MEASURING THE CLEANLINESS OF FILTER MEDIA

Johannes Haarhoff and Samantha van Staden

Department of Civil Engineering Science, University of Johannesburg
Corresponding author: J. Haarhoff, PO Box 524, Auckland Park, 2006, South Africa
Tel/Fax: +27 11 489 2148, E-mail: jh@ing.rau.ac.za

ABSTRACT

Filter media starts its working life as almost pure silica, freshly crushed, sieved, washed and dried. Upon examination a few years later, we find discoloured, often sticky material hardly recognisable as the original. As long as the media retains its granular character and the filter beds stay smooth and level, this is no cause for great concern. However, when the media forms clumps, when cracks become apparent in the bed or the filtrate quality deteriorates for no apparent reason, the media demands closer attention. Such media investigations have been carried out for more than a decade at the Water Research Group of the University of Johannesburg. Drawing on this reservoir of experience and case studies, this paper reviews the different approaches to measuring and expressing the degree of cleanliness of in situ filter media. A conceptual model of the different types of specific deposit on the media is developed first, classifying the specific deposit into those fractions that are washed out by the treatment plant backwash system, the fraction hat can be additionally washed out by a laboratory column, the fraction that needs mechanical agitation to be stripped off the media, and the fraction that can only be chemically stripped. Typical values for the four fractions, as measured during a comprehensive survey of South African water treatment plants, are presented, together with suggested remedial measures for each of the media fractions.

INTRODUCTION

Operators are likely to ask two questions when they encounter suspiciously dirty filter media at their treatment plants. First: Is the filter media really so dirty that further steps should be investigated to improve the filter media cleanliness? Second: How can one, systematically and rationally, begin to correct the situation? These are the very questions that prompted the Water Research Group at the University of Johannesburg (UJWRG) a decade ago to start a systematic survey of filter media at a wide variety of South African water treatment plants. The answer to the first question had already been partially provided at the previous WISA Conference in Cape Town during 2004, and will be briefly reviewed again. The answer to the second question had to await a number of analytical procedures developed by the UJWRG. The remainder of the paper will be devoted to a summary of these procedures, how they should be interpreted and how their results could suggest optimal media rehabilitation procedures.

Given that media cleanliness (more specifically the measurement of *specific deposit*) is not a common, standard procedure, two introductory comments are in order. The first comment deals with the *expression* of specific deposit. In earlier reports the

UJWRG chose to express the specific deposit in terms of *mass of solids* per *mass of media*, with the units as *mg/g*. As more case studies were investigated with a variety of different media types, these results could not be directly compared. The specific deposit is the function of the *voids* amongst the grains and is not affected by the density of the grains. In the interest of a more universal expression of specific deposit, which is independent of the media grain density, the specific deposit will be expressed as *mass of solids* per *volume of media*, with the units in kg/m^3 which are also easier to imagine. The conversion of the earlier mass/mass measurements to the suggested mass/volume measurements is straightforward, requiring only the media density and porosity.

The second comment deals with the experimental measurement of the amount of specific deposit removed by a cleansing step. There are two options; one can measure the cleanliness of the *media* before and after the cleansing step, and obtain the removal by subtraction. Alternatively, one can measure the cleanliness of the *water* used in the cleaning step, which will provide a direct measure of the specific deposit removed. The detailed procedure for doing this is provided in a companion paper (Van Staden and Haarhoff, 2006) (1). Where both methods are possible, the latter approach provides more reliable results and will be used.

