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PEOPLE-CENTRED APPROACHES TO WATER AND ENVIRONMENTAL SANITATION

Impacts of coagulation on upflow roughing filtration in layers

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In community water supplies, technologies that are people-centred are encouraged to ensure sustainability. Upflow roughing filtration in layers (URFL) is a simple pre-treatment process applied to reduce raw water turbidity without the aid of coagulation to levels acceptable for effective slow sand filtration (SSF). However, practical applications of URFL are limited to raw waters with turbidity < 20 - 50 NTU. Incorporation of simple coagulation, achieved by gravity dosing equipment, can provide an opportunity for URFL to treat higher turbidity raw waters. This paper present results of a study carried out on the impacts of low-dosage simple coagulation on URFL performance. The main evaluation criterion was the effluent turbidity. Intermittent coagulation was studied as well, including its effect on, headloss and filter media cleaning. The URFL unit was regularly challenged with high turbidity loads without adjusting coagulant dosages. Coagulation was achieved with lower-than conventional dosages. URFL effluents were sent to SSF, whose effluent turbidity was analysed.

Introduction

Background

The optimisation of water treatment technologies that are people-centred, i.e. managed by people, especially in small communities, must be an ongoing practice. This is particularly important to ensure sustainability.

Many conventional water treatment schemes (coagulation, flocculation sedimentation, rapid sand filtration) used in rural/small communities, especially in developing countries, are usually unsustainable (Mwiinga, 2002). This is usually attributed to their complexity and high operation/maintenance costs, especially with respect to the pre-treatment processes.

Roughing filtration (RF) is a simple pre-treatment technology, using gravel to reduce turbidity in raw water without the aid of coagulation (Wegelin, 1996; Galvis et al., 1998). It has the potential to be sustainable in small and/or rural communities. The absence of coagulation make practical applications of RF limited to less than 150 NTU raw water with easily settled suspended solids. High turbidity and colloidal raw water is bound render RF ineffective (Wegelin, 1996, Mwiinga et al. 2002).

Types of roughing filtration and experiences

Figure 2 shows the different types of RF, distinguished by the flow direction and filter media configuration.

The horizontal-flow roughing filtration (HRF) type was the first to be used in public water supply (Baker, 1981). Hence, during the resurgence era (beginning 1980) of the RF technology, HRF type received wide application. Because of its longer filter length, it provides longer retention times and thus permits better removal of suspended solids by gravitational settling and attachment mechanisms than in the other types. However, later practical application experiences have indicated that the upflow types can perform better (Ingallinella et al.,(1998)

Ingallinella et al. (1998) evaluated a full-scale HRF plant, subjected to high turbidity raw water (400 NTU) without coagulation. Its turbidity removal efficiency was < 50%. Up-flow roughing filtration in series (URFS) with coagulation (60 mg/l) were then tested and produced a less 5 NTU effluent.

Up flow roughing filtration in layers (URFL)

URFL offers a competitive option to HRF and URFS in terms of capital costs, operation & maintenance. However its comparatively shorter filter length hinders its performance. Nevertheless, simple coagulation is likely to improve its performance.

Aim

The main aim of the study was to investigate the impacts of coagulation on URFL with respect to the effluent quality, headloss development and filter runs, sludge build-up and filter media cleaning. The attendant interest was to study how irregular and intermittent low dose coagulation can influence URFL performance.

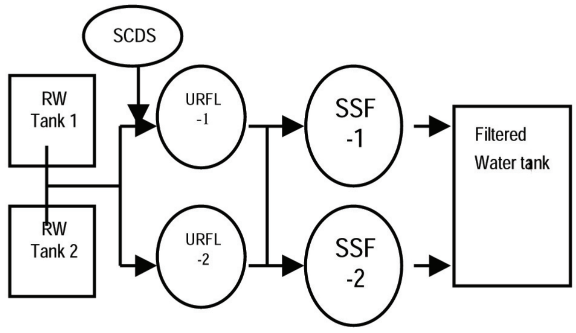
Methods and materials

The study was carried out on a small-scale plant made of upflow roughing filtration in layers (URFL) followed by slow sand filtration (SSF).

