The following is a compilation of articles that appeared in the Ohio Section AWWA newsletters from the Winter 1997 through Spring 1999. These articles were presented by Nick Pizzi, Environmental Engineering & Technology Inc. and Tim Wolfe, Montgomery Watson.

Maintaining Filters - Part I of a Series
Bed Depth - by Nick Pizzi, EE&T Inc.

In our last issue, we promised a five-part series on filter maintenance. The first part - **Bed Depth** - beings with this issue.

Since filter backwashing and other operating practices can result in media loss in the filter, the total media depth should be measured periodically to determine if the existing media still meets original specifications. It is not unusual to lose some media each year, especially if the bed is of dual media construction comprised of sand and anthracite. The backwash velocities required to clean a sand bed may wash away some of the anthracite, which has a density less than that of silica sand. Excessive media loss can be, however, an indication of poor operational technique or an indication of filter bottom problems, and will eventually result in filter effluent degradation.

How deep is deep?

In part, the ability of a filter to trap floc particles in suspension at normal operating rates is a function of bed depth and media size. The minimum standard for proper filter construction is that the ratio of the bed depth in millimeters divided by the effective size in millimeters should be at least 1,000, or:

$$L/d_{eff} \geq 1{,}000$$

In practice, it is common for plant operators to maintain a bed that is 15% in excess of the minimum standard. For example, a six-foot deep monomedia bed comprised of 1 mm anthracite coal would be more than sufficient because six feet is 72 inches, and 72 inches times 25.4 mm/inch = about 1,830 mm. Using the formula, we see that 1,830 mm/1 mm = 1,830 - a ratio that more than covers the guidelines for sufficiency. For multimedia beds, use the same formula to calculate the ratio for each layer of the bed separately, and then add the results together. A dual media bed consisting of 36 inches of 1 mm anthracite and 6 inches of 0.5 mm sand would produce a ratio of (915 + 305) = about 1,220. A loss of just a few inches of anthracite in this example bed would be critical.

Beds other than mono-media or dual media, such as tri-media or coarse mono-media beds may require a higher ratio.

How do I measure bed depth?

Bed depth is a measure of the amount of filter media in the cell, not the support gravel or underdrains. After checking the original specifications, measure the bed depth by poking a 3/8 - inch steel rod down into the media until the gravel or support media is reached. Experienced operators can develop a “feel” for the difference in resistance that the rod meets at the interface of the media and the gravel. Others can hear the distinctive “crunch” as the rod hits its mark. When you have satisfied yourself that you’ve found the depth, pinch the rod at the surface and carefully pull it out. Tape the rod at that mark, and get a measurement in inches. Poke the rod into other areas of the filter bed to determine if the filter media is level, or the underdrain is disturbed. Within reason, the rod should always come close to the tap mark wherever you poke it in.

This measurement will be very important when we discuss bed expansion, but it will also tell you quickly when the need arises for the installation of additional filter media.

Maintaining Filters - Part II of a Series
Bed Expansion - by Nick Pizzi, EE&T Inc.

In our last issue, we began a five-part series on filter maintenance by looking at bed depth. This is part II - Bed Expansion. We will examine proper backwash characteristics using the information we gained in our last report.

Using the example from the last issue, we measured and determined that our dual media filter had 42 inches of media. The configuration was comprised of 36 inches of 1 mm anthracite supported by 6 inches of 0.5 mm sand. We were satisfied that this bed configuration was sound in that it has an L/D ratio of 1,220, and therefore should be capable of reducing turbidities in a well conditioned and pretreated water to below our target of 0.1 NTU on a consistent basis. Assuming good pretreatment, operators would be correct in believing that this bed should produce quality effluent for years to come. A key component for this continued performance, however, is thorough bed expansion in the backwash cycle. A bed that is washed poorly will eventually be at risk for degradation, and water quality will suffer. What constitutes a poor backwash? Or how does an operator know if a filter is being backwashed properly? Measure the bed expansion during the backwash routine, and some answers to these questions will present themselves.

