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Project Summary

Filtration of *Giardia* Cysts and Other Substances Volume 1: Diatomaceous Earth Filtration

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How effective is filtering drinking water through diatomaceous earth to remove *Giardia lamblia* cysts, total coliform bacteria, standard plate count bacteria, turbidity, and particles? We evaluated the process for a range of operating conditions and simulated ambient conditions. Hydraulic loading rates imposed were 2.44, 4.88, and 9.76 m/hr (1, 2, and 4 gpm/ft^2). Seven grades of diatomaceous earth were used. Temperatures were from 5° to 19°C; concentrations of *Giardia* cysts ranged from 50 to 5000 cysts/L; and bacteria densities were varied from 100 to 10,000/100 mL.

The results of this study showed that diatomaceous earth filtration is an effective process for water treatment. *Giardia* cyst removals were greater than 99.9 percent for all grades of diatomaceous earth tested, for hydraulic loading rates of 2.44 to 9.76 m/hr, and for all temperatures tested. Percent reduction in total coliform bacteria, standard plate count bacteria, and turbidity are influenced strongly by the grade of diatomaceous earth used. The coarsest grades of diatomaceous earth recommended for water treatment (e.g., C-545®)* will remove greater than 99.9 percent of *Giardia* cysts, 95 percent of cyst-sized particles, 20 to 35 percent of coliform bacteria, 40 to 70 percent of heterotrophic bacteria, and 12 to 16 percent of the turbidity from Horsetooth Reservoir water. The use of the finest grade of diatomaceous earth (i.e., Filter-Cel®), or alum coating on the coarse grades, will increase the effectiveness of the process, resulting in 99.9 percent removals of bacteria and 98 percent removals of turbidity.

This Project Summary was developed by EPA's Municipal Environmental Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

Introduction

This study was conducted at Colorado State University under a cooperative agreement with the U.S. Environmental Protection Agency (EPA) to determine the effectiveness of diatomaceous earth filtration for removal of *Giardia* cysts. At the same time, removals of turbidity, total coliform bacteria, standard plate count bacteria, and particles were determined. Operating conditions examined included the grade of diatomaceous earth, hydraulic loading rates, influent concentrations of bacteria and *Giardia* cysts, head loss, run time, temperature, and the use of alum-coated diatomaceous earth.

Giardia lamblia is a protozoan prevalent in the clear, cool waters characteristic of the Rocky Mountain region. This organism causes giardiasis, a harmful but nonfatal intestinal disease. Many communities use water from these Rocky Mountain streams, which are considered pristine pure because they look aesthetically pleasing and will meet the 1-NTU turbidity water quality standard. How to treat these waters has become an important concern over the last few years as outbreaks of giardiasis have occurred. Economical and effective filtration systems are needed to remove *Giardia* cysts. Designs appropriate for small water systems are particularly needed.

Diatomaceous earth filtration was introduced in 1942 as a technology for water treatment. The process was adopted by the U.S. Army for field use in 1944 after being shown effective for removal of *Endamoeba histolytica* cysts.The basic principles of the process were outlined in the 1940's and 1950's, and further studies were made in the 1960's.

The diatomaceous earth filtration process consists of three basic operations: (1) precoating, (2) filtering, and (3) cleaning. In precoating, an initial filter cake consisting of a 3- to 5-mm layer of powder-sized diatomaceous earth filter medium is applied to a support membrane called a septum. The cake is applied by circulating flow from the precoat tank through the filter, causing the slurried diatomaceous earth to be deposited on the filter septum. In filtering,the second step of the process, raw water combined with bodyfeed passes through the filter cake. The bodyfeed consists of a filter medium slurry metered into the raw water stream during filtration. The continuous addition of bodyfeed maintains the filter cake permeability. In the third operation, cleaning, the filter cake is removed from the septum and discarded.