A PROPOSED CONCEPTUAL FRAMEWORK

It is necessary to start with a conceptual framework to guide the reader through the rest of the paper, with reference to Figure 1. It is proposed that five different states of cleanliness of filter media are recognised:

- BPSD (Before Plant Specific Deposit). This is a measure of how clean the filter media is after a typical filter run at the treatment plant, *before the media is cleaned by the treatment plant backwash system*.
- APSD (After Plant Specific Deposit). This is a measure of how clean the filter media is *after the media had been backwashed by the backwash system at the treatment plant*. Where the same filter bed had been subjected to more than one consecutive wash, the state of cleanliness is designated by APSD[1] after the first wash, APSD[2] after the second wash, and so on.
- ACSD (After Column Specific Deposit). This is a measure of how clean the filter media is *after the media had been washed under standardised conditions in a laboratory column*. This backwash rate is selected to be close to the point where hydrodynamic shear is at its maximum (Amirtharajah et al., 1991), and the wash is continued for five minutes.
- AISD (After Inversion Specific Deposit). This is a measure of how clean the filter media is *after it had been subjected to standardised agitation and cleaning in the laboratory*. The standardised agitation is achieved by placing the media in a measuring cylinder with water, and inverting the cylinder a fixed number of times. Of six different methods that were comprehensively compared (Van Staden and Haarhoff, 2004) (2), this method is the best compromise between reproducibility and simplicity.
- AASD ((After Acid Specific Deposit). This is a measure of how clean the filter media is *after it had been immersed in a strong acid*. At this point, the filter media should be perfectly clean and in practically the same state as when it was new.

The five measures described above can now be used to separate the specific deposit into four fractions:

- (BPSD – APSD) is a measure of the specific deposit that is removed by the treatment plant backwash system.
- (APSD – ACSD) is a measure of the additional specific deposit that can be washed out in the laboratory, which could not be washed out at the treatment plant. If this is a small quantity, it would indicate an efficient treatment plant backwash system that does almost as good as the laboratory method under optimal conditions.
- (ACSD – AISD) is a measure of those "soft" deposits which cannot be removed by backwashing only, not even in the laboratory under optimal conditions. This fraction indicates a recalcitrant, sticky deposit which will not be removed regardless of how well the plant backwash system works.
- (AISD – AASD) is a measure of the specific deposit that cannot be readily removed from the media by physical means, but which requires chemical stripping. This fraction is best thought of as the "hard deposits", whereas the first three fractions above would make up the "soft deposits".

