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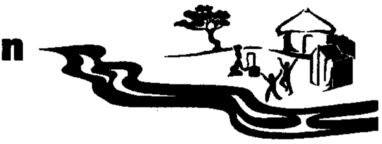
WATER AND SANITATION FOR ALL: PARTNERSHIPS AND INNOVATIONS

# Removal of heavy metals by slow sand filtration



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THIS PAPER IS concerned with a low cost approach of treating micropollutants such as heavy metals and persistent organics by slow sand filtration (SSF). It was initiated as a result of the concern over the levels of the heavy metals in natural sources in Bangladesh which is the main investigator's home country. Slow Sand Filters (SSFs) are probably the most effective, simplest and least expensive water treatment process in developing countries. SSFs require few technical components and usually no chemicals.

Heavy metals are present in abundance naturally and enter the water cycle through a variety of geochemical processes. Many metals are added to water by industrial processes. Disposal of untreated wastes, surface run-off and highway run-off also cause metal pollution of surface water. Heavy metals are also present in solid wastes, municipal sewage sludges and landfill leachate (Pradhan and Levine, 1992 and Marquies *et al*, 1976). High concentrations of heavy metals in water supplies are undesirable because of adverse effects on health, environmental toxicity, corrosion of pipeworks and the aesthetic quality of the water environment. The most toxic metals are arsenic, copper, cadmium, lead and mercury. Muscular and cardiovascular disorders, brain, liver and kidney damage are caused by heavy metals in water (Sawyer and McCarty, 1987).

Research work is going on in different countries in various situations to find the probable mechanisms of metal toxicity as well as suitable technologies for the removal of heavy metals from water. Metal uptake by micro-organisms, the development of biomass, adsorption onto activated carbon, coal and peat, the use of chemical pre-treatment have all proved effective to some extent in removing heavy metals from water. However, very little research has been done on the extent of heavy metal removal by conventional water treatment processes such as sand filtration. Schmidt (1977) reported nearly complete removal of heavy metals from water by slow sand filtration. Sontheimer (1980) reported 33-94 per cent removal of heavy metals from water by slow sand filtration. Ellis (1985) and IRC (1987) suggested 30-90 per cent removal of heavy metals by slow sand filtration. The published results are taken from the experience of different water works where there is little control of other variables. Virtually no extensive laboratory and pilot studies have been carried out to find the mechanisms and efficiency of SSF in removing heavy metals.

The paper describes research undertaken to study the performance of SSFs in removing heavy metals including the influence of organic load, flow rate and filter bed depth in order to determine the mechanisms of heavy metal removal. Consequently, it is hoped that treatment efficiency may be optimised for heavy metal removal.

## Experimental study

To carry out the experimental investigation, four separate laboratory scale SSFs were constructed. The filters are of 60 mm diameter and are divided into two sections by flange in the middle to make scraping of the sand surface possible. The filters are fed from individual overhead tanks containing different heavy metal salts. Four influent tanks are fixed at the top to maintain gravity flow. Salts of Cadmium (Cd), Copper (Cu), Chromium (Cr)and Lead (Pb) are mixed in each of the overhead tanks. Cadmium sulphate, copper nitrate, chromium nitrate and lead nitrate were chosen for their easy solubility in water. The overhead tanks are fed from a single common tank at the bottom. Sewage was added to the contents of this tank to maintain various controlled levels of organic load (TOC). The doses of Cu, Cr, Pb and Cd were maintained at 10 mg/l, 100 µg/l, 60 µg/l and 100 µg/l respectively. The concentrations of heavy metals in surface water depends on the degree of pollution. The doses of different metals in this investigation were selected considering the WHO guidelines of those metals for drinking purpose. The selected dose of Cu was higher than the other metals because of its higher recommended value for drinking purposes. The WHO guidelines for Cu, Cr, Pb and Cd in drinking water are 20 mg/l, 50 µg/l, 10 µg/l and 3 µg/l respectively. The temperature was kept constant at 20°C by means of a thermostatically controlled heating probe.

Sand of grade 0.20 mm to 0.70 mm (with effective size of 0.35 mm, uniformity coefficient of 1.56 and hydraulic size of 0.39) was used for all four filters. The total depth of sand bed in each filter was 1.20m. Sampling taps were fitted at 0.40m and 0.80m depth to identify the effects of sand bed depth. Four different flow rates of 0.1 m/hr, 0.2 m/hr, 0.3 m/hr and 0.4 m/hr were considered to study the effects of filtration rates. Three different TOC levels of 4 mg/l, 8 mg/l and 12 mg/l were considered to investigate the effects of organic loading. The performance of the filters was evaluated using the percentage removal criteria as the measure of efficiency. Average perform-

**Table 1:** **Variation of percentage removal efficiencies of heavy metals by different filters at various TOC levels at the flow rate of 0.1 m/hr.**

| Filter/Metal | % removal efficiencies of heavy metals at TOC of | | |
|---|---|---|---|
| | 4 mg/l | 8 mg/l | 12 mg/l |
| F1/Cu | 98.2 | 98.6 | 99.6 |
| F2/Cr | 96.7 | 97.0 | 97.2 |
| F3/Pb | 90.6 | 94.2 | 100.0 |
| F4/Cd | 94.0 | 96.2 | 96.6 |

ance was calculated by using results from three sets of tests. Each set of tests continued for one week. Percentage removal of heavy metals was the main item for investigation. Percentage removal of faecal coliforms (FC), turbidity and the variation of pH were also considered for further information to evaluate the filtration efficiency and filter response at different test conditions.