Bed expansion - achieve too little or too much of it, and you can expect problems. Too little bed expansion will leave the bed with an overabundance of floc retention, and this will tend to shorten filter runs and risk the passage of particles into the finished water. Too much bed expansion can cause loss of media and strip away needed ripening that has been patiently built up over the preceding run, causing a need for a greater ripening period.

Experts seem to agree that a 30% bed expansion is indicative of the wash rate that is best suited for cleaning the filter. The flow of water needed to expand the bed by 30% of its depth - (in our example, 30% of 42 inches is about 12 or 13 inches) - should be carefully determined on a seasonal basis by operations.

It is important to remember that the temperature of the backwash water plays a significant role in the ability to expand a filter bed. It takes a higher flow rate of warmer water to achieve a 30% bed expansion than it does for colder water, **but the 30% requirement stays the same, warm or cold.**

How do I measure bed expansion?

The picture above shows several of the tools which are used in the filter maintenance program, and the odd looking one with “pan pipes” strapped together and cemented to a plastic block is the bed expansion tool. It is constructed so that each pipe is 1 inch higher than its neighbor, and all of the pipes rest on a 2-inch base. It has been fitted with a 3/4-inch plastic pipe-threaded end so that an extension of any length can be screwed on. This arrangement allows the operator to lower the unit onto the bed while remaining “up top” and out of the way of the wash.

This tool is anchored to the railing or other appurtenance near the filter so that the base rests just on the top of the bed before washing. It is important that the tool not move during the wash. When the wash begins, the tool will sink into the bed like it was quicksand - therefore the anchoring is necessary unless you are willing to stand in one position for many minutes holding this awkward piece of equipment.

It is best to start the measurement with a freshly washed bed because visual inspection of the tool is difficult to impossible as solids begin to wash over the troughs. With the tool in place, start the backwash and observe the media as it begins to rise, covering each successive pipe in turn. The tool you see in the picture above is built for a 30-inch bed, and so a larger tool would be necessary for our example. Imagine, though, that our tool has 12 pipes. A two-inch base then would allow for the measurement of 14 inches of rise, and we could easily determine if we achieve that as the wash continues.

The key is that, at the high rate of wash, all 12 pipes would be covered - but no more. Being a dual media bed, it would have been advantageous to have ramped up to a point somewhat lower than a 30% expansion - say 100% - or 4 inches (2 pipes + the base). This ramping will help to wash each strata of the bed properly, and prevent excessive mixing of the media. It is simple then to wash at the high rate until the backwash water clears to below 10 NTU, and then the wash can be terminated.

While measuring the bed for percent expansion, it's a good idea to make other visual observations. The bed should be observed for flow patterns of wash water as it first rises above the media, the color of the water, and the evenness with which the water approaches the troughs. This is a good time to note the flow rates that are used to achieve each pipe on the tool if you have flow measuring devices. It not, make a note of the relative position of the valve handles in some fashion so that these positions can be duplicated.

Measurements for bed expansion, taken three times per year at randomly chosen filters, can help ensure good bed cleaning. Next issue, we'll discuss how to measure the effectiveness of the wash process through core sampling of the bed.

These measurements will be compared to the amount of floc material left in the bed after wash to determine any need for adjustment. Remember: if your washwater varies in temperature with the season, so should your washwater usage rate vary.

Maintaining Filters - Part III of a Series
Filter Coring - by Nick Pizzi, EE&T Inc.

This is the third article in a series on filter maintenance, and it deals with the inspection process called *filter coring*.

The real proof of where the particles are being removed in the filter bed during a filter run, and whether the backwash conditions being used are effective can best be determined by performing a filter coring.

