Pebble matrix filtration in Papua New Guinea

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Slow Sand Filters become inoperative during heavy rains when the raw water supply becomes turbid. A novel pre-treatment method called Pebble Matrix Filtration was tested in the laboratory and then tried out in the field in Papua New Guinea. Pre-treatment was shown to reduce turbidity and faecal coliforms dramatically.

Slow Sand Filters (SSFs) are an essential element of water treatment works in many developing and developed countries. The World Health Organization (WHO) recommends the use of slow sand filters for the treatment of drinking water, particularly for rural or village supply. The simple designs of slow sand filters permit the use of local materials and skills in their construction, operation and maintenance. No chemicals are used for their operation, and almost no instrumentation is required, so the cost of imported materials and equipment can be kept to a minimum. The SSF is very effective in pathogen removal and generally produces an effluent satisfying bacteriological drinking-water quality requirements. It therefore satisfies the needs of a water-treatment facility in low-income countries. Handbooks containing guidelines for the design and construction of these simple but efficient natural filters have been published by WHO and the International Reference Centre for Water and Sanitation (IRC).[1,2]

There are no SSFs operated by the water board or other water companies in Papua New Guinea at present. This may be because the simple-technology image has resulted in it being considered generally inappropriate by some designers, but such perceptions are rapidly changing in the light of the rising demand for higher drinking water quality standards. In the past 10–15 years, there has been a renaissance of interest in the potential use of slow sand filtration throughout the world.

A long-standing problem with slow sand filters is that they deteriorate during periods of heavy rain when the supply of raw water becomes turbid. A typical example is the Bumbu River in the Morobe Province, PNG, where 3000 mg/l suspended solids is quite common during rainy periods. The silts and clays in muddy water clog the surface layer of sand and fill the pores between the sand grains, with a consequent loss of flow capacity and a rapid rise in head-loss across the filter. This shortens the filter runs, necessitating frequent cleaning, thereby disrupting the water supply.

It is therefore vital to protect the SSF from such effects during monsoon or heavy rainfall periods by the use of pre-treatment methods. A novel pre-treatment method called Pebble Matrix Filtration (PMF), developed at University College London, proved to satisfy these conditions and showed promise in the laboratory.[3] Other books highlight the developments in slow sand filtration from around the world.[4]

After the laboratory trials in London using kaolin clay suspensions in London tap water, the PMF had to be tested out using natural raw water in PNG. It was also necessary to examine the feasibility of construction, operation and maintenance of a PMF under rural PNG conditions and then to assess its suitability as a pre-filter for SSF in treating surface waters for village water supply. The design and construction of the system were carried out by students of the Department of Civil Engineering at University of Technology.

Pebble Matrix Filter (PMF)

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 and then through a matrix of pebbles and sand mixture. The upper part of the pebbles-only bed has some pre-filtering effect, but the reduction in suspension concentration occurs mainly in the lower part of pebble–sand mixed bed.

Initially it was accepted that the ability of the PMF to cope with very high turbidity was just a useful empirical phenomenon with no rational explanation. However, the use of endoscopes in the laboratory revealed that the capacity of the PMF to accept high deposit loadings without a great drop in pressure is attributable to flows over the pebble surfaces acting as a 'wall-effect', and to 'lens-like' cavities found underneath the pebbles. These additional flows (macro) are a significant fraction relative to the flow passing through the sand (micro) and maintain a high effective permeability throughout the bed, allowing an incoming suspension to penetrate to the deeper, as yet unclogged, sand. The PMF was to perform as a pre-treatment unit before SSF, therefore it was not expected on its own to produce potable water. Hence, filter cleaning was carried out by 'two drainage cycles' (first by draining down the supernatant water in the filter and then refilling with raw water while the drain valve was closed, and then reopening the drain valve) followed by a backwash with raw water under gravity.[5]

First PNG trial plant

In order to test the technology in the field, a PMF unit and two SSF units were constructed at Ambuasuz village, 14 miles outside Lae. The PMF pre-treated water was fed into one SSF and the other SSF acted as a reference filter. About 2.5 m of head was allowed between the dam outlet and the PMF for gravity flow and the same head was used for backwashing the PMF.