Operating parameters for diatomaceous earth filtration include the grade of diatomaceous earth (a commercial designation of particle size), hydraulic loading rate, precoat thickness, bodyfeed concentration, terminal headloss, and run time. Chemical coating of the diatomaceous earth may be used under some circumstances to improve removal effectiveness.

The protozoan *Giardia lamblia* is of interest because it causes giardiasis. This organism has been identified as a pathogen only recently. Giardiasis is considered a serious problem in mountainous and forested regions of the United States where the organism is endemic; the *Giardia* cysts shed by dogs, humans, and animals, such as the beaver, are believed to be of the *Giardia lamblia* species.

The *Giardia lamblia* trophozoite (Figure 1a) can reside in the intestine of a variety of warm-blooded animals. The cyst (Figure 1b) is the form shed and transmitted. An infected person may shed up to 900 million cysts per day. The cyst form of the organism is hardy and may remain viable for a long period (2 months, for example), particularly in cold water. Infection is caused by ingestion; an infective dose may be from 1 to 10 cysts and the incubation period is 1 to 2 weeks. A surface water supply source is a vehicle for cyst transmission.

Materials and Methods

Design of Tests

The objective of the experimental program was to evaluate the removal effectiveness of diatomaceous earth filtration for the dependent variables (*Giardia* cysts, total coliform bacteria, standard plate count bacteria, turbidity, particle counts, and headloss) as a function of the independent variables (grade of diatomaceous earth, run time, headloss, hydraulic loading rate, temperature, influent coliform concentration, and alum coating). This was achieved by changing a given independent variable over a range of magnitudes and observing the effect on the filtration performance (i.e., the dependent variables).

Tests were terminated either at the predetermined head loss across the septum of 40 psi, or after a given period of operating time. The precoat application was established at 1 kg/m^2 (0.2 lb/ft^2) for all tests. The bodyfeed concentration was established by using successive concentrations until a linear headloss versus time relationship was found.

The pilot plant was used mostly in the laboratory, but final confirming tests were conducted in the field. The filter, the main element of the system (Figure 2), consisted of a 1-ft^2 septum enclosed in a pressure housing. The septum used in this work was stainless steel wire mesh of 110 x 24 wires per in.^{2}. The operations were controlled by the ancillary pumps, valves, and gauges.

Experimental Procedures

Giardia testing began with the processing of *Giardia* cysts from dog fecal samples. The processing consisted of adding the infected feces to distilled water, straining the feces and then making a count of cysts in the fecal concentrate.

A known concentration of the *Giardia* concentrate was then added to a 1400-L filter feed tank. This tank was a modified milk cooler that could be maintained at 2 to 15 ± 1°C. The filter feed tank was filled with Horsetooth Reservoir water and cooled before the addition of the cysts. Primary settled sewage was added also to increase the concentration of total coliform bacteria.

Preparation for a test run began with the precoat step. After precoating, 10 mg/L chlorine was added for disinfection, and the recycle of precoat water was continued for 10 min The chlorine was purged by operating in the filtering mode for 30 min Sampling was started after the 30-min washout period.

Samples were obtained from the filter feed tank and from the effluent side of the filter for measurements of turbidity, particle counts, total coliform bacteria, standard plate count bacteria, and