Filter coring is an inspection technique that examines the amount of floc particles that remain attached to the filter media at successive levels of the entire depth of the bed. Careful extraction of bed strata, or "cores", taken before and after filter washing, provide the operator with an opportunity to quantify solids retention in the bed. A simple tool made of a five-foot length of 1 ½ inch electrical conduit is used as the corer, after it has been marked at the appropriate sections. The tool is sectioned with an indelible marker at the 0-2 inch mark, the 2-6 inch mark, and the 6-12, 12-18, 18-24, 24-30 inch marks, etc., for the entire length necessary to reach the bottom of the bed. This configuration of tool material and diameter seems to work best: other materials (plastic pipe) and sizes do not seem to provide sufficient adhesive power for both sand and anthracite, nor do they provide sufficient volume of sample for analysis. In addition to the tool, a number of sealable plastic "baggies" are needed as containers for the media samples. A before and after set of baggies should be provided, two each for each strata that will be sampled. The baggies should be coded with the marker to correspond to the levels on the coring tool.

The coring procedure is performed after the bed has been completely drained. For best results, begin the procedure while the bed is still damp, as this will provide for optimum media adhesiveness. Two small (2'X2') pieces of plywood placed on the bed will allow two operators to stand comfortably with minimal bed disruption. One operator inserts the coring tool into the bed at right angles until the 2-inch mark is reached. Carefully extracting the tool so as not to lose the contents of the sample, the operator empties the contents of the tool into the baggie, which is held open by the second operator, by gently blowing into the other end of the pipe. This procedure is repeated two more times at two nearby by separate locations so that reasonably representative samplings of the upper two inches of the media are obtained and placed into a baggie.

The next extraction is obtained from the 2-6 inch strata, and the operator must carefully inset the coring tool into the same three holes to get the samples. Care must be taken so as not to cross-contaminate the coring tool with material which may fall into each sampling hole, and the tool exterior should be wiped off between each sampling as an added precaution. This procedure is repeated until all representative strata of the bed are obtained. As each baggie is filled, it is marked, sealed, and stored topside for future analysis. The clear plastic baggies allow for a visual inspection of the media, and in this way mudballs and other debris that may be present can be observed. For dual and mixed media configurations, at least one baggie will yield a mixed layer (e.g., sand and anthracite), and this layer should be closely examined for any interesting characteristics including mudballs, particle size distribution, and of course the depth at which it was obtained. The D_{90}/D_{10} ratio will have a direct impact on this strata.

When all core extractions have been obtained, the bed should be washed in the usual fashion. This is an excellent opportunity to observe the backwash process for any anomalies, and samples of the backwash water can be obtained from the trough overflows for analysis. A plot of the backwash water turbidity versus time can offer additional insights of the inspection process. After washing, "after" core samples of the bed should be obtained as before.

Both sets of baggies, containing the before and after core samples, are brought to the lab for turbidity or floc retention analysis. The goal is to measure retention as NTU per 100 grams of media. A plot of these results gives a profile of the bed at each depth, before and after backwashing, which can be used to refine the backwash process.

In the lab, 50 gram portions of each baggie are weighted and placed into separate 500 mL beakers. Five successive 100 mL portions of turbidity free water are used to wash down and agitate the sample for 30 seconds. These five portions are carefully poured into a 1,000 mL beaker, and a turbidity of the resultant suspension is measured. When all of the before and after measurements are had, the results are multiplied by two, and plotted on a graph depicting the results.

Kawamura has suggested guidelines for sludge retention that are shown in Table 1.

Table 1 - Floc Retention Guidelines

NTU/100 grams	Action to Take
<30 NTU	Bed is too clean - examine wash rate and length - this bed will not ripen quickly
30 - 60 NTU	Well cleaned and ripened bed - no action required
60 - 120 NTU	Slightly dirty bed - reschedule retention analysis soon
>120 NTU	Dirty bed - reevaluate filter wash system and procedures
>300 NTU	Mudball problem - rehab bed