Description of the plant

Layout

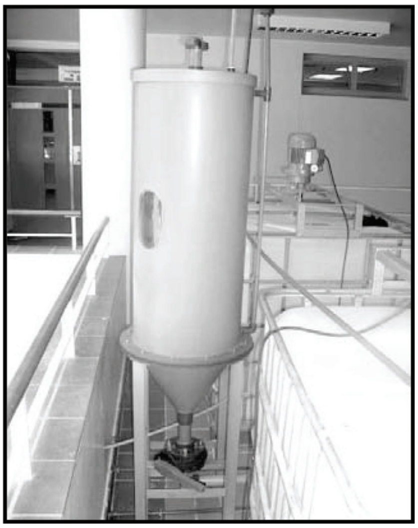
Figure 1 shows the schematic layout of the plant, consisting of two identical production lines, of which one was preceded by coagulation. Chemical dosing was achieved by a Simple Chemical Dosing System (SCDS), operated by gravity (see Photograph 1). The SCDS development was part of the project. Photograph 2 shows the full plant.



KEY:

- **SCDSàSimple (gravity) Chemical Dosing System**
- **RW à Raw Water**
- **URFL à Upflow Roughing Filtration in Layers**
- **SSF àSlow Sand Filtration**

Figure 1. Schematic layout of the URFL-SSF Plant



Photograph 1. The constant-head SCDS located near the raw water tanks

Design of URFL and SSF units

Each URFL filter unit had 3 layers of filter gravel (20cm top layer, 1.18–4.75mm; 40cm middle layer, 4.75 – 9.51mm; 60cm bottom layer, 9.51 - 19.1mm). A 20cm gravel layer (25-35mm) supported the bottom layer and a 20cm gravel layer (25-35mm) overlaid the top layer to provide shading to prevent the supernatant algae blooms.

Photograph 2. The URFL-SSF plant

Each URFL unit was constructed in 3 segments of opaque uPVC cylindrical units; each segment was provided with 2 transparent windows opposite to each other, which allowed viewing of the filter media in each of the three layers and thus observations of the accumulation of suspended solids/flocs (see Photograph 2). A conical bottom of each URFL unit facilitated the fast drainage of returned suspended solids.

SSF filter media was a 80cm deep sand-bed with an 80 cm depth of supernatant water. Sieve analysis of the sand used in the SSF revealed an effective diameter (de) of 0.21mm, and a uniformity coefficient (UC) of 3, which meet the specifications for SSF filter media. A 20cm graded gravel layer (1.18 to 19.1 mm) supported the SSF sand-bed. SSF units were constructed in two segments of opaque uPVC cylindrical units; each segment was provided with 2 transparent windows, to allow viewing the filter media and supernatant water (see Photograph 2). The support gravel was placed in conical bottom attached to the cylinders.

Operation and maintenance

Data were collected over four periods between November 2002 and December 2003. The reported data were collected over the following periods:

- Period 1: 6th November – 2nd December 2002
- Period 2: 17th December 02 – 24 March 2003
- Period 3: 27th September – 22nd October 2003
- Period 4: 23rd October – 1st December 2003

URFLs were operated at an average filtration rate of 0.5

m/h, except in period 4 when a filtration rate of 0.9 m/h was applied. SSFs were operated at an average filtration of 0.15 m/h.

Daily operation activities for both SSF and URFL included checking flow rates using rotameters, analysing influent and effluent water quality, and reading off head-loss development. Ensuring continues flow and adequate simulation of raw water was one of the daily operations.

Daily maintenance activities involved checking for any damage to or leakage from the plant, observing the accumulation of flocs in the URFL and keeping the plant area tidy. The accumulation of flocs in the URFL was observed through the transparent windows.

Raw water and data collection

Raw water turbidity was simulated using tap water and Kaolin clay. Approximately 0.5 g of the kaolin clay when mixed with 1000ml of tap water gave a turbidity of 100 NTU. A peristaltic pump was used to dose clay suspension at constant rates into a raw water feeder tank for the plant.

The main water quality parameter analysed in the influent and effluents of both URFL and SSF was turbidity. The measurements were done on site using a HACH 2000P portable turbidimeter. At least three samples of the influent and effluent of both URFL and SSF were taken for analysis on each day of sampling. Raw water pH, conductivity and temperature were occasionally measured.