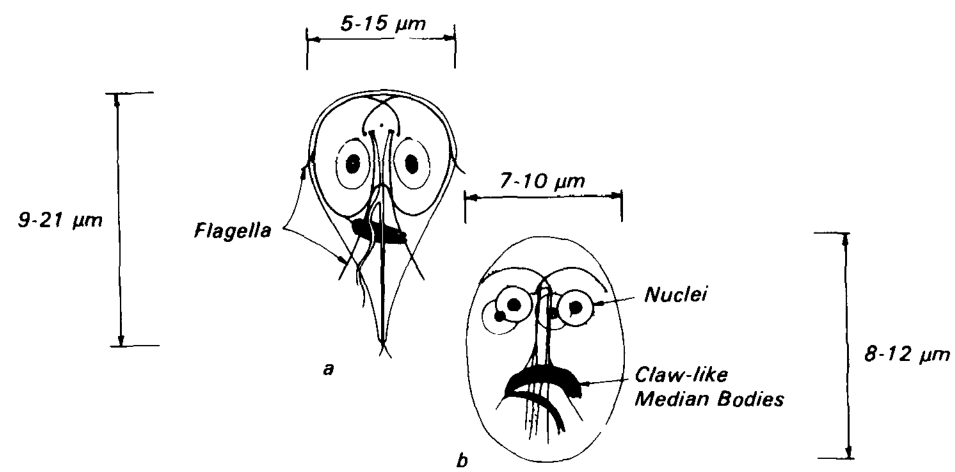

Figure 1. Sketches of a) trophozoite and b) cyst stages of Giardia lamblia *(Jakubowski and Hoff, 1979).*

Giardia cysts. Grab samples were collected for all parameters except *Giardia* cysts. Other measurements included elapsed time from beginning of run, headloss, hydraulic loading rate, and water temperature.

The *Giardia* cyst sampling technique used a 142-mm-diameter polycarbonate membrane filter with a 5- μm pore size to remove and concentrate the cysts from the sampled water. After the sample was concentrated, the membrane filter was washed and the wash water was analyzed for cysts by microscopic counting. The influent water in the filter feed tank and the diatomaceous earth effluent were both sampled for *Giardia* cysts in this manner. The influent sample volume ranged between 2 and 10 L, and the effluent sample volume ranged between 86 and 174/L.

Field tests to verify laboratory findings were conducted in April and May 1983. The April test used raw water from the Cache La Poudre River, and the May tests used water from Straight Creek and Laskey Creek at the Dillon, Colorado water treatment plant.

Leak Testing

During the initial phases of experimentation, the need to determine whether a leak was present in the filter septum or its manifold became apparent. Thus a technique was developed to test for leaks. First the filter was precoated with 2 kg/m^2 of the finest grade of diatomaceous earth, Filter Cel. This grade was determined to be capable of removing 100 percent of the applied coliform bacteria. Then the filter was operated at 1 gpm/ft^2 for 1 hr with a high influent coliform concentration. If any coliforms were detected in the effluent, the equipment was assumed to have a mechanical problem resulting in a leak, and the problem was corrected. This technique was used as a quality control measure throughout all testing.

Results

The diatomaceous earth filtration process was found to be effective for removing *Giardia* cysts under virtually all operating conditions tested No cysts were detected in the filter effluent when normal water treatment practices were simulated. Note, however, that removals of bacteria, turbidity, and particles in the 6.35-μm to 12.67-μm size range were functionally dependent on: (1) grade of diatomaceous earth, (2) use of chemicals, (3) hydraulic loading rate, and (4) influent concentrations.

Overall Process Effectiveness

Giardia cyst removals were greater than 99.9 percent, regardless of grade of diatomaceous earth, filtration rate, temperature, duration of test, or influent concentration of *Giardia* cysts (when cysts are fewer than 10,000/L). The single breakthrough occurred at a high influent concentration of 33,600 cysts/L.

Figure 3 illustrates the uniformly high removals of *Giardia* cysts. Testing was done only for the water treatment grades, since removals would have been at least as much for the finer grades.

The grade of diatomaceous earth was not a factor in removal of *Giardia* cysts, even with grades C-545 and C-535. These grades create a filter cake with reported median pore sizes of 17 and 13 μm, respectively, which are larger than *Giardia* cysts. However, many pores were apparently smaller than the cysts and blocked their passage.