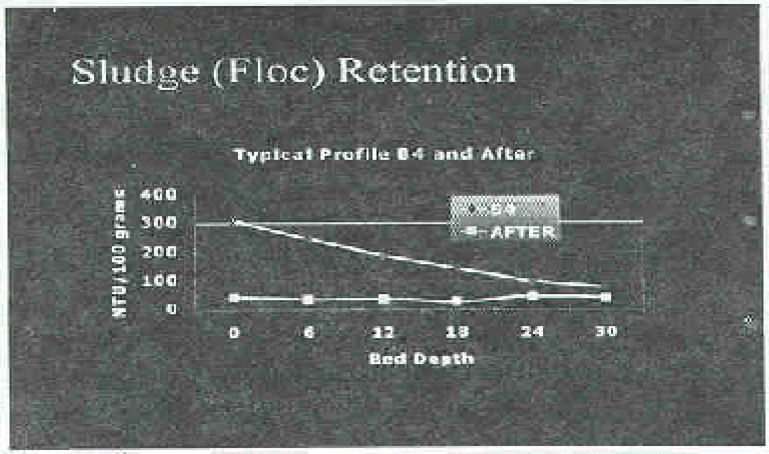


Figure 1

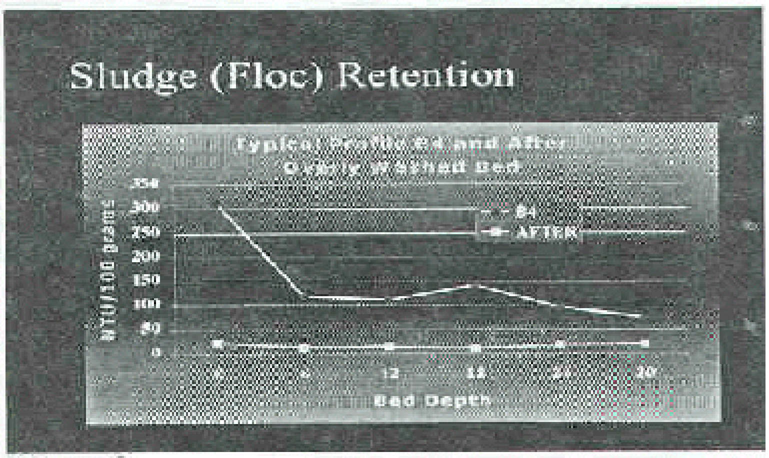


Figure 2

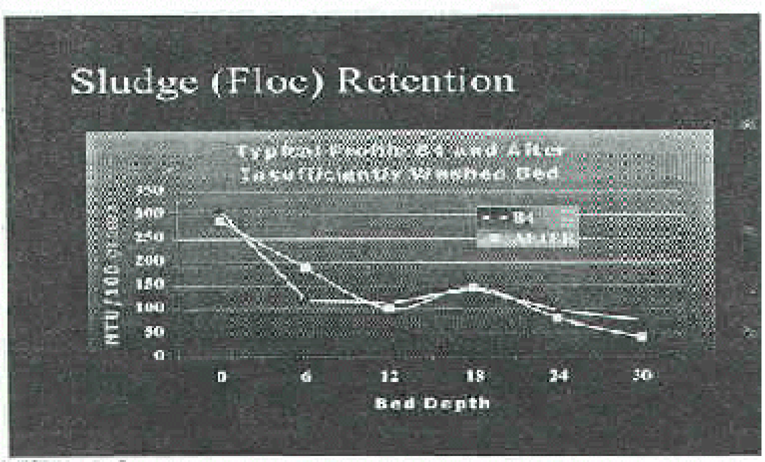


Figure 3

These guidelines should be regarded as a starting point, and may be inappropriate or misleading at any individual utility. The point here is that each operation should, in time, be able to develop a “normal” set of guidelines for use based on repeated and regular analysis of their own conditions. Two approaches might be considered depending on the condition of the overall and individual filter effluent quality of the utility.

- **If the quality is good**, then these guidelines could be considered irrelevant with respect to local conditions. The utility could simply measure the actual floc retention characteristics of their filters and “write” their own guidelines as a baseline of what is normal for them.

- **If the quality of the effluent is poor**, then these guidelines offer a good starting point and goal for comparison. Once the floc retention characteristics of the local filters are obtained, the operators might try to optimize the process until further floc retention analysis shows conformance with these guidelines.