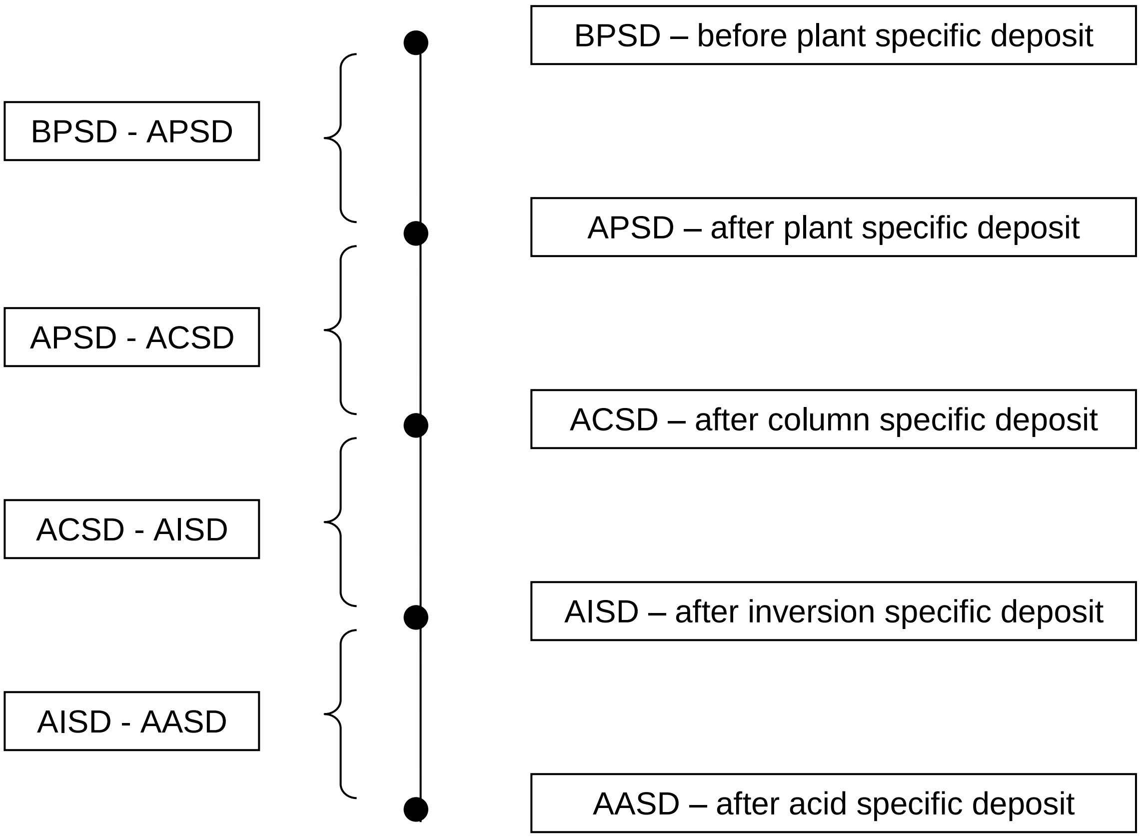

Figure 1. Conceptual model of specific deposit fraction, with the terminology adopted in this paper.

ANALYTICAL MEASUREMENTS

Without getting into the detailed analytical procedures, which will be comprehensively described in an upcoming research report (WRC Project K5/1525/3/4) (3), it is suggested that the four fractions of the specific deposit are measured in the following order:

1. Backwash a dirty filter and measure (BPSD – APSD) directly from the filter backwash water.
2. Sample the washed filter bed in a representative way and measure (APSD – AISD) by the cylinder inversion method.
3. Take more media from the washed filter bed and subject it to a laboratory wash. Measure (APSD – ACSD) directly from the backwash water emanating from the laboratory column.
4. Calculate (ACSD – AISD) = (APSD – AISD) - (APSD – ACSD).
5. Take a small sample of the media after the cylinder inversion test and immerse in sufficient 20% hydrochloric acid to strip all chemical deposits from the media. The mass loss of the media is a direct measure of (AISD – AASD).

ACCEPTABLE LIMITS FOR (APSD – AISD)

Specific deposit consists of “hard” (mostly calcium carbonate) precipitates that will gradually form on the media and which is practically impossible to remove by normal physical means, as well as the “soft” matrix of particles temporarily detained in the filter bed before being washed out during the next backwash cycle. The border between “hard” and “soft” deposits is necessarily arbitrary - the more aggressive the stripping method, the more deposits will be removed. The AISD, as defined by the cylinder inversion method, was adopted as the border between “hard” and “soft” deposits. When operators investigate the efficiency of their treatment plant backwash systems, only the “soft” deposits should realistically be considered, as the “hard” deposits are commonly regarded as part of the media. (Excessive “hard” deposit is another problem due to imperfect chemical dosing which has nothing to do with inadequate backwashing.) The benchmark for perfectly clean media, that can be achieved by physical means only, is therefore taken as the AISD state of cleanliness.

A set of criteria was therefore proposed (Van Staden and Haarhoff, 2004) (4), based on a comprehensive survey of measured (APSD – AISD) values, coupled with careful visual classification of the media by experienced researchers into categories of “clean”; “somewhat dirty with no mudballs”; “small mudballs” and “definite mudball formation”. These criteria, after a significant expansion of the experimental database, are still considered to be valid and are shown in Table 1.

Table 1: Average (APSD – AISD) and visual classification of filter beds after a single backwash cycle, with suggested classification limits.

Limit	Classification	(APSD – AISD) (kg/m^3)
1	Media appeared clean	0.0 – 4.0
2	Media somewhat dirty, no mudballs	4.0 – 7.0
3	Small mudballs	7.0 – 15.0
4	Definite mudball formation	15.0 –

THE TREATMENT PLANT SURVEY

The analyses in the remainder of this paper are drawn from a database which was assembled as follows:

- Eight plants (designated from A to H) were visited at seven different locations
- The plants were intermittently visited from May 2002 until January 2005 and a total of 31 plant visits were made
- The specific deposit was measured for 194 different samples, of which 60 were from activated carbon, 28 from sand/anthracite mixtures and 106 from silica sand alone.