Removal of coliform bacteria, standard plate count bacteria and turbidity approached 100 percent for the smallest grades of diatomaceous earth and fell below 40 percent for the coarsest grades (Figure 3). Removals of total coliforms and standard plate count bacteria would follow this trend regardless of the water source. Turbidity removal, however,

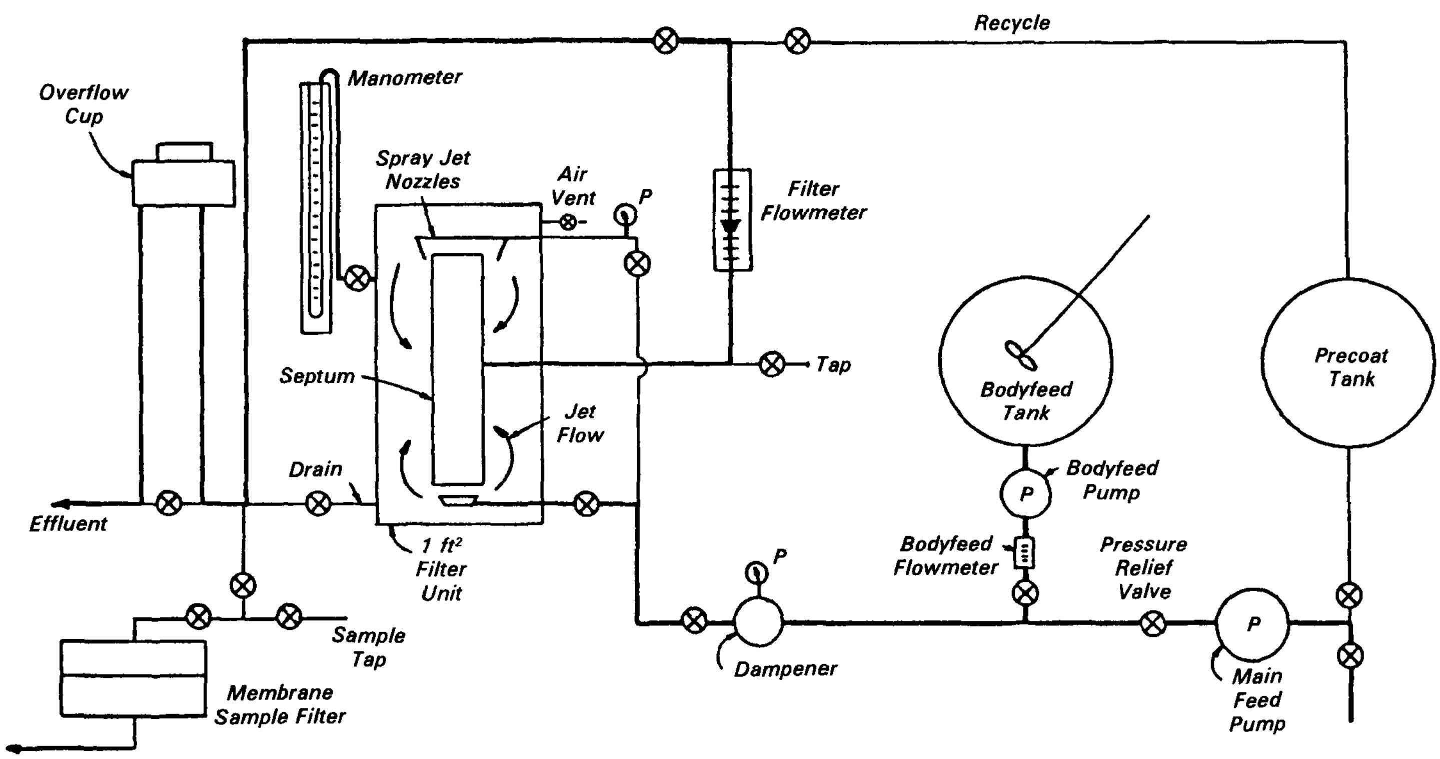

Figure 2. *Layout of diatomaceous earth filtration pilot plant.*

would depend on the size of the particles making up the turbidity; improved removal would result if the turbidity consisted of larger particles.