Operators should remember, however, that conditions at their utility (process type, operating habits, etc.) may produce significant deviation from these published guidelines, and that the only acceptable use of them is contingent on the quality of the effluent. This author does not advocate change in plants where quality is good simply because these guidelines are not met. Rather, they are printed here to provoke vigorous examination of local filter and treatment conditions.

Figure 1 is an example of a before and after backwash solids retention plot for a dual media filter that has 12 inches of 0.5 mm E.S. sand and 18 inches of 1 mm E.S. anthracite. The before plot shows that there is good penetration of floc material into the depth of the bed, and that there is extra capture of material at the interface of the sand and coal area. This is typical of a dual media filter which is operated a 4 gpm/sq.ft.

Note that after backwash it is evident that the floc material has been removed evenly from each layer of media, and that sufficient material has been left in the bed to assure a mature, ripened bed. This filter should be ready for service as is, and can be expected to produce a quality effluent in short order. There is an indication that the filter was not operated for too long a duration, as there is little floc penetration into the lower layers. This is prudent operation in that the bed is not overburdened with floc. This bed may be able to withstand some hydraulic shock without loss of floc material into the clearwell - there is “room” for mistake.

The next graphic is constructed from data gathered from a dual media unit at the Garret A. Morgan Plant in Cleveland, Ohio. Note that the before wash data looks normal, but that the after data indicates an overly washed bed which is stripped of ripened material. This filter was washed at too high a rate, and for too long a period, and will now require a longer ripening period before it will produce a quality effluent. This is typical in many water treatment plants where the operators are trying to be sure that they do a good job of cleaning the bed. The turbidity value of the backwash water at the end of the wash cycle was measured at 2 NTU, far in excess of the AWWA recommendation of 10 NTU as a cutoff for backwashing.

The last graphic shows conditions of a filter that has not been washed sufficiently. Note that there is little change in the amount of material removed from the bed. This may be an indication of insufficient wash velocity, and the profile indicates the need for a closer inspection of both the backwash habits of the operator as well as the capability of the entire backwash system.

In the next article, we will examine the backwash analysis techniques.

Maintaining Filters - Part IV of a Series
Bed Depth - by Tim Wolfe, Montgomery Watson

To assure effective filtration performance, the filter bed must be maintained in top operating condition by properly backwashing the media layer(s). Effective backwashing of a filter bed depends on two principal factors:

1. Backwashing at the appropriate (optimum) backwash rate for all media layer(s) in the filter bed during each season of the year (i.e., at various water temperatures), and
2. Backwashing for the proper length of time so:
   - cleaning of the filter bed is maximized, but the amount of spent backwash water is minimized, and
   - ripening of the filter bed occurs in an effective manner when a freshly backwashed filter is returned to service (e.g., as a goal during the ripening period, the maximum filter-effluent turbidity should ideally be less than 0.3 NTU, and the filter-effluent turbidity should ideally drop to less than 0.1 NTU in less than 15 minutes).

The appropriate backwash rate at various water temperatures can be determined by using readily available computer backwash models. The proper length of time to backwash a filter bed can be obtained by collecting samples of the spent filter backwash water while the filter bed is being backwashed. These two items are discussed in greater detail in this article.

Appropriate (Optimum) Backwash Rate

During backwashing with water, the filter bed must be allowed to expand sufficiently to promote adequate scrubbing of the media grains against each other so particles attached to the media are released. The majority of the particles are generally removed in the upper 6 to 9 in. of each media layer. Therefore, it has been concluded (**1**) the optimum backwash rate is one that develops an expanded-bed porosity of 0.7 for the effective size (E.S.), d_{10}, of the media (i.e., the E.S. is located near the top of each media layer where most of the particles have been removed). An expanded-bed porosity of 0.7 results in media grains that are just barely touching each other during backwashing - so the particles can be scrubbed loose and removed from the filter media.