The pertinent media properties of the different filter beds are shown in Table 2.

Table 2. Properties of the filter beds surveyed.

Plant	Date	Material density	Dry bulk density	Porosity	d10 (μm)	d60 / d10	Depth (mm)	Backwash rate (mm/s)
A (sand)	All dates	2479	1297	0.52	722	1.39	525	2.70
B (sand)	All dates	2601	1334	0.51	879	1.48	600	4.34
C (GAC 1)	All dates	1535	514	0.34	761	1.87	1400	5.60
C (GAC 2)					1204	1.49	1400	5.60
D (sand)	All dates	2651	1412	0.53	912	1.64	755	5.00
E (sand)	All dates	2601	1334	0.51	902	1.41	920	2.67
F (sand/anthracite)	Up to 02/2004	1957	1035	0.53	674 (sand) 1368 (anthr.)	1.51 (sand) 1.57 (anthr.)	173 (sand) 162 (anthr.)	7.90
F (sand/anthracite)	After 02/2004	2288	1118	0.49	674 (sand) 1368 (anthr.)	1.51 (sand) 1.57 (anthr.)	173 (sand) 162 (anthr.)	7.90
G (sand)	All dates	2597	1258	0.48	719	1.66	462	6.93
H (sand)	All dates	2678	1369	0.51	669	1.51	720	7.85

RESULTS OF THE TREATMENT PLANT SURVEY

(BPSD – APSD): Specific deposit removed by the treatment plant backwash systems
During the treatment plant visits, the first step was to remove the designated filters from service and backwash them once. This does not mean that these filters were then loaded necessarily to the point where they would have been backwashed under normal conditions – most of them were therefore only partly as dirty as they normally would have been. The mass of specific deposit that was washed out, nevertheless provides a first indication of how much is typically removed during a backwash cycle. The masses of specific deposit washed out by the first backwash during the site visits are summarised in Column 3 of Table 3. The low values in Table 3 obviously correspond to those filters which were only in service for a short time before the site visit. The values suggest that a maximum of about 5 kg/m^3 was washed out by the first wash.

(The results in Column 3 of Table 3 reflect the values after five empty bed volumes of washwater had passed through the filter bed. In a companion paper dealing comprehensively with the kinetics of specific deposit washout, it is shown that the removal of specific deposit is very strongly correlated with the number of bed volumes. Filters with low backwash rates take a longer time to come clean, and filters with high backwash rates are cleaned much quicker. When plotted against the bed volumes, however, the kinetics are remarkably similar. To enable a more rigorous comparison amongst the treatment plants, the washout of the specific deposit was determined after five bed volumes, even if the wash did continue for a longer period.)

Table 3. The media fractions measured during the treatment plant survey.

Treatment Plant	Date of Test	(BPSD – APSD[1]) (kg/m^3)	APSD[1] – ACSD (kg/m^3)	ACSD – AISD (kg/m^3)	AISD – AASD (kg/m^3)	AISD – AASD (%)
A	09/2003	1.51	-	-	-	-
	02/2004	-	-	-	12.0	0.9
	07/2004	0.12	0.76	2.09	21.7	1.7
	01/2005	4.34	2.60	4.86	9.5	0.7
D	08/2003	0.25	-	-	-	-
	02/2004	-	-	-	176.0	12.5
	02/2004	-	-	-	181.1	12.8
	08/2004	0.25	1.75	2.12	245.7	17.4
	01/2005	0.26	1.59	5.74	83.8	5.9
F	08/2003	0.55	-	-	-	-
	02/2004	-	-	-	4.4	0.4
	07/2004	0.94	1.86	2.69	9.1	0.8
	07/2004	0.33	1.10	4.39	123.6	11.1
	01/2005	0.84	5.04	7.41	6.2	0.6
G	09/2003	1.21	-	-	-	-
	02/2004	-	-	-	55.3	4.4
	07/2004	-	-	-	53.0	4.2
	01/2005	1.66	0.64	0.75	47.8	3.8
H	09/2003	2.34	-	-	-	-
	02/2004	-	-	-	79.2	5.8
	07/2004	1.30	0.72	0.72	77.7	5.7
	01/2005	1.24	1.85	1.82	88.8	6.5
Min.		0.12	0.64	0.72	4.4	0.4
Max.		4.34	5.04	7.41	245.7	17.4
Ave.		1.14	1.79	3.26	75.0	5.6