The two SSF tanks were of 0.9 m diameter, 2.5 m high and were assembled on site, by joining half-culvert rings made of corrugated galvanized iron. Sand of 'effective size' d_{10} = 0.3 mm was selected from a local beach as the filter medium (here d_{10} = Hazen's effective grain size in mm, relative to which 10 per cent of the sample is finer). Transparent plastic tubes of 5 mm diameter were fitted at different heights for head-loss monitoring through the bed. The filters were operated at a filtration rate of 0.2 m/h.

One PMF tank of 0.6 m diameter and 1.4 m tall made of half-culvert rings of corrugated galvanized iron was assembled on site by the same method used in constructing SSF tanks. Rounded smooth pebbles of approximately 50 mm diameter were handpicked from a local river aggregate site. For the preliminary experiments, a pebble bed depth of 80 cm was partly infilled to a depth of 40 cm with medium pool-sand of grade 16/30 (0.50–1 mm), purchased from a local supplier. Similar arrangements to the SSF using manometers were made for the head-loss monitoring through the PMF bed. The assembly took less than half a day for two people to complete. The details of the PMF unit are shown in Figure 1.

The laboratory under-drain system comprised a cone-shaped bottom filled with marbles for uniform distribution of backwash flow and ease of construction, but in prototype filters several types of under-drain systems were considered: perforated pipes, corrugated pipes, etc. The perforated pipe system was chosen for the under-drains in the field test (see Figure 2). The PMF tank was taken to the site and filled manually with pebbles, infilling the spaces between pebbles with sand, layer by layer about 10 cm thick at a time to the required depth.

The raw water and filtrate turbidities were monitored using a portable turbidimeter, model 'Hach-2100P'. Head-loss measurements through filter beds were carried out manually along the manometers using a tape measure.

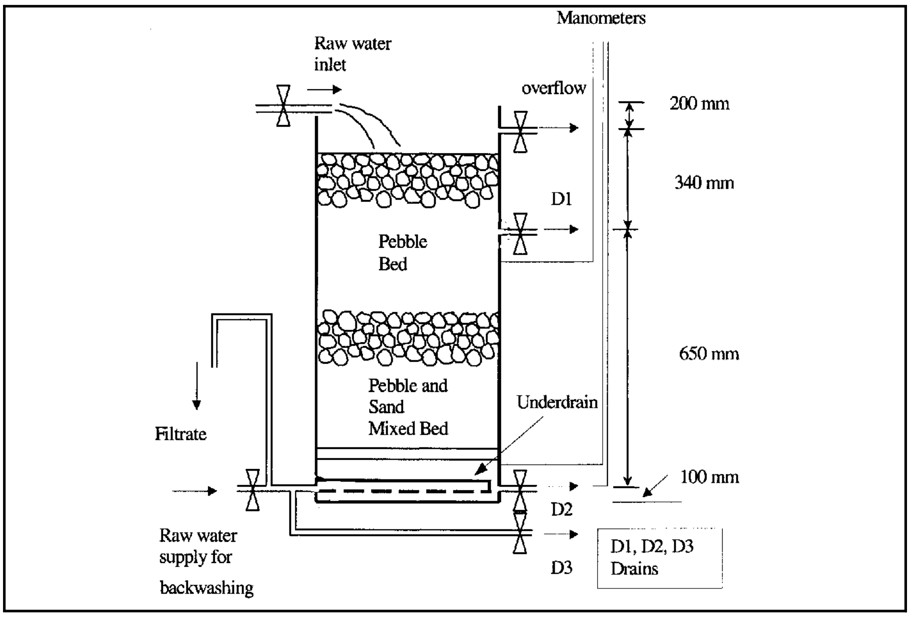

Figure 1 Details of the PMF column, Lae plant

Suspended solids and bacteriological analysis were carried out at the Department's Public Health Laboratory with occasional samples sent to the National Analysis Laboratory (NAL) for confirmation.

