PgDip (Middx), CEng, FCIWEM, MICE, is a Senior Lecturer in Environmental Engineering in the Dept. of Civil Engineering at Papua New Guinea University of Technology, and Honorary Senior Lecturer at University College London (Univ. of London).

Eng. Sumanaweera. S, M.Eng. (AIT), B.Sc.(Eng.), C.Eng.(MIESL) is Assistant General Manager (Research and Development) of the National Water Supply & Drainage Board of Sri Lanka.

these will be protected by PMF to establish the benefits of PMF prefiltration ahead of SSF.

3. Slow Sand Filtration

Filtration of drinking water by slow sand filters 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 filtered water drained from the bottom. The filter consists of a tank, a bed of fine sand (typically d_{10} = 0.30 mm), a layer of 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^3/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 periods of heavy rain, causing disruption to continual operations. To sustain slow sand filters' operation and therefore enable an 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.

4. Kataragama WTP

The Kataragama water treatment plant supplies a population of about 20,000 as regular customers and a further about 2000 visitors from all over the country and abroad during week ends (throughout the year) and another staggering 10,000 pilgrims a day during the Kataragama festival in July. The total output through the plant is 3500 m^3/day. The plant abstracts water from the river "Menik Ganga". 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. A schematic of the existing and proposed plant layout is shown in Fig. I. Although a new Austrian funded high-tech treatment plant is being constructed, the existing slow sand filter system will not be abandoned. The aerators and the sedimentation tank are shown in Photo 1 and an SSF is shown in Photo 2.

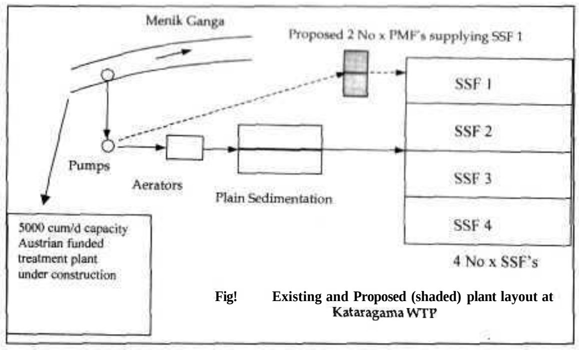

Figure 1: Existing and Proposed (shaded) plant layout at Kataragama WTP

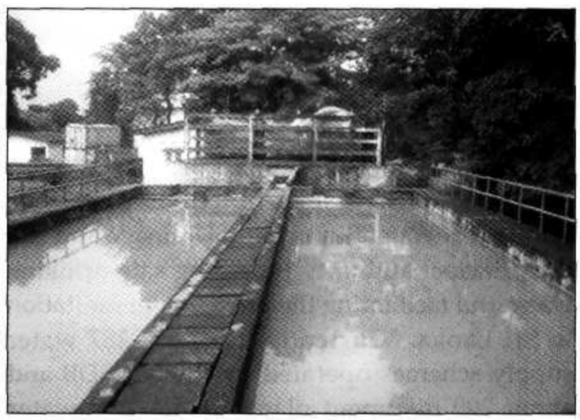

Photo 1. Aerators with Plain Sedimentation

Photo 2. One of the Four SSF

The rainfall in the Menik Ganga basin is subjected to monsoonal variations and occasional high turbidity put the existing four SSFs out of operation several times a year, the most recent shut down occurred in October 2006 where river turbidity was recorded at 585 NTU. Yet, 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/1

(approx. 45-65 NTU) for shorter operation times (2-3 weeks). Photo 3 below shows samples collected in December 2006 with river turbidity at 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.

Photo 3. Water Samples from the River, Sedimentation tank and SSF final

5. 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 (Ives and Rajapakse [6]).

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. 2.