(APSD[1] – ACSD): Additional specific deposit washed out in the laboratory

After backwashing at the treatment plant, media samples were further washed in the laboratory column under optimal conditions. For perfectly efficient treatment plant backwash systems, no more specific deposit would be washed out in the laboratory. For the data reported here, the laboratory column was always loaded with media that had been washed once only by the treatment plant. If a treatment plant routinely uses say two washes, then the media should only be transferred to the laboratory after two plant washes. Once again, the endpoint of all washes was taken as five bed volumes of backwash water. The results are shown in Column 4 of Table 3.

Column 4 of Table 3 shows that the backwash systems at all the treatment plants were fairly effective, with the laboratory column capable of only washing out less than 2 kg/m^3 after the filters had been backwashed at full-scale.

(ACSD – AISD): The non-washable fraction of the specific deposit

How washable is the media? In other words, how much of the specific deposit is so recalcitrant that it cannot be washed off the media grains, even in a well controlled laboratory column? For this measure, the difference between the after inversion deposits (AISD) and the after column deposits (ACSD) is considered, as explained earlier. The deposit removed by the laboratory column (the maximum that can be expected from hydrodynamic shear only) is subtracted from the AISD (which is removed by the much more aggressive cylinder inversion method). The results are shown in Column 5 of Table 3.

Column 5 of Table 3 shows a wide scatter of values, with most of the values fairly high. This supports the conclusion that dirty filter media in practice cannot only be ascribed to imperfect backwashing and maintenance.

<u>(AISD – AASD): The "hard" component of the specific deposit</u>
Finally, the "hard" deposits which are normally considered to be part of the media grains and difficult to remove were determined and the results are presented in Columns 6 and 7 of Table 3.

These values show a very large scatter, which is closely tied to the chemical stabilisation practices at the different treatment plants. These values, high as some of them seem to be, are very typical – values as high as 30% of the filter media mass have been encountered by the project team in previous studies.

<u>Putting it all together</u>
Figure 2 shows these three fractions in the form of a cumulative bar chart for the 10 site visits conducted during this project.

