The in-depth evaluation of three filtration facilities

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Abstract

The filtration plants of three well-run water treatment facilities were recently scrutinised to measure their operational efficiency. When the results from these investigations were compared, it was found that certain problems were common to the three plants and that similar problems were likely to be encountered elsewhere.

The investigation methodology, which included a detailed evaluation of the filter media, backwashing procedures and backwashing efficiency, was first refined and applied to the Balkfontein plant where it showed promise. Sedibeng Water and the Water Research Group (WRG) from RAU undertook this as a combined project.

Shortly after the Balkfontein study commenced, similar studies were initiated at the Midvaal and Rietvlei Water Treatment plants by GFJ (Pty) Ltd, the Midvaal Water Company and the WRG. The results were compared and it was found that the three plants had the following problems in common: excessive media loss, inconsistent media gradings, modified backwash velocities; inefficient backwash water utilisation and the presence of mudballs.

Of these, the low backwash velocities were found to be one of the most significant problems and this could partly be traced to the partial failure of backwash isolation valves.

This paper briefly discusses the evaluation methodologies involved and results returned. It will also highlight problems that the authors expect to be present in other filtration facilities.

Introduction

The RAU Water Research Group was approached by the Scientific Services Division of Sedibeng Water to assist with an investigation into the state of the filters at the Balkfontein water treatment plant. The plant had been experiencing a decrease in effluent quality from its filters over an extended time. This was associated with an increased breakthrough of invertebrates. A preliminary investigation revealed that three aspects of the filters required specific attention. These were:

- the hydraulic control system during filtration,
- the backwash system, and
- the filter media.

The investigation yielded interesting results. This prompted similar studies to be undertaken at the Stilfontein plant of the Midvaal Water Company (GFJ Consulting Engineers played a leading role in this investigation) as well as the Rietvlei Water Treatment Plant operated by the City of Tshwane Metropolitan Municipality. All three plants are operated by a corps of well-trained personnel and make use of advanced operational control methods.

These studies have been completed and provide an opportunity to reflect on the overall status of the filters at the three plants and possibly to use this information to focus the South African water treatment community's attention on the status of their filters.

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Evaluation of filtration plants

Filtration plants evaluated

Three plants were studied: Balkfontein, Stilfontein and Rietvlei. The plants are all comparatively modern and are provided with advanced electronic monitoring and control infrastructure.

Balkfontein has a design capacity of 360 Mℓ/d and abstracts water from the middle Vaal River close to Bothaville in the Free State Province. The water is treated to potable standard and distributed over an area of 8 000 km^2. The process consists of coagulation/flocculation, primary and secondary settling, filtration and disinfection. A lime process is used and the average water pH in the process is in the order of 9.6. Varying levels of turbidity and increasing concentrations of NOM (natural organic matter), algae and their related organic substances, have complicated water treatment over the years. Three process controllers and one supervisor operate the process. Civil, electrical and mechanical maintenance staff provides support.

The Balkfontein filtration plant consists of 30 rapid-gravity filters, each 100 m^2 in area. The filters are operated on a constant rate basis using downstream control. The filters were refurbished as part of an extensive refurbishment and expansion programme in the early 1980s. Filter control and monitoring is effected through an advanced SCADA system. The original filter design called for 750 mm deep silica sand with an effective size of 0.65 mm and a uniformity coefficient of less than 1.4, on a 250 mm gravel bed. Backwash consisted of separate air and water washes. Three water cycles were used preceded by 3 air scours. Originally the first two washes were 3 min and the last was 6 min long.

The plant is operated on a large-scale stop-start protocol to make use of off-peak power tariffs for abstraction and distribution of the treated water. This means that the entire filter plant has to be shut down on a daily basis. Due to the prohibitive cost (in terms of wasted water) and logistics, the filters are not backwashed once the plant is shut down. This protocol is currently under review.