The appropriate backwash rate to create an expanded-bed porosity of 0.7 can be determined using a number of computer backwash models. One model developed by researchers is readily available in the literature (**2**). It should be noted that the viscosity of water plays a major role in the optimum backwash rate (i.e., the colder the water temperature, the lower the required backwash rate). Therefore, the optimum backwash rate should be determined for two to four water temperatures to assure adequate backwashing year-round. This is illustrated in **Table 1** for several filter-media configurations that are commonly used in Ohio WTPs. Please note in the last column of Table 1 - while percent bed expansion is a practical means of checking the backwash rate and is the same at all water temperatures for a given filter-media configuration, the optimum percent bed expansion is not the same for all filter-media configurations. **Figure 1** shows the appropriate backwash rate for various water temperatures for a few common filter media used in Ohio.

						Backwash Rate (gpm/sf)		
Type	Media	Media Depth (in.)	Effective Size (mm)	Uniformity Coefficient	L/d Ratio	Winter (0.5° C)	Summer (20° C)	Bed Expansion (%)
1. Sand	Sand	24	0.45-0.55	<1.65	1,220	18	25	50
2. Dual Anthracite/Sand	Anthracite Sand	12 16	1.0-1.2 0.45-0.55	<1.4 <1.65	1,120	16.5 18	22.5 25	24 50
3. Dual GAC/Sand	GAC Sand	14 16	1.2-1.4 0.40-0.50	<1.4 <1.65	1,180	16 15	21 21	31 49
4. Deep-Bed Anthracite	Anthracite	48	0.9-1.1	<1.5	1,220	14	20	22
5. Deep-Bed GAC	GAC	48	0.9-1.1	<1.5	1,220	11	15	27

Near the end of the backwash rate may need to be increased to completely fluidize the layer(s) of media in the filter bed, particularly if a dual-media or multimedia filter is being used. This allows the media to be fully fluidized, and to then settle down with the media stratified (i.e., with the size of media grains ranging from small to large going from top to bottom of each layer) when the backwash water is turned off.

A good rule of thumb in selecting media sizes for a dual-media filter is to choose a ratio (d_{90} coal / d_{10} sand) of roughly 3 for the coal grains located near the bottom of the coal layer and the sand grains located near the top of the sand layer (i.e., the interface between the two media layers). The coal grains located near the bottom of the coal layer are represented by the d_{90} of the coal (i.e., 90% of the coal grains are smaller than that size). The sand grains located near the top of the sand layer are represented by the E.S. (i.e., d_{10}) of the sand (i.e., 10% of the sand grains are smaller than that size). A ratio greater than 3 results in too much intermixing of the coal and sand layers, and a ratio less than 3 results in little or no intermixing of the two media layers. A small uniformity coefficient (U.C.), d_{60} / d_{10}, of approximately 1.5 is also recommended for each medium to assure a rather uniform grain size within each media layer so the entire filter bed can be adequately fluidized during a backwash.

It is important in selecting media for dual-media and other multimedia filter beds that the appropriate backwash rate should be fairly similar for each media layer. Therefore, a balancing act must be performed in selecting compatible characteristics for each media layer (e.g., E.S., U.C., specific gravity, angularity (or sphericity) and d_{90} / d_{10} of the interface).

Proper Length of the Backwash

The proper length of the backwash can be determined for each season of the year (i.e., at different water temperatures) by:

! backwashing the filter bed for at least 10 minutes at the appropriate (i.e., optimum) backwash rate,
! collecting a sample every 15 seconds of the spent backwash water from the filter trough, and
! measuring the turbidity of these samples.

The turbidity value (in NTU) of the samples is then plotted on the Y-axis versus the time (in min.) at which the sample was collected during the backwash on the X-axis. The proper length of the backwash is defined as the time when the turbidity value of the spent backwash water decreases to less than 10 NTU (see the example in **Figure 2**). A turbidity value of 10 NTU has been promoted by a number of operators as the appropriate turbidity to terminate the backwash (i.e., the filter bed is more likely to exhibit better filter-effluent turbidities during the ripening period when the filter is placed back on line).

