Operational Control of Coagulation and Filtration Processes

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Third Edition

American Water Works Association

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Operational Control of Coagulation and Filtration Processes

AWWA Publications Manager: Gay Porter De Nileon
Project Manager: Martha Ripley Gray
Cover Art: Cheryl Armstrong
Production: Darice Zimmermann, Zimm Services; George Zirfas, CDA
Manuals Specialists: Molly Beach, Beth Behner

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Authors of M37 include:

Chapter 1:	Kwok-Keung (Amos) Au, Greeley and Hansen, Chicago, Ill.; Scott M. Alpert, Hazen and Sawyer, Charlotte, N.C.; David J. Pernitsky, CH2M HILL, Calgary, Alta.
Chapter 2:	Susan Teefy, Water Quality & Treatment Solutions Inc., Castro Valley, Calif.; James Farmerie, ITT Water & Wastewater, Zelienople, Pa.; Elizabeth Pyles, Orica Watercare Inc., Dry Ridge, Ky.
Chapter 3:	Robert Bryant, Chemtrac Systems Inc., Norcross, Ga.; Michael Sadar, Hach Company, Loveland, Colo.; David J. Pernitsky, CH2M HILL, Calgary, Alta.
Chapter 4:	George Budd, Black & Veatch, Harborton, Va.; James Farmerie, ITT Water & Wastewater Products, Zelienople, Pa.; Paul Hargette, Black & Veatch, Greenville, S.C.
Chapter 5:	Kevin Castro, GHD Inc., Cazenovia, N.Y.; Rasheed Ahmad, Department of Watershed Management, City of Atlanta, Atlanta, Ga.
Chapter 6:	Orren Schneider, American Water, Voorhees, N.J.; James Farmerie, ITT Water & Wastewater, Zelienople, Pa.; Gary Logsdon, Consultant, Lake Ann, Mich.
Chapter 7:	A compilation of case studies with authorship of each case study listed
Case Study 1:	George Budd, Black & Veatch, Harborton, Va.; George Duval, Chesterfield County, Va., Midlothian, Va.
Case Study 2:	George Budd, Black & Veatch, Harborton, Va.; Paul Hargette, Black & Veatch, Greenville, S.C.
Case Study 3:	George Budd, Black & Veatch, Harborton, Va.; Paul Hargette, Black & Veatch, Greenville, S.C.; Bill Brewer, Winston-Salem/Forsyth County, City/County Utilities, Winston-Salem, N.C.

Case Study 4: Tom Elford, City of Calgary, Calgary, Alta.; David J. Pernitsky, CH2M HILL, Calgary, Alta.
Case Study 5: David Teasdale, City of Kamloops, Kamloops, B.C.
Case Study 6: Michael Sadar, Hach Company, Loveland, Colo.
Case Study 7: Michael Sadar, Hach Company, Loveland, Colo.
Case Study 8: Robert D. Cummings, Clackamas River Water, Clackamas, Ore.
Case Study 9: Tim McAleer, Palm Beach County Water Utilities, Palm Beach, Fla.; Jose Gonzalez, PVS Technologies, Detroit, Mich.

This manual was approved by the AWWA Coagulation and Filtration Committee. Members of the committee at the time of approval of this third edition were as follows:

R. Ahmad, City of Atlanta, Department of Watershed Management, Alpharetta, Ga.
S. Alpert, HDR Engineering Inc., Charlotte, N.C.
A. Au, Greeley and Hansen, Chicago, Ill.
R. Brown, EE&T, Newport News, Va.
B. Bryant, Chemtrac, Norcross, Ga.
G. Budd, Black & Veatch, Harborton, Va.
K. Castro, GHD, Cazenovia, N.Y.
S. Clark, HDR Engineering Inc., Denver, Colo.
K. Comstock, Brown & Caldwell, Atlanta, Ga.
S. Crawford, CDM, Dallas, Texas
J. Farmerie, ITT Leopold, Zelienople, Pa.
T. Getting, ITT Leopold, Zelienople, Pa.
J. Gonzales, PVS Technologies, South New Berlin, N.Y.
S. Hardy, Hazen & Sawyer, Atlanta, Ga.
P. Hargette, Black & Veatch, Greenville, S.C.
E. Harrington, AWWA Staff Advisor, Denver, Colo.
C. Johnson, CH2M HILL, Orlando, Fla.
W. O'Neil, CDM, Carlsbad, Calif.
D. Pernitsky, CH2M HILL, Calgary, Alta.
J. Pressman, USEPA, Cincinnati, Ohio
E. Pyles, Orica Watercare Inc., Dry Ridge, Ky.
M. Sadar, Hach Company, Loveland. Colo.
O. Schneider, American Water, Voorhees, N.J.
S. Teefy, Water Quality & Treatment Solutions, Castro Valley, Calif.