The Stilfontein plant, operated by the Midvaal Water Company, consists of four independent filtration facilities. The plant has a total design capacity of 250 Mℓ/d and abstracts water from the Middle Vaal River at Stilfontein. The process consists of coagulation/flocculation, dissolved air flotation (DAF), ozone, secondary chemical addition, settling, filtration and disinfection. The North filters were originally constructed in 1967/68 and upgraded in 1975. A lateral system was installed at this time. The South I filter block (lateral system) was constructed in 1975 and the South II filter block (false floor) in 1980. In 1981 the South III filter block was constructed with a false floor system. The East/West filter block was constructed in the early 1960s and modified to a false floor system in the early 1980s.

The Stilfontein plant has a total of 56 rapid gravity filters with surface areas ranging between 37 m^2 and 56 m^2. The filters were originally designed with downstream flow control. The East/West filters are in the process of being rehabilitated and should be finished within this year. The current filter design calls for a filter depth of between 800 and 950 mm deep silica sand with an effective size of 0,70 mm and an uniformity coefficient of less than 1.5. Backwash consists of separate air and water washes. Three water cycles are used preceded by 3 air scours. All the washes are 3 minutes.

An investigation into the integrity of the plant was launched as turbidities of less than 0.5 NTU could not be maintained especially in the light of international trends to aim for final water turbidities of less than 0.1 NTU to minimise health risks associated with pathogen breakthrough.

The Rietvlei Water Treatment Plant treats eutrophied water from the Rietvlei Dam in Pretoria. The plant has a 40 Mℓ/d design capacity and makes use of a direct filtration process. Filtered water is passed through open-bed GAC filters prior to disinfection and distribution. This is required due to the ever-decreasing water quality in the Rietvlei Dam. The plant augments the Rand Water supply to Pretoria and distributes its water to the south and south-eastern portions of Pretoria.

Rietvlei operates 10 DAFF filters, each with a surface area of approximately 22.5 $m^{2.}$ flotation requires that the filters operate at constant rate although a measure of surface level stability is also required - this is achieved through downstream flow control. SCADA is used to effect filter monitoring and control. The filters were upgraded and converted to DAFF (dissolved air flotation and filtration) in 1987. The bed design was modified to dual media filters in the period 1990 to 1992. The dual bed originally consisted of anthracite (150 mm deep of unknown grading), silica (730 mm deep, d_{10}=0.70, UC<1.4) and gravel (250 mm deep). A lateral system is used. Backwash consists of separate air and water washes. The cycle lengths vary as it is controlled manually. The design wash consists of 2 water washes of 6 min duration separated by air washes lasting 3 min.

Evaluation methodology

The same basic methodology was used in the evaluation of the three filtration facilities.

The evaluation of the media was based on the guidelines for filter evaluation suggested by AWWA (2000) and consisted of the following procedures:

(a) Visual inspection of the filter for cracks, holes, depressions or mounds
(b) Determination of washwater trough and walkway levels
(c) Determination of media levels to determine media loss
(d) Gravel layer assessments – to determine underfloor system integrity and washwater distribution,
(e) Mudball and media intermixing inspections
(f) Filter coring for sieve analysis
(g) Floc retention analysis to determine backwash efficiency
(h) Bed-expansion and rate-of-rise measurements
(i) Backwash turbidity analysis, to determine the efficiency of backwash water usage.

Filters were taken out of commission for approximately 2 to 3 h to perform these tests. Detailed methodologies are presented elsewhere (AWWA, 2000). The initial measurements ((a)-(g) above) were taken before backwashing. During backwashing (h) and (i) were performed. After backwashing filter-coring was once again done to collect samples for floc retention analysis. The backwash turbidity and floc retention analysis turbidities, media grain size, media grain size distribution and media specific gravity (SG) were measured using standard laboratory equipment and procedures.

Results and discussion

Detailed results on the three individual evaluations are presented elsewhere (Water Research Group (2001); GFJ (2001) and Spaleck (2001)), each detailing issues relating to specific problems experienced at the separate plants. This paper will, however, concern itself with the most important issues that are common to the three plants, and that are possibly relevant to other plants in South Africa and elsewhere.