## Results and discussion

For case of comparison of data, per cent removal figures are given. It should be noted that to meet the WHO guidelines, the per cent removal of Cu, Cr, Pb and Cd are required as 80, 50, 90 and 97 respectively (as a minimum). All results refer to the final effluent after passing through the 1.20m depth of filter column, unless stated otherwise.

### Effects of TOC on SSF performance at the conventional filtration rate of 0.1m/hr

Table 1 summarises the average percentage removal of heavy metals at different TOC levels.

The results show that removal of all four metals increases with the increase of TOC. Maximum removal is achieved at a TOC of 12 mg/l. The upper limit of TOC has been considered as 12 mg/l because the TOC of river water normally does not exceed this concentration. The results show that the positive effects of organic load are more significant in the case of Pb and Cd than for Cu and Cr. The reason behind the increase of heavy metal removal with the increase of TOC can be explained as the result of adsorption of heavy metals onto organic matter. This can be supported by the heavy metal, TOC and turbidity test results at different flow rates (Tables 3 and 4). The increase in flow rates causes a decrease in TOC and turbidity removal efficiencies which indicates that more organic and suspended materials pass at higher filtration rates carrying more heavy metals in the effluent causing a decrease in percentage removal of heavy metals.

Table 2 shows the percentage removal of TOC, turbidity and faecal coliform. Typical values of turbidity and FC in the influent at a TOC of 12 mg/l were 6.80 NTU and 60000/100 ml respectively. The TOC, turbidity and FC in the effluent were 4.90 mg/l, 0.64 NTU and 3/100 ml respectively. The results indicate that the removal of organic matter, turbidity and faecal coliforms is not affected by the presence of heavy metals in SSFs at the specified dose. Tests for pH indicated that at a flow rate of 0.1m/hr and TOC of 12mg/l, the pH dropped from 7.8 in the influent to 7.3 in the effluent for all metals. This drop of 0.5 indicates the microbiological activity in the SSF, which activity produces $CO_2$ causing a drop in pH.

**Table 2:** **Percentage removal of TOC, turbidity and faecal coliform by different filters at a flow rate of 0.1 m/hr and a TOC of 12 mg/l**

| Filter/Metal | % removal | | |
|---|---|---|---|
| | TOC | Turbidity | Faecal coliform |
| F1/Cu | 58.8 | 90.7 | 99.999 |
| F2/Cr | 58.3 | 90.6 | 99.999 |
| F3/Pb | 57.8 | 90.7 | 99.999 |
| F4/Cd | 58.3 | 90.7 | 99.999 |

**Table 3:** **Effects of filtration rate on the performance of SSF in removing heavy metals at constant TOC of 12 mg/l**

| Filter/Metal | Percentage removal efficiencies of heavy metals at the flow rate of | | | |
|---|---|---|---|---|
| | 0.1 m/hr | 0.2 m/hr | 0.3 m/hr | 0.4 m/hr |
| F1/Cu | 99.6 | 98.3 | 97.8 | 97.3 |
| F2/Cr | 97.2 | 97.2 | 95.8 | 95.1 |
| F3/Pb | 100.0 | 92.7 | 91.6 | 70.4 |
| F4/Cd | 96.6 | 92.4 | 88.4 | 68.1 |

### Effects of filtration rates on the performance of SSF in removing heavy metals

Table 3 summarises the percentage removal of heavy metals at different filtration rates. The results show that increase in filtration rate causes a decrease in removal efficiency. The removal efficiencies of Cu and Cr declined slightly up to a flow rate of 0.4 m/hr. The removal efficiencies of Pb declined gradually up to a flow rate of 0.3 m/hr and then dropped sharply at 0.4 m/hr. So for Cu and Cr, a filtration rate of 0.4 m/hr can be adopted without hampering the removal efficiency, whereas a flow rate of 0.1 m/hr is ideal for Pb and Cd. The decrease in removal efficiency with the increase in filtration rate indicates the adsorption of heavy metals on sand. A reduction of adsorption capacity is expected at higher filtration rates. Table 5 describes the variation of percentage removal efficiencies of TOC, turbidity and FC at various flow rates. The results show a decrease in removal efficiencies with increasing flow rate which also supports the criteria of adsorption of metals on to organic matter.