Other data collected included filter-runs and headloss development.

Coagulation and flocculation

Coagulation was achieved using granular aluminium sulphate (trade name ALUM). The ALUM solution was prepared in a 500 L container and fed to the SCDS by gravity. The ALUM solution was dosed at the inlet weir of URFL-1 where there was high mixing energy to ensure rapid dispersion of the solution for effective coagulation. A dosage of 10-15mg/L was applied. Flocculation then took place within the URFL gravel media.

The strength of the ALUM stock solution was 0.02%, less than the recommended minimum of 1%. ALUM solutions of strength lower than 1% (10g/L) are reported to cause the coagulant chemical to hydrolyse and form agglomerates which reduce the coagulation effectiveness (Holfkes, 1988). It was not feasible to prepare and dose ALUM stock solution of strength greater than 1% because of the low capacity of the plant. The following calculations illustrate the estimation of the maximum possible strength of the solution considering the available limiting plant capacity.

Available data:

- Raw water inflow to URFL-1 (Q1) = 35l/h
- Required ALUM dose (C2) = 100mg/L (optimum determined from Jar Tests)
- Minimum SCDS dosing rate (q) ~ 6.5 L/h (minimum dosing rate requires highest solution strength possible)

The unknown strength of stock solution (C1), can now be determined from mass balance principles represented by the following relationship:

$$C1*q = (Q1 + q)*C2 \tag{1}$$

Making C1 in equation (1) the subject of the formula and inserting the known variables:

$$C1 = [(35 + 6.5) * 100] /6.5 = 638 \text{ mg/L } [0.064\%]$$

The above calculation illustrate that it was not possible to prepare ALUM solution of strength greater than 1% given the capacity of the pilot. Hence coagulation process was expected not to be very effective because of the possible hydrolysis of ALUM as pointed out by Holfkes, 1988.

Results and Discussions

Raw water turbidity simulation

Table 1 shows the daily average turbidity that was fed to production lines 1 and 2.

Table 1. Turbidity analysis of the raw water (NTU)

Trial period	Minimum	Average	Maximum
Production Line 1 (Coagulated)			
Period 1	19.4	53.6	177
Period 2	10.0	94.3	363
Period 3	34.5	91.0	432
Period 4	2.28*	65.5	219
Production Line 2 (No coagulant)			
Period 1	22.1	70.3	339
Period 2	Not run		
Period 3	23.9	89.9	434
Period 4	2.58*	68.1	280
* No simulation			

URFL and SSF effluent turbidity analysis

Figures 3, 4, 5 and 6 show the average turbidity analysis over the four periods. Table 2 summarises the minimum, average and maximum in each period.

Period 1: See Figure 3

Both production lines were operated in this period. Coagulation was applied continuously.

Of the 42 URFL-1 effluent samples analysed, 2 had > 10 NTU turbidity (10.5 & 12.7 NTU); 5 had turbidity between 5 & 10 NTU; the rest recorded less than 5 NTU. Of the 39 URFL-2 effluent samples, none had turbidity < 5 NTU (11 were between 5 & 10 NTU, 22 between 10 & 20 NTU; and the rest above 20 NTU. Both operated for 26 days without reaching terminal headloss, although URFL-2 effluent turbidity started increasing to above 15 NTU after 14 days.

SSF-1 effluent showed a better average turbidity than SSF-2, an indication that turbidity levels can also affect SSF performance.

Period 2: See Figure 4

Only production line 1 was investigated in this period. Coagulation was only applied during day-time. Intermittent coagulation was applied by stopping the dosing when URFL effluents showed turbidity less than 1 NTU and restoring dosing when turbidity levels increased. The first 2 days had turbidity less 1 NTU and on day 3 coagulation was stopped and on the same day the effluent turbidity increased to 3.53 NTU which later rose to 5.14 NTU on day 7. On day 8 coagulation was restored and effluent turbidity dropped to 0.89 NTU! The longest period, over which URFL-1 operated without coagulation but still produced less 5 NTU effluents, was 15 days! This was after there was visible increase in the sludge build-up as observed through the transparent windows (see Photograph 3)

Photograph 3. Sludge build-up in URFL bottom gravel

Between samples 67 and 71 (see Figure 4), raw water turbidity was increased to over 200 NTU to challenge the URFL. The effluent turbidity subsequently increased to a maximum of 55 NTU! This was partly due to excessive floc retention, which also accumulated in the supernatant gravel (see Photograph 4). The filter was subsequently drained and run for 44 days with effluent turbidity less than 5 NTU from raw water with average turbidity between 50 –100 NTU. However, the accumulation of flocs as seen in Photographs 3 and 4, need careful monitoring to avoid floc overflowing to the SSF.