Excessive media loss

Reduced bed depths lead to reduced bed capacity in terms of suspended solids removal and reduced run lengths as well as a reduced capacity for the removal of manganese. Also, since media constitutes one of the most significant sources of head loss during filtration, a variation in adjoining bed depths can affect filtration hydraulics detrimentally. Figure 1 compares current bed depths at the various filtration plants with their respective design depths.

All plants illustrate a significant loss of media. On average only 60% of the original media remains in the filter. Some filters have as little as 20% of the original media depth remaining. It is also interesting to note that the media levels differ significantly between filters in the same plant. This suggests that the factors that lead to media loss are highly variable.

Tests to determine the cause of the media loss are ongoing. At this time it is expected that the delay between the air and water cycle during backwash, needs to be increased to avoid simultaneous air and water expulsion from the bed. The turbulence caused on the surface of the media by the simultaneous expulsion of the air and water could lead to excessive media losses. This phenomenon has been reported on elsewhere (Lombard and Haarhoff, 1995)

Inconsistent media gradings

In general, media grains seem to be larger than indicated by the design specifications (Figs. 2 and 3). In the worst case, the current d_{10} is 70% larger. This has significant impacts on the backwashing requirements of a filter bed. Larger grains require higher backwash rates implying that the beds evaluated in these studies will not be washed sufficiently even if design backwash rates are maintained.

Reasons for the larger grains are process effects (deposition of

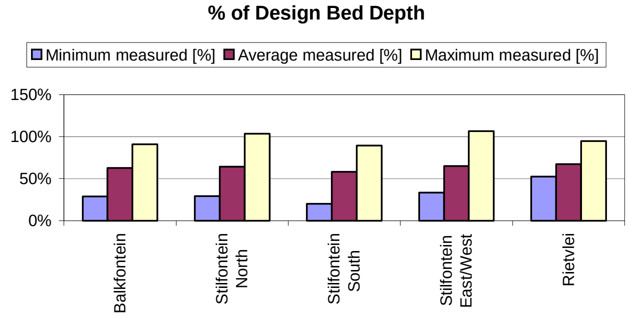

Figure 1
Comparison of current media depths to design depths

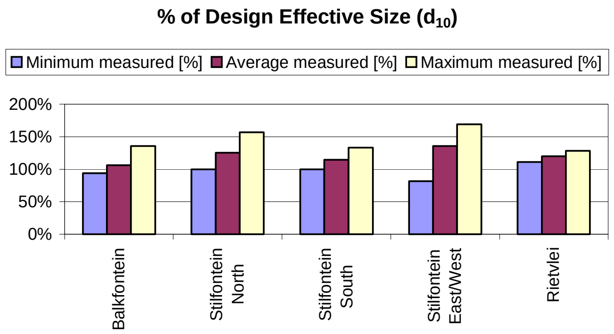

Figure 2
Comparison of current media effective sizes to design values

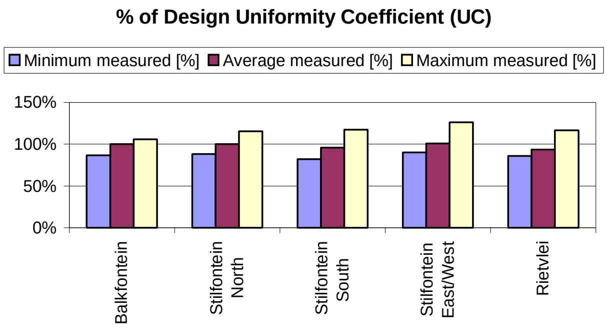

Figure 3
Comparison of current uniformity coefficients with design specifications

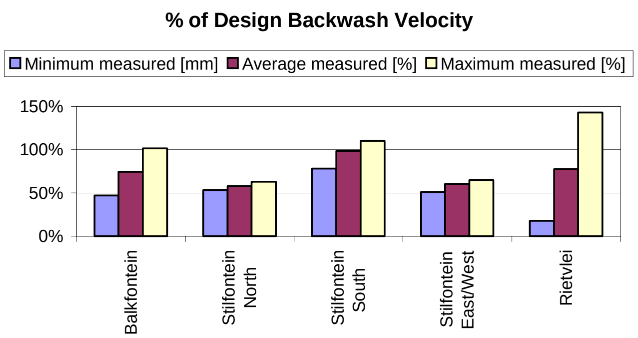

Figure 4
Comparison of measured backwash rates with design rates

calcite) as well as the placement of media during and after construction that is not according to specification. Intermixing of sand and fine gravel during backwash can also lead to the measurement of larger effective sizes.