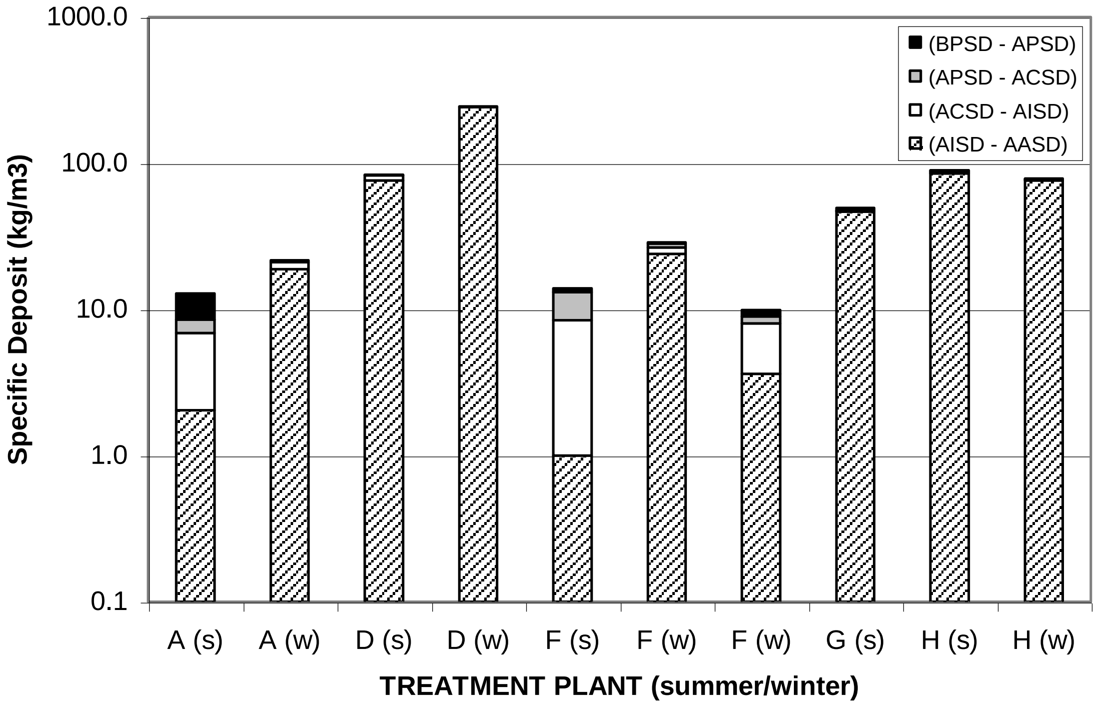

Figure 2. Cumulative specific deposit fractions (both "hard" and "soft" deposits) measured during the treatment plant survey.

It is immediately obvious that the "hard" deposits, which can only be removed by acid, dominate the specific deposit in most cases. However, these deposits are considered by most to be a part of the media once they are formed. The focus of this report is rather on the parts of the specific deposit that could be operationally removed after they are formed. Figure 3 therefore shows the same values as in Figure 2, but without the "hard" deposits.

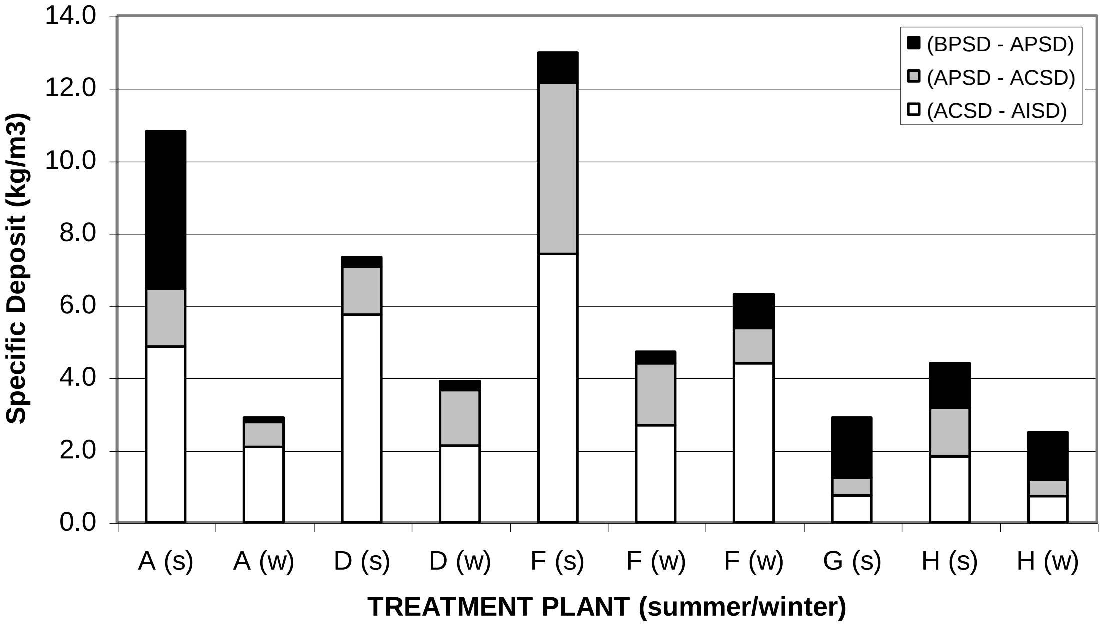

Figure 3. Cumulative specific deposit fractions (only the "soft" deposits) measured during the treatment plant survey, with (s) designating summer visits and (w) winter visits.