Regular incomplete draining of the URFL units can prevent excessive floc build-ups. It is not necessary to completely drain and flush out all flocs as the presence of flocs also enhances further entrapment of finer flocs.

Photograph 4. Sludge accumulation in URFL supernatant gravel

Period 3: See Figure 5

Both production lines were operated in this period.

URFL –1 run for 22 days with an average effluent turbidity of 6.63 NTU. On the 23rd and 24th day, effluent turbidity increased due to excessive sludge accumulation. URFL –2's average effluent turbidity was 13.8 NTU.

Between the 3rd and 6th days, inclusive, both URFLs were subjected to high turbidity raw water ranging from 100 NTU to 434 NTU. URFL-1 maintained turbidity effluents less than 10 NTU on the 3rd and 4th days, but increased to between 12.5 and 15.7 NTU on day 5. On day 6 raw water turbidity dropped to less than 100 NTU and URFL effluents also improved to less than 10 NTU for URFL-1. Through this same period, URFL-2 effluent turbidity increased to between 15.4 and 47.8 NTU! This indicated the capacity of coagulated URFL to better handle sudden increases in turbidity raw water compared to URFL when no coagulation is used.

SSF-1 performed better than SSF-2 as it received better quality effluents from URFL-1. This demonstrates that when URFL is used with coagulation there is a less risk of floc overflows than with conventional URFL units.

Period 4: See Figure 6

Both URFLs were operated in this period without SSF. In this period, the filtration rate was increased to 0.9 m/h.

For the first 13 days, URFL-2 (without coagulation) performed better overall, with an average effluent turbidity of 8.46 NTU compared to 15.1 NTU for URFL-1. Both were cleaned on day 13, after which URFL-1 performed better comparatively for 27 days. However, URFL-1 was occasionally drained, once a week, to reduce the amount of flocs retained, which ensured its sustained performance compared to URFL-2. As a result URFL-1 did not reach its maximum headloss.

Table 2. Daily average turbidity analysis

Trial Period	URFL-1 Raw water	URFL-2 Raw water	URFL-1 Effluent	URFL-2 Effluent	SSF-1 Effluent	SSF-2 Effluent
Period 1: 6th Nov – 1st Dec 2002						
Minimum	19.4	22.1	0.38	5.54	0.33	0.81
Average	53.7	70.3	3.30	12.8	0.98	1.81
Maximum	177	388	12.17	35.9	3.31	4.29
Period 2: 17th Dec – 24th March 2003						
Minimum	10.0	Not run	0.15	Not run	0.14	Not run
Average	94.4	Not run	4.10	Not run	0.58	Not run
Maximum	363	Not run	55.2	Not run	1.99	Not run
Period 3: 27th Sept – 22nd Oct 2003						
Minimum	34.5	23.9	1.81	3.86	0.22	0.32
Average	91.0	89.9	6.63	13.8	0.42	0.64
Maximum	432	434	21.1	47.8	1.03	1.37
Period 4: 23rd Oct – 1st Dec 2003						
Minimum	2.28	2.58	0.54	0.91	Not run	Not run
Average	65.5	68.1	10.8	12.9	Not run	Not run
Maximum	219	280	93.1*	34.43	Not run	Not run

* Recorded on day when there was floc overflow. Without this value, max was 40.7 NTU

