

the IESWTR achieve an average of 3 log *Cryptosporidium* removal. The following discussion illustrates why EPA believes that available data support this estimate.

While *Cryptosporidium* removal at full scale plants is difficult to quantify due to limitations with analytical methods, pilot scale studies show that reductions in aerobic spores and total particle counts are often conservative indicators of filtration plant removal efficiency for *Cryptosporidium* (Dugan *et al.* 2001, McTigue *et al.* 1998, Yates *et al.* 1998, Emelko *et al.* 1999 and 2000). Surveys of full scale plants have reported average reductions near 3 log for both aerobic spores (Niemiński and Bellamy, 2000) and total particle counts (McTigue *et al.* 1998). Consequently, these findings are consistent with an estimate that average removal of *Cryptosporidium* by filtration plants is approximately 3 log.

Pilot scale *Cryptosporidium* spiking studies (Dugan *et al.* 2001, Huck *et al.* 2000, Emelko *et al.* 2000, McTigue *et al.* 1998, Patania *et al.* 1995) suggest that a conventional treatment plant has the potential to achieve greater than 5 log removal of *Cryptosporidium* under optimal conditions. However, these high removals are typically observed at very low filter effluent turbidity values, and the data show that removal efficiency can decrease substantially over the course of a filtration cycle or if coagulation is not optimized (Dugan *et al.* 2001, Huck *et al.* 2000, Emelko *et al.* 2000, Harrington *et al.* 2001). Removal efficiency also appears to be impacted by source water quality (Dugan *et al.* 2001, McTigue *et al.* 1998). Given these considerations, EPA believes that 3 log is a reasonable estimate of average *Cryptosporidium* removal efficiency for conventional treatment plants in compliance with the IESWTR or LT1ESWTR.

The Stage 2 M-DBP Advisory Committee did not address direct filtration plants, which lack the sedimentation basin of a conventional treatment train, but recommended that EPA address these plants in the LT2ESWTR proposal (65 FR 83015, December 29, 2000) (USEPA 2000a). While some studies have observed similar levels of *Cryptosporidium* removal in direct and conventional filtration plants (Niemiński and Ongerth, 1995, Ongerth and Pecoraro 1995), EPA has concluded that the majority of available data support a lower estimate of *Cryptosporidium* removal efficiency for direct filtration plants.

As described in section IV.C.5, pilot and full scale studies demonstrate that

sedimentation basins, which are absent in direct filtration, can achieve 0.5 log or greater *Cryptosporidium* reduction (Dugan *et al.* 2001, Patania *et al.* 1995, Edzwald and Kelly 1998, Payment and Franco 1993, Kelley *et al.* 1995). In addition, Patania *et al.* (1995) observed direct filtration to achieve less *Cryptosporidium* removal than conventional treatment, and McTigue *et al.* (1998) found a higher incidence of *Cryptosporidium* in the treated water of direct filtration plants. Given these findings, EPA has estimated that direct filtration plants achieve an average of 2.5 log *Cryptosporidium* reduction (*i.e.*, 0.5 log less than conventional treatment).

i. Dissolved air flotation. Dissolved air flotation (DAF) is a solid-liquid separation process that can be used in conventional treatment trains in place of gravity sedimentation. DAF takes advantage of the buoyancy of oocysts by floating oocyst/particle complexes to the surface for removal. In DAF, air is dissolved in pressurized water, which is then released into a flotation tank containing flocculated particles. As the water enters the tank, the dissolved air forms small bubbles that collide with and attach to floc particles and float to the surface (Gregory and Zabel, 1990).

In comparing DAF with gravity sedimentation, Plummer *et al.* (1995) observed up to 0.81 log removal of oocysts in the gravity sedimentation process, while DAF achieved 0.38 to 3.7 log removal, depending on coagulant dose. Edzwald and Kelley (1998) demonstrated a 3 log removal of oocysts using DAF, compared with a 1 log removal using gravity sedimentation in the clarification process before filtration. In bench scale testing by Harrington *et al.* (2001), DAF averaged 0.5 log higher removal of *Cryptosporidium* than gravity sedimentation. Based on these results, EPA has concluded that a treatment plant using DAF plus filtration can achieve levels of *Cryptosporidium* removal equivalent to or greater than a conventional treatment plant with gravity sedimentation.

b. *Slow sand filtration.* Slow sand filtration is a process involving passage of raw water through a bed of sand at low velocity (generally less than 0.4 m/h) resulting in substantial particulate removal by physical and biological mechanisms. For the LT2ESWTR proposal, EPA has reviewed two additional studies of slow sand filtration.

Fogel *et al.* (1993) evaluated removal efficiencies for *Cryptosporidium* and *Giardia* with a full scale slow sand filtration plant. The removals ranged

from 0.1–0.5 log for *Cryptosporidium* and 0.9–1.4 log for *Giardia*. Raw water turbidity ranged from 1.3 to 1.6 NTU and decreased to 0.35–0.31 NTU after filtration. The authors attributed the low *Cryptosporidium* and *Giardia* removals to the relatively poor grade of filter media and lower water temperature. The sand had a higher uniformity coefficient than recommended by design standards. This creates larger pore spaces within the filter bed that retard biological removal capacity. Lower water temperatures (1 °C) also decreased biological activity in the filter media.

Hall *et al.* (1994) examined the removal of *Cryptosporidium* with a pilot scale slow sand filtration plant. *Cryptosporidium* removals ranged from 2.8 to 4.3 log after filter maturation, with an average of 3.8 log (at least one week after filter scraping). Raw water turbidity ranged from 3.0 NTU to 7.5 NTU for three of four runs and 15.0 NTU for a fourth run. Filtered water turbidity was 0.2 to 0.4 NTU, except for the fourth run which had 2.5 NTU filtered water turbidity. This study also included an investigation of *Cryptosporidium* removal during filter start-up where the filtration rate was slowly increased over a 4 day period. Results indicate that filter ripening did not appear to affect *Cryptosporidium* removal.

The study by Fogel *et al.* is significant because it indicates that a slow sand filtration plant may achieve less than 2 log removal of *Cryptosporidium* removal while being in compliance with the effluent turbidity requirements of the IESWTR and LT1ESWTR. The authors attributed this poor performance to the filter being improperly designed, which, if correct, illustrates the importance of proper design for removal efficiency in slow sand filters. In contrast, the study by Hall *et al.* (1994) supports other work (Schuler and Ghosh 1991, Timms *et al.* 1995) in finding that slow sand filtration can achieve *Cryptosporidium* removal greater than 3 log. Overall, this body of work appears to show that slow sand filtration has the potential to achieve *Cryptosporidium* removal efficiencies similar to that of a conventional plant, but proper design and operation are critical to realizing treatment goals.

c. *Diatomaceous earth filtration.* Diatomaceous earth filtration is a process in which a precoat cake of filter media is deposited on a support membrane and additional filter media is continuously added to the feed water to maintain the permeability of the filter cake. Since the IESWTR and LT1ESWTR, EPA has reviewed one new study of DE filtration (Ongerth and Hutton 2001). It supports the findings of