FIGURE 1
Optimal Backwash Rates

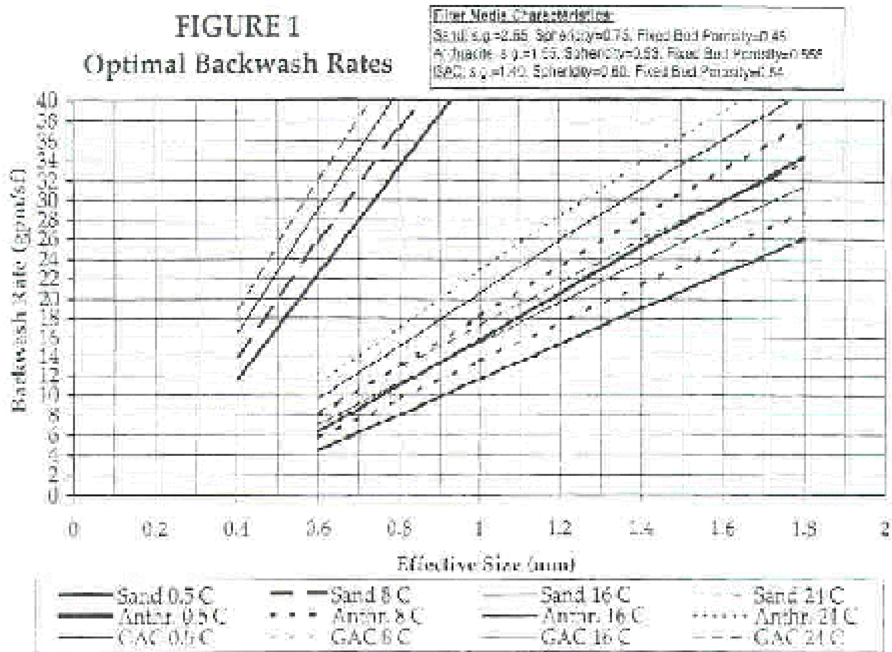
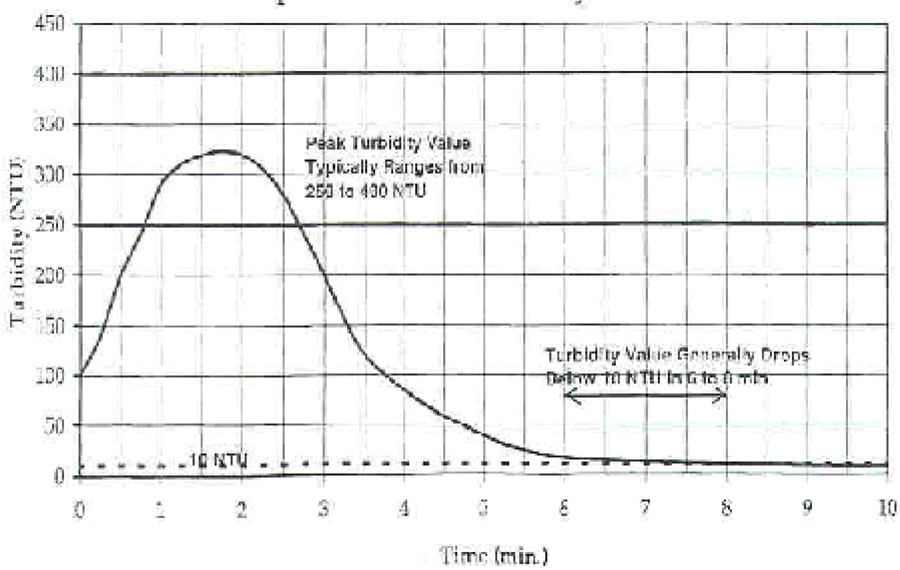


FIGURE 2
Spent Backwash Turbidity Profile



Other Items of Importance

Achieving the optimum backwash rate and the proper length of the backwash both point to one thing - **an operator should be present when a filter is being backwashed, even if the filter backwashing procedure is partially automated.** In addition to making sure the filter is being backwashed appropriately, an operator can check items such as:

- depth of filter media,
- uneven filter media levels,
- presence of mudballs,
- uneven distribution of the backwash water across the entire filter,
- media being lost over the side of the backwash trough, etc.