The upper part of pebbles only has some prefiltering effect, but the improvement in suspension solids concentration is dominated by the pebble-sand mixture which provides the secondary finer filtration. It is also possible for the upper pebbles to act as a contact flocculator due to the velocity gradients between them. Three different sand grades in the range of 0.355-2.00 mm were tested with same pebbles of about 50 mm in diameter, at filtration rates of 0.72-1.56 m^3/h and Kaolin clay concentrations from 500-5000 mg/1. Initial laboratory experiments with kaolin suspensions showed that with 500 mg/l kaolin suspension (similar to maximum suspended solids experienced by Menik Ganga during 2006 monsoon period) filtering through a total bed depth of 1300 mm, containing 950 mm of infill sand (0.50-1.00 mm) at a filtration rate of 0.72 m^3/h, the filter run lasted 116 hours, until breakthrough of filtrate (>25 mg/1) producing a head loss of 1.5 m. Generally the filter runs with the coarsest sand (1.00-2.00 mm) were unsatisfactory, and the runs with 2000 mg/1 had to utilize a total bed depth of 1300 mm with 950 mm of sand infill to obtain a reasonable run length of 18 hours before filtrate breakthrough. Similarly, with the finest sand (0.355-0.710 mm grade) when the filter was loaded with a 5000 mg/1 kaolin suspension the filter was able to maintain a filtrate quality not exceeding 25 mg/1 for 8.5 hours only (at 0.72 m^3/h).

Regeneration of the PMF is achieved by a method called "Drainage and Backwash" (photos 4.1-4.3). That is, two drainage cycles (first, drain down the existing water, then re-fill the filter with raw water and drain again) followed by backwashing to expand the sand into the pebble pores above. Regular backwashing can also be done using raw water with an occasional backwash using product water to keep filters clean on the long run.

As demonstrated earlier, one distinct advantage of the PMF is that it can sustain very high silt loads without creating large pressure drops (head loss) through the filter. Such a performance could not be maintained by a normal primary rapid sand filter, because of the very rapid rise of head loss that would be experienced. Other advantages of the PMF are that they do not require any chemicals for their operation and backwashed water can be collected into a sump and discharged later or recycled in the process, making the entire process environmentally sustainable. On the negative side it may not be always possible to find rounded pebbles of about 50 mm in size, readily available at sites and in such situations artificial materials with similar texture and suitable density would have to be sought, or consider using broken road stones instead. However, the performance of such alternative materials needs to be evaluated through further research.

Under Papua New Guinea conditions where materials have to be transported to rugged rural areas with very limited road access, the total cost of a PMF and SSF system with fittings, flow meters, manometers, underdrains, filter media and labour but excluding storage with filter tanks made of galvanized iron culvert rings were estimated to be around US$ 12,500, 23,000 and 32,500 (based on March 2000 prices) for populations of 400, 1000 and 2000 respectively. However, other construction materials such as reinforced concrete or Ferro-cement tanks would keep the construction costs much lower in other countries and, therefore, currently under consideration in the Kataragama Project.