Results and discussion

The plant was commissioned successfully in late 1999. Unlike in the laboratory trials, large amounts of algal growths were noticed both in the PMF and in the reference SSF, whereas the SSF fed from the PMF filter was virtually free from growths. As a result, the head-loss in the former SSF was as high as 140 cm compared to 10 cm in the latter after four months. At the end of the fourth month the reference SSF was cleaned, and the sand washed and replaced, whereas the SSF that received PMF pre-treated water continued in operation without cleaning, resulting in a final head-loss of only 15 cm by the fifth month. Due to very low head-losses the PMF was operated for over two months without backwashing, consequently the filter pores became clogged. The bed required manual cleaning due to mud-ball formation after six months of operation. These experiments proved that with fairly low-turbidity raw waters, the combination of a PMF and a SSF would allow up to six months of operation without cleaning if desired, a condition that may well suit rural PNG conditions.

Although the field backwash rate obtained with the available head was much lower (10 m/h) compared to laboratory backwash rate of 50 m/h, a satisfactory cleaning was achieved with two drainage cycles followed by backwashing once for five minutes.

Since the construction of the raw water storage reservoir the inlet turbidity to the PMF rarely exceeded 50 NTU (Nephelometric Turbidity Units), whereas turbidities of

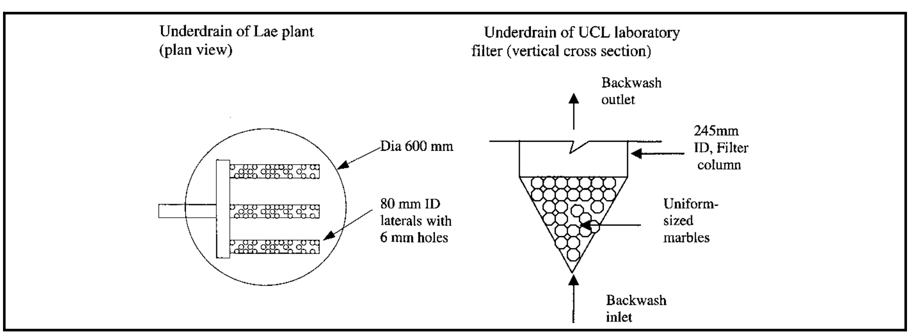

Figure 2 PMF underdrains of Lae and UCL filters

100–200 NTU were very common prior to construction. Filtrate turbidities of both SSFs were below 0.3 NTU. Faecal coliforms of 1300–1600 CFU (Colony Forming Units) and total coliforms of 2200–2800 CFU in the raw water were reduced to zero faecal and total CFU in 100 ml samples of both SSFs. These preliminary results show that the PMF is a useful tool in prolonging the life of an SSF and the system can be used as a package in rural drinking water treatment plants. Some intermittent simulated high turbidity experiments (made by adding silt to the raw water) were also conducted with the PMF. With the support of 'Eda Ranu', a PNG water company, further investigations using naturally high-turbidity water of the Bumbu River are being conducted at a new site near Butibum village, a short distance from Lae City.

Conclusions

A non-chemical, simple filtration system comprising an SSF with a PMF as pre-filter proved to satisfy the water treatment requirements of rural conditions in PNG. The satisfactory construction and commissioning of a field-scale plant in Lae confirmed the feasibility of constructing such a system under PNG conditions and eliminated some doubts regarding cleaning difficulties of the PMF. Preliminary field tests also confirmed the laboratory scale experiments and all the indicators are that the PMF is a useful tool in protecting an SSF in all weather conditions, especially during rainy periods. It is desirable to incorporate a larger-scale treatment plant into a future treatment facility and the Water Board is very interested in the developments so far.

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