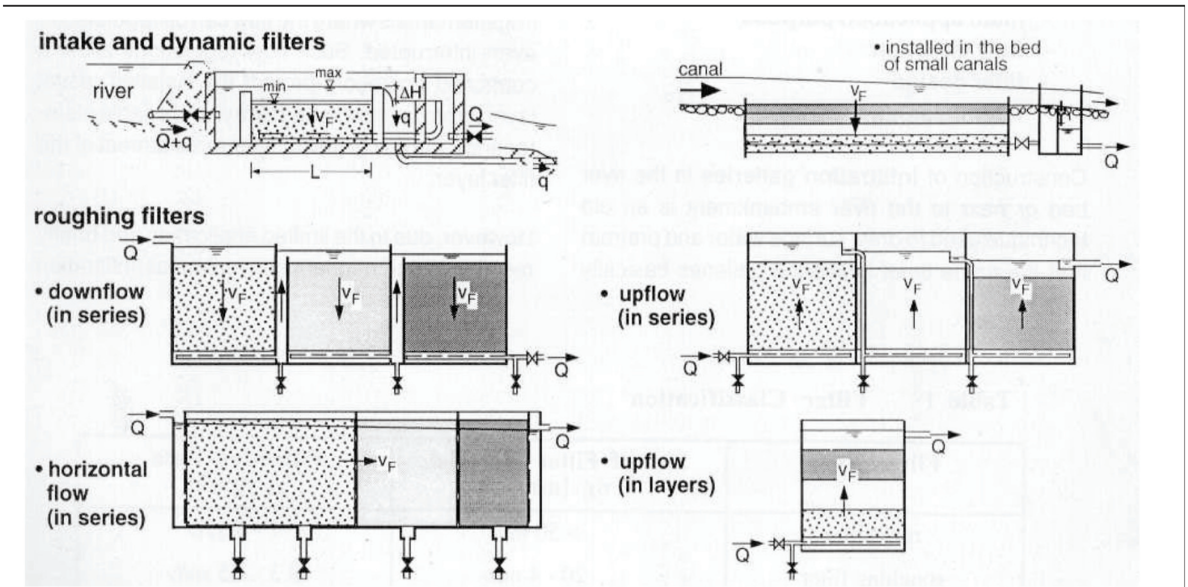


Figure 1. Types of roughing filters

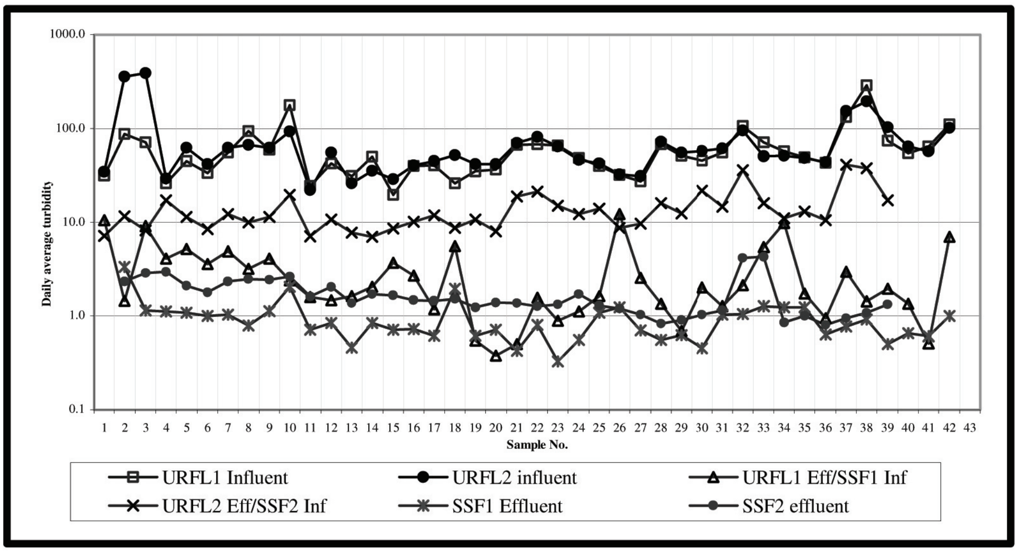


Figure 3. Period 1 average turbidity analysis results

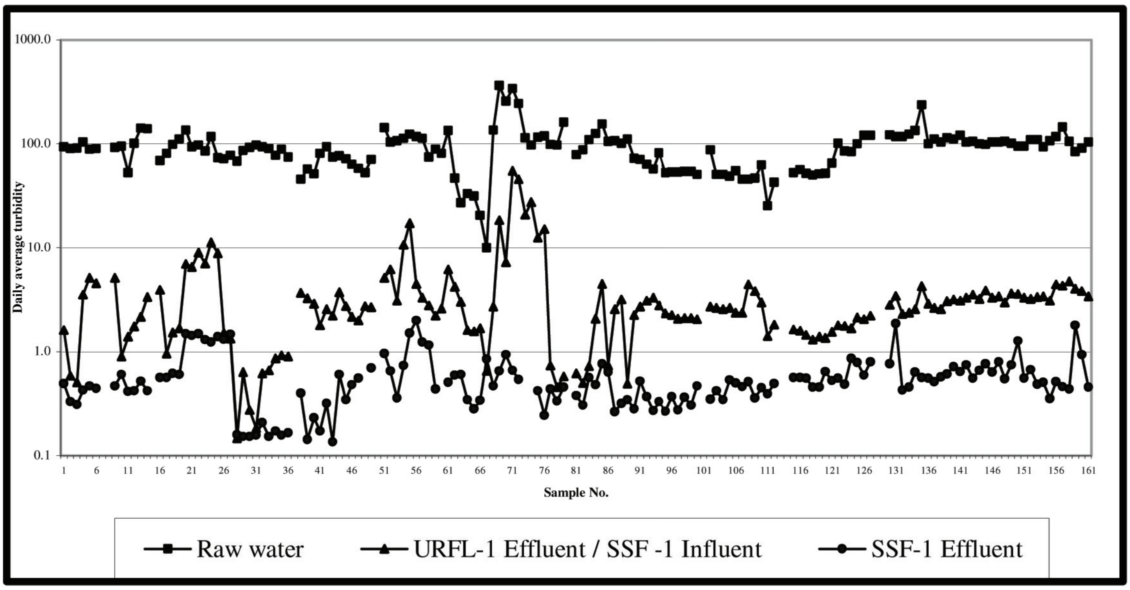


Figure 4. Period 2 average turbidity analysis results

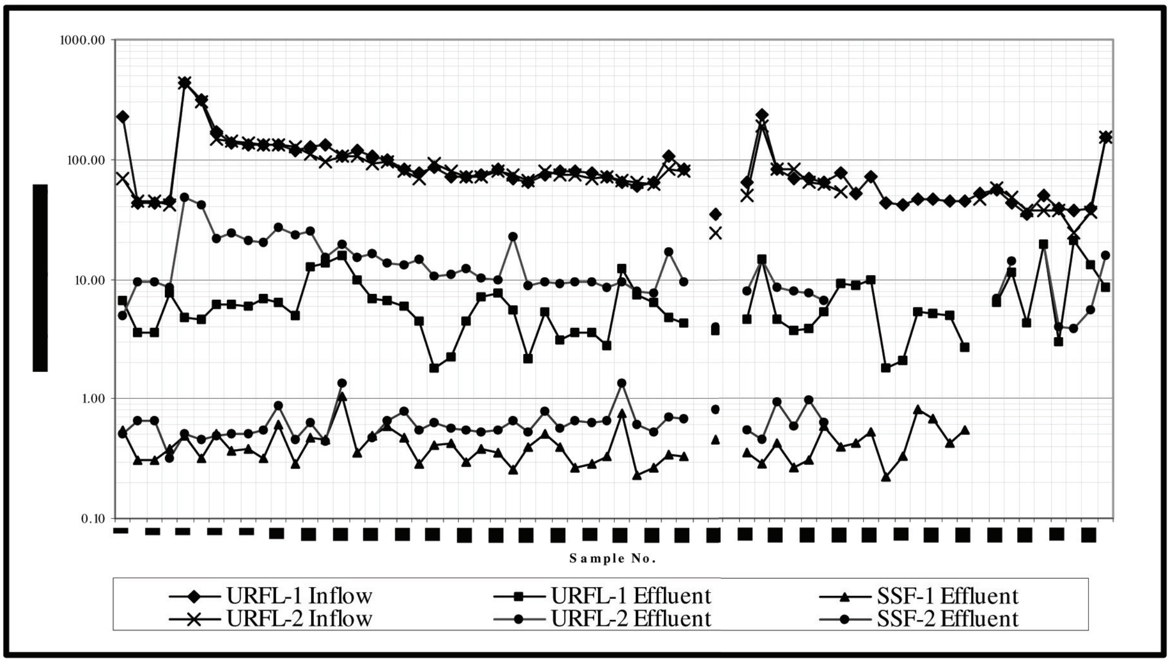


Figure 5. Period 3 average turbidity analysis results

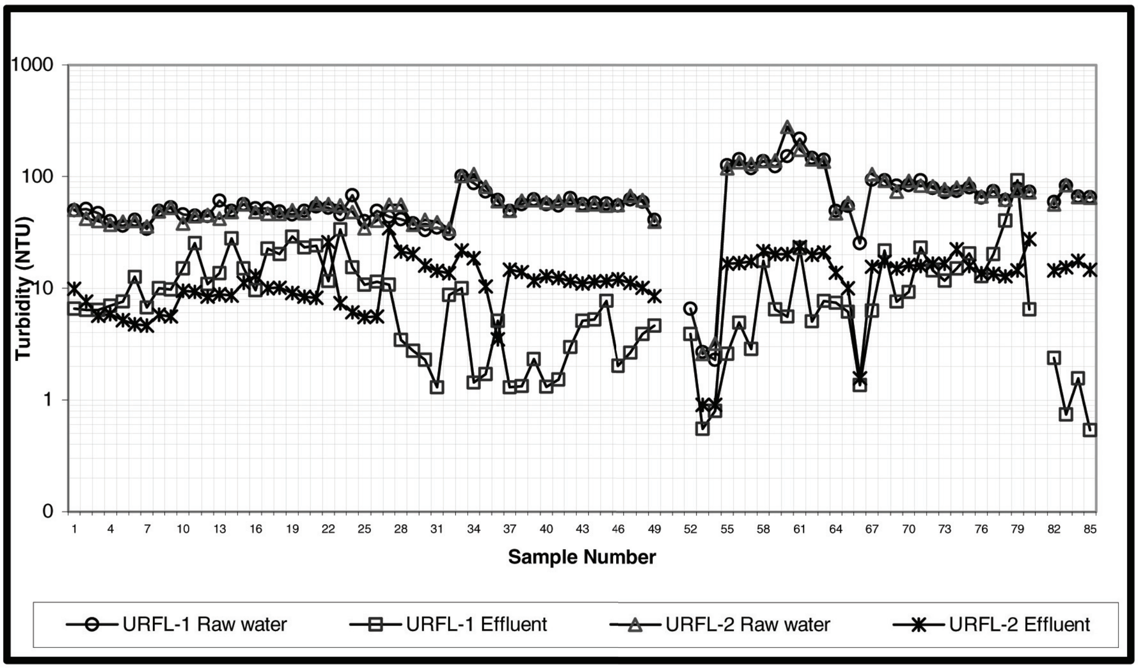


Figure 6. Period 4 average turbidity analysis results

Summary of results

1. Coagulation enhances performance of URFL in handling high turbidity raw waters without increasing the chemical dosages. SSF is adequately protected against higher and varying turbidity
2. Lower coagulant dosages, than in conventional coagulation, are applicable in URFL and can save costs.
3. Intermittent coagulation is feasible in URFL and can save operational costs.
4. Visual observation of URFL filter media cleaning by draining indicated that coagulated flocs were readily washed out. Without coagulation, suspended solids still remained after draining. Coagulated flocs ensure easy cleaning and can prolong the life of the URFL media.
5. Coagulant chemical dosing in URFL does not need stringent control as in conventional coagulation. Simple gravity dosing systems can be used.

Conclusion

Coagulation has a positive impact in enhancing the performance of URFL. Preceded by coagulation, URFL can accommodate raw water turbidity variations without producing unacceptable effluent for SSF (>10NTU) and with minimum floc overflow risk compared to conventional sedimentation tanks. However, regular draining (weekly or as required) is necessary to prevent excessive accumulation of flocs which can lead shorter filter runs.

Well-controlled and maintained coagulation in water treatment is without doubt able to enhance the water purification processes. But reaping the benefits of coagulation without strict attendant operation and maintenance demands that go with conventional high technology chemical dosing systems, is a bonus to the enhanced purification process.

The combination of coagulant chemical dosing using the simple (gravity) chemical dosing system provides a much more appropriate water treatment scheme that is more people-centred in small and rural water supplies than conventional schemes can do.

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