Effects of Operating Conditions on Removals

Operating conditions examined include grade of diatomaceous earth, hydraulic loading rate, *Giardia* cyst concentration, bacteria concentration, temperature, duration of filtration run, and alum coating of the diatomaceous earth. The influence of each condition on removals of turbidity, bacteria, *Giardia* cysts, and particles is reported in the following paragraphs.

Grade of Diatomaceous Earth

As mentioned earlier, removals of *Giardia* cysts are greater than 99.9 percent for all earth tested, but removals of turbidity, standard plate count bacteria, and total coliform bacteria are strongly influenced by grade Removals of particles in the 6.35- to 12.67-μm size range were uniformly high (87 to 94 percent) for the water treatment grades of diatomaceous earth, thus indicating no correlation of particle removal to grade.

Hydraulic Loading Rate

Some scatter occurs in the data on the effects of hydraulic loading on removals of particles, standard plate count bacteria, coliform bacteria, and turbidity; but the trends are toward declining removals with increasing hydraulic loading rate. Percent removals of total coliform bacteria were affected the most, standard plate count bacteria declined nominally, and particles and turbidity were affected only moderately. The fine clays constituting most of the raw water turbidity passed readily through the C-503 and C-545 diatomaceous earth grades at all hydraulic loading rates. Hydraulic loading rate had no detectable influence on removal of *Giardia* cysts, since all but one test resulted in complete removal of the influent cysts. Because the cysts are larger than some of the pores in the filter cake (which vary statistically), they will be blocked by some pore as they are convected by the flow within the cake.

