

at lower than required effluent turbidity levels).

Letterman *et al.* (2001) evaluated the effect of turbidimeter design and calibration methods on *inter-instrument* performance, comparing bench top to on-line instruments and instruments within each of those categories from different manufacturers. The study used treated water collected from the filter effluent of water treatment plants. Reported sample turbidity values ranged from 0.05 to 1 NTU. Samples were analyzed in a laboratory environment. The results are consistent with those of the WS041 study, specifically the positive bias of on-line instruments. However, Letterman *et al.* found generally poor agreement among different on-line instruments and between bench-top and on-line instruments. The authors also observed that results were independent of the calibration method, though certain experiments suggested that analyst experience may have some effect on turbidity readings from bench-top instruments.

Sadar (1999) conducted an *intra-instrument* study of low level turbidity measurements among instruments from the same manufacturer. This study was performed under well-controlled laboratory conditions. *Intra-instrument* variation among different models and between bench top and on-line instruments occurred but at significantly lower levels than the Letterman *et al.* *inter-instrument* study. Newer instruments also tended to read lower than older instruments, which the author attributed to a reduction in stray light and lower sensitivities in the newer instruments. Sadar also found a generally positive bias when comparing on-line to bench-top and when comparing all instruments to a prepared standard.

The American Society for Testing and Materials (ASTM) has issued standard test methods for measurement of turbidity below 5 NTU by on-line (ASTM 2001) and static (ASTM 2003) instrument modes. The methods specify that the instrument should permit detection of turbidity differences of 0.01 NTU or less in waters having turbidities of less than 1.00 NTU (ASTM 2001) and 5.0 NTU (ASTM 2003), respectively. *Inter-laboratory* study data included with the method for a known turbidity standard of 0.122 NTU show an analyst relative deviation of 7.5% and a laboratory relative deviation of 16% (ASTM 2003).

In summary, the data collected in these studies of turbidity measurement indicate that currently available monitoring equipment can reliably

measure turbidity at levels of 0.1 NTU and lower. However, this requires rigorous calibration and verification procedures, as well as diligent maintenance of turbidity monitoring equipment (Burlingame 1998, Sadar 1999). Systems that pursue additional treatment credit for lower finished water turbidity must develop the procedures necessary to ensure accurate and reliable measurement of turbidity at levels of 0.1 NTU and less. EPA guidance for the microbial toolbox will provide direction to water systems on developing these procedures.

c. *Request for comment.* EPA invites comment on the following issues regarding the proposed *Cryptosporidium* treatment credit for combined filter performance:

- Do the studies cited here support awarding 0.5 log credit for $\text{CFE} \leq 0.15$ NTU 95% of the time?
- Does currently available turbidity monitoring technology accurately distinguish differences between values measured near 0.15 NTU?

9. Roughing Filter

a. *What is EPA proposing today?* The Stage 2 M-DBP Agreement in Principle recommends a 0.5 log presumptive credit towards additional *Cryptosporidium* treatment requirements for roughing filters. However, the Agreement further specifies that EPA is to determine the design and implementation criteria under which the credit would be awarded. Upon subsequent review of available literature, EPA is unable to identify design and implementation conditions for roughing filters that would provide reasonable assurance of achieving a 0.5 log removal of oocysts. Consequently, EPA is not proposing presumptive credit for *Cryptosporidium* removal by roughing filters. Today's proposal does, though, include a 0.5 log credit for a second granular media filter following coagulation and primary filtration (see section IV.C.13).

b. *How was this proposal developed?* Roughing filtration is a technique used primarily in developing countries to remove solids from high turbidity source waters prior to treatment with slow sand filters. Typically, roughing filters consist of a series of sedimentation tanks filled with progressively smaller diameter media in the direction of flow. The media can be gravel, plastic, crushed coconut, rice husks, or a similar locally available material. The flow direction in roughing filters can be either horizontal or vertical, and vertical roughing filters can be either upflow or downflow. The media in the tanks effectively reduce the

vertical settling distance of particles to a distance of a few millimeters. As sediment builds on the media, it eventually sloughs off and begins to accumulate in the lower section of the filter, while simultaneously regenerating the upper portions of the filter. The filters require periodic cleaning to remove the collected silt.

Review of the scientific and technical literature pertaining to roughing filters has identified no information on removal of *Cryptosporidium*. Information is available on removal of suspended solids, turbidity, particles, fecal coliforms and some algae, but none of these has been demonstrated to be an indicator of *Cryptosporidium* removal by roughing filters. Moreover, roughing filters are not preceded by a coagulation step, and studies have found that some potential surrogates, such as aerobic spores, are not conservative indicators of *Cryptosporidium* removal by filtration when a coagulant is not present (Yates *et al.* 1998, Dugan *et al.* 2001). Thus, it is unclear how to relate results from studies of the removal of other particles by roughing filters to potential removal of *Cryptosporidium*.

In addition, some studies have observed very poor removal of *Cryptosporidium* by rapid sand filters when a coagulant is not used (Patania *et al.* 1995, Huck *et al.* 2000). Based on these findings, it is expected that there would be situations where a roughing filter would not achieve 0.5 log *Cryptosporidium* removal. Because available data are insufficient to determine the conditions that would be necessary for a roughing filter to achieve 0.5 log *Cryptosporidium* removal, EPA is unable to propose this credit. The following discussion describes four studies that analyzed the effectiveness of roughing filters for removing solids, turbidity, particles, fecal coliforms, and algae.

Wegelin *et al.* (1987) conducted pilot-scale studies on the use of horizontal roughing filters to reduce solids, turbidity, and particles. Testing was performed to determine the influence of different design parameters on filter performance. Data from the parameter testing was used to establish an empirical model to simulate filtrate quality as a function of filter length and time for a given filter configuration. Using the mathematical model, the researchers found that long filters (10 m) at low filtration rates (0.5 m/h) were capable of reducing high suspended solids concentrations (1000 mg/L TSS) down to less than 3 mg/L.

Further work by Wegelin (1988) evaluated roughing filters as pretreatment for slow sand filters for