It is evident from Figure 3 that the treatment plants investigated cover a wide range of media cleanliness – from "clean" media to "dirty with definite mudball formation" according to the guidelines presented earlier. Furthermore, the summer values are consistently two to three times higher than the winter values. (The values for Plant G could unfortunately not be measured during the winter visit due to practical difficulties). It is tempting to ascribe the cleaner filters in winter exclusively to the higher viscosity and hydrodynamic shear of the colder backwash water, but the issue seems much more complex than that. The non-washable fraction (ACSD-AISD) contributes a surprisingly large part to the specific deposit – in most cases more than half of the total. To get all the treatment plants within the guidelines proposed earlier, it is obvious that more vigorous backwashing alone will not solve the problem. Some means have to be found to also reduce the non-washable fraction.

What does this non-washable fraction consist of? Previous work (Clements and Haarhoff, 2004) (5) as well as the increased deposit in the summer months, suggest that biofilm formation may be the key to the problem of insufficiently cleaned filter media. The volatile fraction of the specific deposit, which is assumed to be mostly biological in origin, was therefore measured on each of the samples. The relationship between the volatile fraction of the specific deposit and the specific deposit remaining after controlled laboratory backwashing is shown in Figure 4.

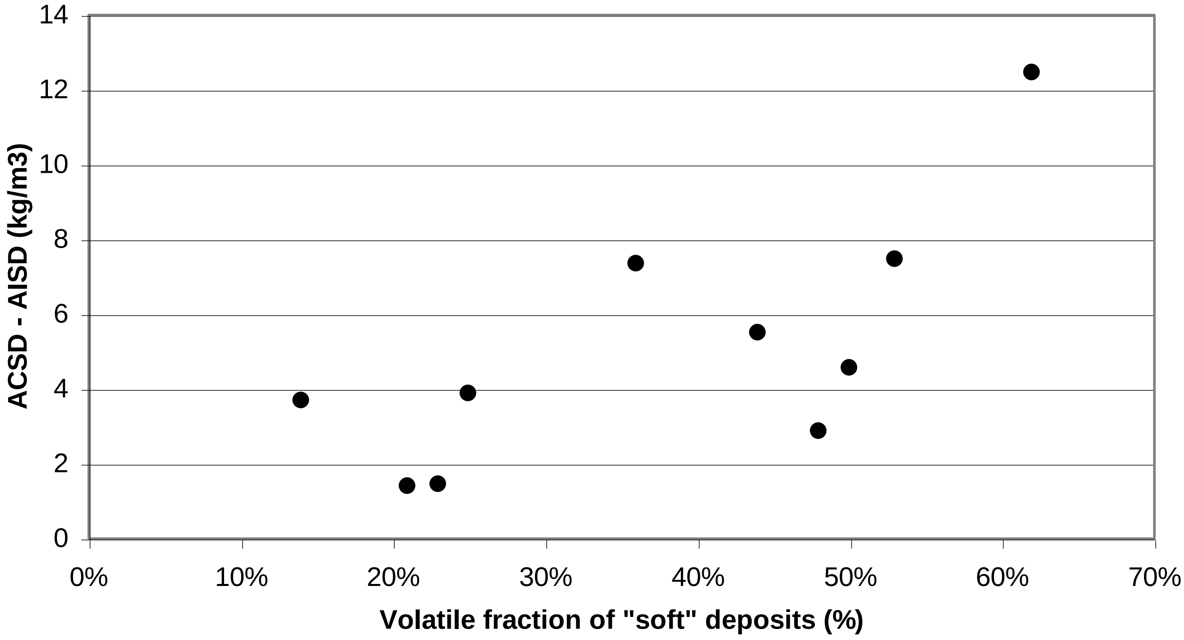

Figure 4. Relationship between volatile fraction and the non-washable specific deposit.