### Effects of sand bed depth on the performance of SSF in removing heavy metals

Table 5 summarises the variation of heavy metal removal efficiency by different SSFs with filter bed depth at various filtration rates. The results show that the removal efficiency increases with the increase of bed depth. Although the removal efficiency increases with depth, only 0.4m of bed is enough to remove Cu and Cr. The importance of sand bed depth is more significant for Pb and Cd. The removal efficiency increases sharply with depth and optimum removal is achieved at 1.2m. SSFs therefore work as deep bed filters for Pb and Cd. As the depth increases, the total adsorption capacity also increases. So adsorption is one of the likely mechanisms for removing heavy metals by SSF. This finding has also been supported by batch adsorption tests.

### Mechanisms of heavy metal removal by SSF

It has already been discussed that adsorption of heavy metals to sand and organic matter are the two likely mechanisms of removing heavy metals by SSF. A number of other batch experiments have also been carried out and these suggest that precipitation and bioaccumulation of heavy metal into the schmutzdecke are the other likely mechanisms for removal of metals.

## Conclusions

The following conclusions can be drawn from the study regarding the removal of heavy metals in SSFs.

- SSFs can be used to remove heavy metals from surface water. Although a conventional filtration rate

**Table 4:** **Effects of filtration rate on the performance of SSF in removing TOC, turbidity and FC at a constant TOC of 12 mg/l**

| Filter/ metal | % removal efficiencies of | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | TOC at | | | | Turbidity at | | | | FC at | | | |
| | 0.1 m/hr | 0.2 m/hr | 0.3 m/hr | 0.4 m/hr | 0.1 m/hr | 0.2 m/hr | 0.3 m/hr | 0.4 m/hr | 0.1 m/hr | 0.2 m/hr | 0.3 m/hr | 0.4 m/hr |
| F1/Cu | 58.8 | 58.5 | 57.1 | 56.7 | 90.7 | 87.8 | 85.6 | 84.5 | 99.99 | 99.98 | 99.96 | 99.95 |
| F2/Cr | 58.3 | 59.3 | 55.6 | 54.7 | 90.6 | 87.8 | 86.2 | 84.5 | 99.99 | 99.98 | 99.96 | 99.95 |
| F3/Pb | 57.8 | 58.9 | 55.6 | 55.5 | 90.7 | 87.5 | 85.5 | 84.2 | 99.99 | 99.97 | 99.96 | 99.94 |
| F4/Cd | 58.3 | 58.5 | 56.1 | 56.0 | 90.7 | 87.7 | 85.4 | 84.0 | 99.99 | 99.97 | 99.95 | 99.94 |

**Table 5:** **Effects of filter bed depth on the performance of SSF in removing heavy metals at various flow rates and at constant TOC of 12 mg/l**

| Filter/ metal | % removal efficiencies of heavy metals at a filter depth of | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0.40m at | | | | 0.80m at | | | | 1.20m at | | | |
| | 0.1 | 0.2 | 0.3 | 0.4 | 0.1 | 0.2 | 0.3 | 0.4 | 0.1 | 0.2 | 0.3 | 0.4 |
| F1/Cu | 98.5 | 97.5 | 96.8 | 97.0 | 99.4 | 98.7 | 97.9 | 97.8 | 99.6 | 98.3 | 97.8 | 97.3 |
| F2/Cr | 96.3 | 95.8 | 93.4 | 93.0 | 97.0 | 96.4 | 95.0 | 93.9 | 97.2 | 97.2 | 95.8 | 95.1 |
| F3/Pb | 78.2 | 65.0 | 66.8 | 46.7 | 95.9 | 86.9 | 87.3 | 62.4 | 100.0 | 92.7 | 91.6 | 70.4 |
| F4/Cd | 73.1 | 61.9 | 50.7 | 50.0 | 89.3 | 78.3 | 65.0 | 59.0 | 96.6 | 92.4 | 88.4 | 68.1 |

(0.1 m/hr) and filter bed depth (1.2m-1.5m) are adequate for all four metals ( Cu, Cr, Pb and Cd ), optimisation of parameters depends on the individual metal. The removal efficiencies of other pollutants are not affected by the heavy metals at the specified doses.

- The removal efficiency of heavy metals increases with the increase of TOC and the maximum removal is achieved at 12 mg/l of TOC. The positive influence of TOC is more significant for Pb and Cd than Cu and Cr.
- The removal efficiency of heavy metals decreases as the filtration rate increases. It has been observed that a filtration rate of 0.4 m/hr could be adopted for Cu and Cr but for Pb and Cd, the conventional filtration rate of 0.1 m/hr is recommended.
- Heavy metal removal efficiency by SSF decreases with a decrease of sand bed depth. It indicates the importance of adsorption in removing heavy metals by SSF. A filter bed depth of 0.4m is enough to remove Cu and Cr whereas Pb and Cd are removed through the whole sand bed. So SSF acts as a deep bed filter for Pb and Cd.
- Adsorption of heavy metals to sand and organic matter are two likely mechanisms for removing heavy metals by SSF. Precipitation and bioaccumulation (not discussed in this paper) of heavy metals are the other likely mechanisms.

So the evidence indicates that (perhaps contrary to popular belief ) SSFs are very effective in removal of heavy metals at conventional flow rate and design parameters.

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