As noted previously, most of the particles are removed in the upper 6 to 9 in. of each media layer in the filter bed. **Therefore, surface wash is helpful in breaking up the media grains that may be stuck together with a large amount of particles that have been removed (often referred to as mudballs).** The surface washing is generally performed after the water level in the filter has been lowered to just above the media surface, but prior to starting the filter backwash. Often, the surface washing is continued during the initial stages of backwash while the backwash rate is being ramped up to the optimum backwash rate (i.e., as the media layers are being expanded). Ideally, a subsurface wash in dual-media filters (i.e., located at the interface of the coal and sand layers) could be used to break up any media grains that are stuck together at the interface. Subsurface washers can be a maintenance headache (i.e., out of sight can lead to problems), and can be avoided by carefully selecting the media layers so the proper amount of intermixing takes place at the interface as noted previously.

The trend today is toward higher filtration rates, which at times involves using deeper filter beds. **One rule of thumb is that air scouring should be considered for filters in which the total bed depth for all filter media layers is greater than 48 in.** For these deeper filter beds air scouring is often substituted for surface wash. Air scouring is usually performed prior to backwashing the filter bed with water to avoid the violent backwashing of the media that results when air and water are used simultaneously (i.e., due to the implosion of the air bubbles). Using air and water simultaneously is generally not warranted for filters in water treatment plants, and can lead to excessive loss of filter media.

References

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2. Dharmarajah, A.H. and Cleasby, J.L., “Predicting the Expansion Behavior of Filter Media”. Journal, American Water Works Association, Vol. 78, No. 12, Dec. 1986, pp. 66 - 76.

Final in the Filtration Series
"Achieving Balance" - by Nick Pizzi, EE&T Inc.

By now, it should be apparent to the staffs of surface water treatment plants that there has been a shift in regulatory philosophy with respect to filter operations. The measure, or worth, of water quality will no longer be determined by the turbidity of the "plant tap" sample alone. Now, with the promulgation of the IESWTR, **the contribution of each individual filter will be measured, assessed, and reported.** In essence, the water quality of the plant will be judged by the output of the worst filter on-line.

This philosophy returns us to a time when filtration was the most important unit process available in the quest for public health. Before the advent of chlorination, operators depended on filtration to remove harmful microorganisms from the water supply, public records of many cities reveal that when filtration was installed at water plants, a decrease in community disease was noticed. This direct cause and effect relationship between unit process and public health was the single most important discovery of the day - a shift of thought that brought science into the craft of water supply and treatment.

Soon after, chlorination was discovered, and brought into vogue as a first line of defense against disease causing organisms. Generations of plant operators lost sight of the importance of filtration, and began to think of it as a simple polishing process - one that improved the "clarity" of the water. Improving the clarity, we were told, would discourage consumers from seeking alternative, and perhaps less safe water supplies.

The past few years have brought us back to our roots. Improved detection techniques have shown that protozoa in water supplies can sometimes be quite numerous, both in nature and in the plant process - and in water that is crystal clear.

We now know that chlorination cannot inactivate many of these organisms. We must optimize other unit processes to accomplish that. Filtration, in concern with chlorination, serves as a synergistic and scientific approach to that end, and contributes to the overall community health.

Science and craft have achieved balance once more. View the suggestions at the bottom in that spirit.

Filtration Checklist

- Check your filters for conformance to the original specifications for media depth and size.
- Review backwashing techniques with your operators - all of them.
- Check the turbidity output of each filter in the first 15 minutes of runtime.
- Check the number of hydraulic changes made in a given day - can they be reduced in frequency or magnitude?
- Think of your filters as particle storage devices - not particle removal devices. There is a price to be paid for long-term storage.
- Drain your filter and enter it once a year at a minimum - you may be surprised.
- Your plant water quality is only as good as your worst filter allows - find out which filter is your worst.
- If your surface water treatment plant does not have provision to measure and record turbidity on a continuous basis from each filter, you should be making plans to do so - soon.