Uniformity coefficients, in general, appear to be close to design specifications. Some filters do, however, contain media with much higher values than specified. In these specific cases, where the grains are larger than anticipated, the higher uniformity coefficients add to the insufficiency of the backwash design.

Modified backwash velocities

The results generated here are possibly the most surprising of all the results. In all plants, most of the filters experienced wash rates that were well below the design rate. In the worst case, the rate was approximately 20% of the design rate. This has obvious impacts on the amount of shear and agitation experienced by the media in the beds and therefore on the efficiency of the backwash.

At this point it is thought that the reduced rates are mainly caused by the failure of backwash isolation valves on the backwash manifold to close completely. A large volume of the backwash water is lost to other filters. Detailed measurements at Stilfontein indicated that average losses on the different filtration facilities ranged from 11 to 26.5% of the total volume of water delivered by the backwash pumps. The remainder of the reduction in backwash rate can be attributed to wear and tear on the backwash pumps, increased head losses due to the deterioration of the backwash manifold, as well as increased losses due to the partial blockage of nozzle caps by grains lodged in the slots. The last cause listed here has the potential for the creation of significant additional head losses.

The results reported on here might appear to be contradictory to the media loss reported on earlier. However, as all three plants make use of water and air scour, all three plants are vulnerable to the combined effect of air and water discharge mentioned earlier.

The presence of mudballs

The floc retention test gives an indication of how well the filter is cleaned during backwash. For this test, the equivalent of 100 g of sand is rinsed with 500 ml of water, and the turbidity of the water returned as the result. The guideline values for interpretation state that below 60 NTU is indicative of a clean filter, 60 to 120 NTU indicates a reasonably clean filter, 120 to 300 NTU is a dirty filter and above 300 NTU is very dirty with potential mudball problems. The average turbidity for the floc retention analysis performed on the three plants is consistently above 300 NTU (Fig. 5). At Balkfontein several filters exceeded turbidities of 1 000 NTU.

The guideline values are, however, considered to be conservative. The results are also highly dependent on external factors such as method of agitation. Work is currently underway to revise these guidelines upward for South African plants dealing with turbid waters.

However, the extensive mudballing encountered at the three plants, as reflected in the visual inspection confirms that mudballing is a common occurrence. This is considered to be a result of the low backwash velocities used.

Flow distribution during filtration

A snapshot study done at Midvaal Water Treatment Plant indicated that the filters experienced a significant variation in filtration rates. Filtration rates varied between 0.33 to 4.25 m/h for filters that were supposed to be filtering at the same rate. Although not to the same degree, the same phenomenon was noticed at Balkfontein. The filtration rates are also not constant and vary significantly over time - basically constituting surges on the filter.

Inefficient backwash water utilisation

An evaluation of the backwashing procedure, done by logging the wash effluent quality during backwash, revealed that wash water was being used inefficiently (Fig. 6). After approximately 3 min the backwash water quality remained constant. This indicates that solids were being removed from the bed at a constant rate. Based on these findings long water washes were divided into shorter washes at the Balkfontein plant. An additional air scour cycle was also introduced between water cycle 3 and 4. In this way the same amount of water is used, but an increased rate of solids removal is attained (Fig. 7). This figure illustrates that the water originally used after 3 min removes turbidity from the filter more efficiently if used in a new wash cycle after air scour.

Conclusions

It would appear as though most of the problems experienced in filters can be related to a failure to properly clean the media and also in the failure of the hydraulic control systems, both during filtration and backwashing. These aspects are normally controlled by mechanical equipment that are subject to wear and tear and therefore cannot be guaranteed to perform to specification indefinitely. A thorough and complete evaluation of the important control items is required on a regular basis.