Figure 4 provides strong empirical support for suggesting that the non-washable "soft" deposits are largely composed of biofilm. Should this indeed be the case, it means that rehabilitation efforts should be directed towards the prevention, or breakdown of biofilm rather than towards simply improving the mechanics of the backwash system.

SUMMARY OF RESULTS

The conceptual framework presented at the start, coupled with the results of the treatment plant surveys, brings a hitherto obscured understanding of filter cleanliness into much better focus. The winter survey (July 2004) and the summer survey (January 2005) yielded 10 data points which brought new insights:

- A normal, reasonably effective backwash at a treatment plant removed 0.89 kg/m^3 (median, varying between 0.12 kg/m^3 and 4.34 kg/m^3) of specific deposit. This variation depended on how dirty the filters were and the operational practice at the treatment plant.
- This does not mean that the filter media was perfectly clean. By washing the media in a laboratory column, a further 1.34 kg/m^3 (median, varying between 0.47 kg/m^3 and 4.73 kg/m^3) was washed from the media.
- When this media was subjected to even more agitation, namely a standardised cylinder inversion procedure, yet more specific deposit was released from the media. During the surveys, the median value was 2.41 kg/m^3 (median, varying between 0.72 kg/m^3 and 7.41 kg/m^3).
- Finally, the remaining specific deposit was stripped by immersion in a strong acid. This removed a median of 35.2 kg/m^3 of specific deposit (showing an extreme variation between zero and 241.8 kg/m^3).

- The specific deposit removed by the treatment plants was therefore a relatively small fraction of the overall specific deposit, supporting the qualitative observation at numerous other treatment plants that filter media, after a few years of operation, become unacceptably dirty.
- The chemical precipitates, which are impossible to remove unless strong acid is used, are best considered to be ‘hard” deposits and part and parcel of the filter media. Their prevention and removal requires chemical intervention which is beyond the scope of this paper.
- Filters were consistently cleaner in winter than in summer.
- The non-washable fraction of the “soft” deposits made up more than 50% of the total specific deposit and seems to hold the key to improving filter cleanliness.
- There is strong empirical evidence that this non-washable fraction consists predominantly of biofilm. This finding is a valuable pointer towards better focused rehabilitation strategies, currently being investigated.
- There are large and significant differences amongsth different treatment plants, suggesting that different rehabilitation strategies will be required at different treatment plants.

ACKNOWLEDGMENT

Some of the data reported in this paper were collected during a research project sponsored by the Water Research Commission and are presented here with the consent and encouragement of Dr. Gerhard Offringa, the project manager.

REFERENCES

(1) SJ van Staden and J Haarhoff, Effective Filter Backwashing with Multiple Washes of Air and Water, Tenth Biennial Conference of the Water Institute of Southern Africa, Durban, ref. 200 (2006).

(2) SJ van Staden and J Haarhoff, A Standard Test for Filter Media Cleanliness, Water SA 30 (1), p.81-88 (2004).

(3) Water Research Commission, Investigation into Alternative Methods to Clean Filter Media in Rapid Gravity Sand Filters to Ensure Optimal Performance and Quality Filtrate, Unpublished, Reference No. K5/1525/3/4 (2006).

(4) SJ van Staden and J Haarhoff, An Improved Filter Media Test for Troubleshooting and Rehabilitation of Problem Filters, AWWA Water Quality and Technology Conference, San Antonio, USA (2004).

(5) M Clements and J Haarhoff, Filter Media Expansion During Backwash – The Effect of Biological Activity. Ninth Biennial Conference of the Water Institute of Southern Africa, Cape Town, (2004).