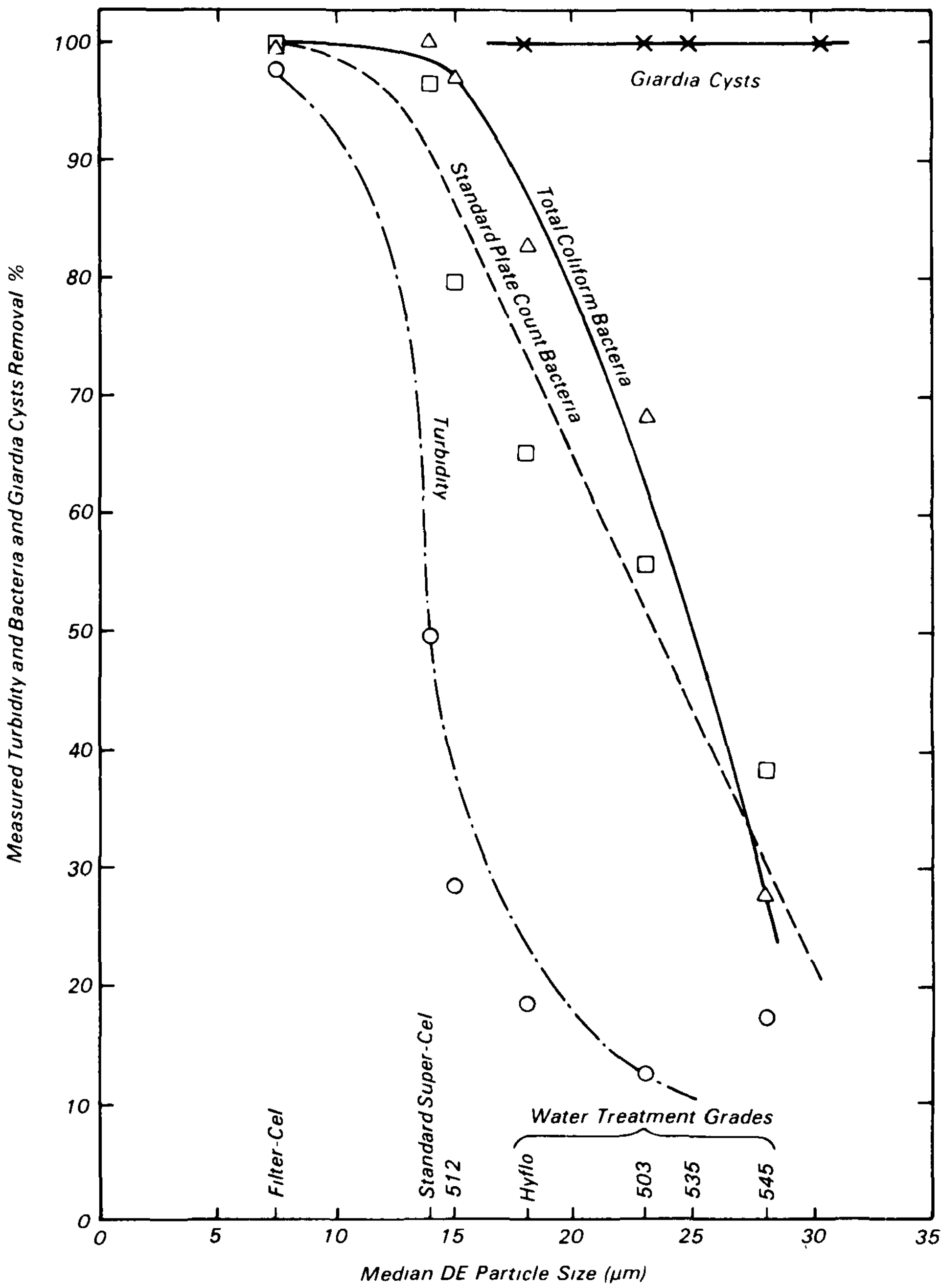

Figure 3. *Removals of turbidity, bacteria, and* Giardia *cysts for different grades of diatomaceous earth Turbidity and bacteria data points represent avaerages for six 5-hr test runs* Giardia *cyst data are averages for 32 test runs of various durations*

Giardia Cyst Concentrations

No discernible relationship existed between the *Giardia* cyst influent concentration and cyst removal. Influent *Giardia* cyst concentrations ranged from 500 to 10,000 cysts/L, with one exception of 33,600 cysts/L. Only for the latter case were cysts detected in the effluent stream. This result indicates that *Giardia* removal for expected ambient influent concentrations will be virtually 100 percent.

Bacteria Concentration and Turbidity

The influent concentration of total coliforms has a stronger influence on removals for the water treatment grades of diatomaceous earth than for the finer grades. This phenomenon is reasonable, since the finer grades can completely strain coliform bacteria.

Turbidity did not vary enough in the waters tested to determine whether a relationship existed between influent levels of bacteria and their removal. For the laboratory tests with Horsetooth Reservoir water, the influent turbidity levels ranged only between 4.5 and 5.4 NTU.

Most turbidity in Horsetooth water was caused by particles smaller than 1 μm. Consequently, a 1-NTU turbidity standard could be attained only with the finest grade of diatomaceous earth or by using alum-coated diatomaceous earth. Removals of coliform bacteria were therefore higher, since they were larger than much of the turbidity. The small turbidity particles found in Horsetooth Reservoir are not necessarily characteristic of all waters, since many sources have been treated to meet a 1-NTU standard with water treatment grades of diatomaceous earth and without chemicals.

Temperature

Water temperature did not appear to affect any of the parameters measured. Because the removal process in diatomaceous earth filtration is physical, slightly poorer removals might be expected at lower temperatures because shear forces are higher. This possible effect was not noticeable, however, since it was masked by the significant changes in removal caused by variations in influent concentration and flow rate.