Despite the problems that were identified in these three plants, the water quality, although not good, did not deteriorate to completely unacceptable levels. This in itself should act as a warning as it would appear that filters develop problems over long periods and also decrease their effluent quality gradually. If operators are not vigilant, as in the cases reported on here, this deterioration can go by unnoticed, possibly resulting in sudden and catastrophic filter breaches. The results from the three studies also indicate that there are problems common to the different plants and a quick evaluation of these parameters at other plants would indicate whether those plants are at risk. In any event, a properly planned and structured filter evaluation programme with diligent record-keeping should be incorporated in the operational procedure for any filtration facility.

Acknowledgements

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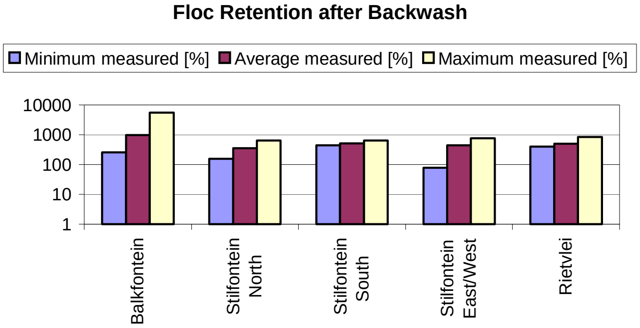

Figure 5
Floc retention results for the three plants

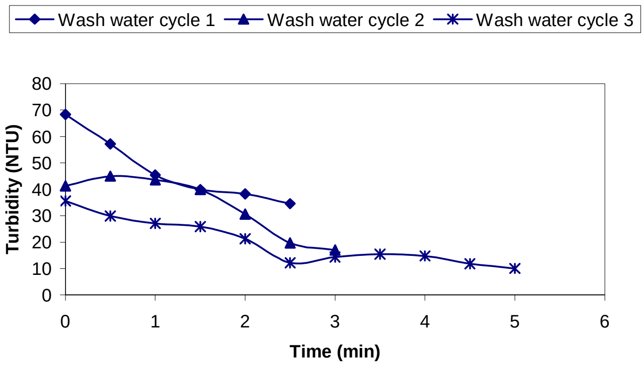

Figure 6
Wash water turbidity profile indicating reduced removal after 3 min

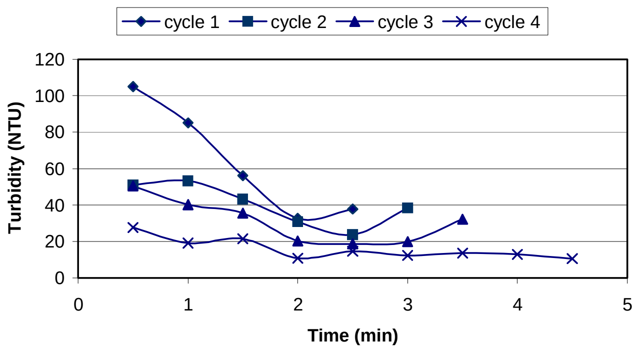

Figure 7
Wash water turbidity profile after introduction of the 4^{th} water cycle

References

AWWA (AMERICAN WATER WORKS ASSOCIATION) (2000) Video: Filter Surveillance Techniques for Water Utilities. Catalogue no. 65160. Denver, CO.

WATER RESEARCH GROUP (RAU) (2001) Unpublished report to Sedibeng Water: The Evaluation of the Rapid Gravity Sand Filters and Filtered Water Quality at the Balkfontein Water Treatment Plant: Final report on the Findings. June 2001

GFJ (Pty) Ltd (2001) Unpublished report to the Midvaal Water Company: Filter Integrity Investigation. August 2001

LOMBARD HK and HAARHOFF J (1995) Filter nozzle and underdrain systems used in rapid gravity filtration. *Water SA* **21** (4) 281-298.

SPALECK CE (2001) Unpublished undergraduate project investigation report: *"Die Evaluasie van die Diepbedfilters by Rietvlei Watersuiweringsaanleg"*. Rand Afrikaans University, Department of Civil and Urban Engineering. November.