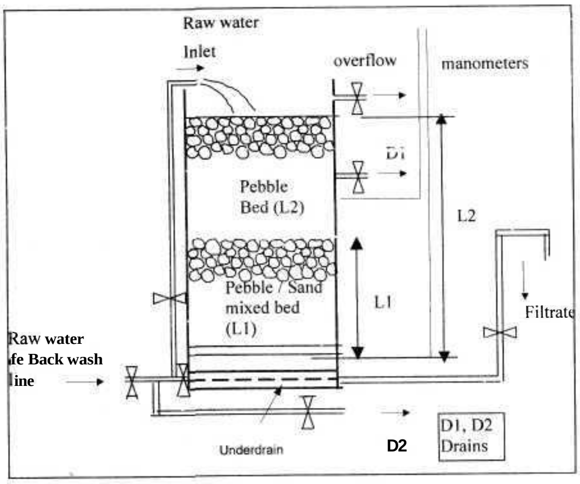

Fig. 2 Schematic of a Pebble Matrix Filter

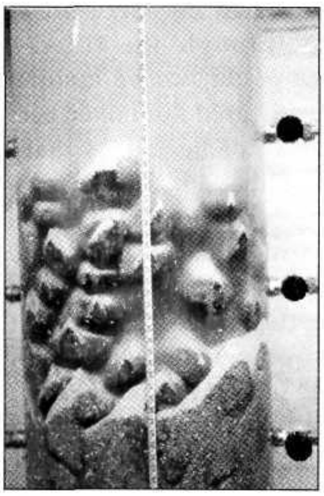

Photo 4.1 Clogged PMF

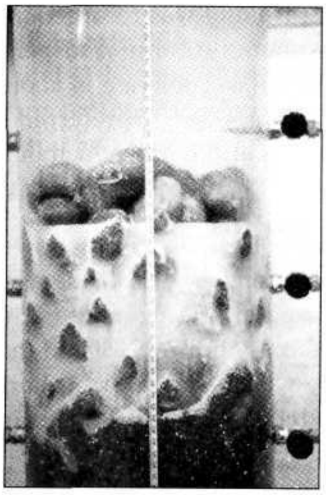

Photo 4.2 Start of the First Drainage Cycle

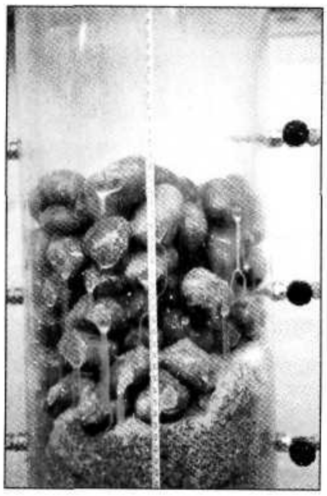

Photo 4.3 End of the First Drainage Cycle.

Following successful PMF laboratory experiments in London, two pilot plants have been constructed in Lae, Papua New Guinea. These PNG field experiments further confirmed the London laboratory experiments. As a result of the successful PNG field trials, lately another pilot plant (PMF together with SSF in series) has been constructed and tested in Vrnjacka Banja, Serbia and Montenegro and Mexico. The construction of the first full-scale PMF units at Kataragama WTP is due for completion in September 2007 and, hopefully, its benefits in protecting one of the four existing SSF, during the coming monsoon period will be evaluated.

6. Conclusions

1. Laboratory trials in London proved that the PMF can bring down suspended solids of 5000 mg/l down to 25 mg/l.

2. Field tests in PNG, Serbia and Montenegro proved that suspended solids up to 1000 NTU were successfully removed by PMF to acceptable limits into SSF.

3. The pilot full scale trial at Kataragama water treatment plant, expected to complete construction in September 2007 and monitoring treated water quality will be carried out up to 2008.

Acknowledgements

The authors would like to thank the General Manager of NWSDB Mr. M. Wickramage for supporting this project first in 1996 and again this time. Eng. S.R.J.R. Senanayaka, Additional General Manager (Development) for kindly accepting to implement the project. Eng. A. Kumararatne, and Eng. A. Munasinghe of Planning & Design for supporting the proposal to World Bank Development Marketplace Global competition. Dr. S. Pilapitiya of World Bank for kindly agreeing to be the Project Advisor (PA) and last, but not least, Mr. S. Gallege for proposing the PMF project to NWSDB first in 1996 and again in 2006 along with a research and development team from the NWSDB. The funds received through Mondialogo Engineering Award and the Development Marketplace of World Bank is greatly acknowledged with thanks to DM team.

References

1. Galvis. G, Latorre. J, Ochoa. A.E. and Visscher. J.T., Comparison of horizontal and upflow roughing filtration, Advances in slow sand and alternative biological filtration (Ed. Graham. N and Collins. R), Wiley, 1996.

2. Clarke. B.A., Lloyd. B.J., Jones. C.J. and Evans. H.L., Water treatment by multistage filtration utilizing gravel prefilters and fabric enhanced slow sand filters, Advances in slow sand and alternative biological filtration (Ed. Graham. N and Collins. R), Wiley, 1996.

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

4. Rajapakse. J.R and Ives. K.J., Field trials of a simple surface water treatment package for rural supply, Journal of Env. Eng. Soc., The Environmental Engineer, IEAust, Vol 4, No 1, Autumn 2003.

5. Rajapakse, J.P., Branislava. J and Ljubisavljevic. D., Pebble matrix filtration field trials in Serbia and Montenegro, Journal of Env. Eng. Soc., The Environmental Engineer, lEAust, Vol , No , 2005.

6. Ives. K.J. and Rajapakse. J.P., Pretreatment with pebble matrix filtration. In: Slow sand filtration - Recent Developments in water treatment technology (Ed: Graham. N.J.D), Ellis Horwood, Chichester, UK, 1988.