Alum Coating

Alum-coated diatomaceous earth removed significantly more total coliform bacteria, standard plate count bacteria, and turbidity than did the uncoated diatomaceous earth. Coarse grades of diatomaceous earth were used (e.g., C-545 and C-503), and both the precoat and bodyfeed were coated while in slurry form. Removals of total coliform bacteria ranged from 96 to 99.9 percent compared with 30 to 70 percent without alum coating. Removals of standard plate count bacteria ranged from 79 to 99.5 percent compared with 38 to 56 percent without alum coating. Turbidity removals ranged from 66 to 99 percent compared with 11 to 17 percent without alum coating. These results demonstrate a marked improvement in treatment with alum coating and illustrate how diatomaceous earth filtration can be applied in otherwise marginal situations.

Note, however, that not all water sources can be treated to a 1-NTU standard with the normal water treatment grades of diatomaceous earth. To obtain a 1-NTU effluent for these special cases, the advantages of alum coating must be weighed against using a finer grade of diatomaceous earth. Both techniques will reach the desired goal, but only pilot plant studies and economic considerations will determine which approach should be taken.

Field Testing

Field tests were conducted to confirm the laboratory results. Water was obtained from the Cache La Poudre River and from the raw water intake at the Dillon water treatment plant. Turbidity conditions were about 4 NTU for tests conducted April 17, 1983, at the Cache La Poudre River, and about 0.6 NTU for the May 1983 tests at Dillon. Despite the use of these different water sources, no *Giardia* cysts were detected in any filtered water samples. Removals of turbidity, total coliform bacteria, and total plate count bacteria were all consistent with laboratory results.

Conclusions

1. Diatomaceous earth filtration is virtually 100 percent effective in *Giardia* cyst removal for all grades of diatomaceous earth over a wide range of conditions.

2. Grade of diatomaceous earth is the most important factor in the removal of bacteria and turbidity. Removals effected by coarse and fine grades were, respectively, 17 and 98 percent for turbidity, 28 and 99.9 percent for coliform bacteria, and 38 and 99.8 percent for standard plate count bacteria.

3. Increasing the hydraulic loading rate causes a decrease in removals of bacteria and turbidity for the water treatment grades of diatomaceous earth. The effect was strongest for coliform bacteria and weakest for turbidity. Hydraulic loading rate showed no effect on the removal of *Giardia* cysts.

4. Water temperature did not influence the effectiveness of diatomaceous earth filtration, as demonstrated by testing over the range of 3.5° to 15°C. The results are not, however, conclusive.

5. Bacteria removal decreased with increased influent concentrations of bacteria, especially for the coarser grades of diatomaceous earth. A three-log increase in influent coliforms reduced removals from 77 to 39 percent for C-545; but for C-512, a two-log increase in coliforms reduced removals only from 96 to 92 percent.

6. Bacteria removals decreased slightly with increasing filtration time--from 87 to 79 percent in 5.5 hr for C-503 and from >99.98 to 99.92 percent for Standard Super-Cel.

7. Alum-coated diatomaceous earth filtration removed significantly more turbidity and bacteria than diatomaceous earth filtration with no alum. The use of alum coating increased removals from 17 to 99 percent for turbidity, from 30 to 96 percent for total coliform bacteria, and from 56 to 99.5 percent for standard plate count bacteria.

8. Increased removals of turbidity and bacteria can be accomplished either by chemically coating the diatomaceous earth or by using a smaller grade.

9. Field testing with two different raw waters yielded the same results as laboratory tests.

10. Pilot-plant testing should be done before implementing any full-scale application of diatomaceous earth filtration. Applicability, design criteria, and operating conditions cannot be determined without pilot tests.

11. Periodically, a diatomaceous earth filtration system should be checked for leaks by applying Filter-Cel and then filtering a coliform-contaminated water. In production of potable water, this should be done only as a part of a routine performance evaluation program in which careful controls are set up to ensure that a cross connection is not possible.

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The complete report, entitled "Filtration of Giardia *Cysts and Other Substances: Volume 1: Diatomaceous Earth Filtration," (Order No. PB 84-212 703; Cost: $19.00, subject to change) will be available only from:*
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