Introduction

The first successful practice of water filtration in the United States involved use of slow sand filters in which raw water was applied directly to large sand beds, but these filters were not suitable for treatment of muddy river waters like those found in the Ohio, Mississippi, and Missouri River valleys and their tributaries. In the 1890s and very early 1900s, George Fuller's filtration tests in Louisville and Cincinnati and Alan Hazen's testing program in Pittsburgh showed that turbid waters could be treated successfully by addition of coagulant chemical, clarification, and rapid sand filtration. The capability of a process train consisting of coagulation, mixing, flocculation, sedimentation, and rapid sand filtration to treat raw water having a wide range of turbidity resulted in widespread acceptance of this process train, which came to be called conventional treatment in the United States. Adoption of conventional treatment by a large number of water systems and of chlorination by even more water systems resulted in a very large decrease in the number of cases and number of deaths caused by typhoid fever in the early decades of the twentieth century.

Prior to World War II the focus on water treatment was on disinfecting water and providing clear water to drink. Coagulation and filtration had been shown to remove a substantial fraction of bacteria from water, and combined with chlorination, conventional treatment provided a double barrier against passage of pathogenic bacteria into drinking water. With the realization that viruses also could be transmitted by drinking water, the microbiological challenge broadened. Conventional treatment was found to be capable of removal of polioviruses in the 1960s, and in the 1980s and 1990s removal of protozoan cysts was shown to be within the capabilities of coagulation and filtration when these processes are managed properly. Results of studies on removal of asbestos fibers by coagulation and filtration proved that this process could remove both microbes and inorganic particles in a very wide range of sizes, from considerably less than 1 µm to tens of µm.

Regulatory requirements related to turbidity of filtered water have become more stringent over the decades, but regardless of the regulatory requirement, the drinking water industry has been able to look to some water systems that set their own goals for filtered water turbidity that were considerably more stringent than those set by regulators. This continues to be the case, as at some filtration plants the operating goal is to produce filtered water turbidity of 0.1 ntu or lower. The Partnership for Safe Water encourages the approach of continually striving to improve filtered water quality. Research for removal of viruses, bacteria, protozoan cysts, and asbestos fibers supports the concept that attaining very low filtered water turbidity is an effective means of consistently attaining the best removal of particulate contaminants. Employing proper coagulation chemistry is fundamental to successful filtration for controlling particulate contaminants.

In addition to playing such an important role in removal of particles in granular media filtration, coagulation also has had other important applications, and new ones are being identified. For precipitative lime softening plants that do not soften at a high pH and remove magnesium, the calcium carbonate crystals that are precipitated in the softening process carry a negative charge, and use of a positively charged coagulant or polymer aids in effective clarification and filtration. When surface waters are softened in this manner, use of a coagulant is required by the Surface Water Treatment Rule (SWTR). Depending on the nature of natural organic matter (NOM) found in water, chemical coagulation can be effective for removing a substantial fraction of the NOM. Rapid oxidation of reduced iron and arsenic results in floc formation with sorbed arsenic on the iron floc, and this can be an effective approach to arsenic removal. Coagulation has also proven to be useful in pretreatment of some waters for membrane filtration.

With the discovery in the 1970s of the formation of trihalomethanes (THMs) in drinking water because of chlorination, an additional purpose beyond control of turbidity was found for coagulation and filtration. Early studies of THMs indicated that three control strategies could be pursued:

- Change to a disinfectant that did not form trihalomethanes
- Remove NOM that reacts with chlorine to form THMs
- After THMs are formed, treat water to remove them

Treating water to remove THMs generally was not practical, so much of the effort to control these compounds focused on changing to a disinfectant that would not form THMs and removing NOM prior to chlorination. Removing the NOM by applying coagulation and clarification in a more effective manner, combined with delaying the introduction of chlorine into water until after clarification was completed, was shown to be an economical means of lowering the concentration of THMs in some waters. Thus the benefits of effective coagulation and clarification were extended beyond removal of turbidity-causing particles and removal of microorganisms.

With the passage of increasingly stringent regulations on the concentration of disinfection by-products (DBPs) in drinking water, removal of NOM has become a regulation-driven goal for many water utilities that depend upon surface water sources and even for some that treat groundwater. For many utilities, meeting both surface water treatment regulatory requirements for filtered water turbidity and the requirements for DBPs can be challenging. NOM often provides an important contribution to the negative surface charges found on both organic and mineral particles, so the nature of NOM and its concentration in water can have a strong influence on the type and dosage of coagulant needed for optimizing coagulation, clarification, and filtration.

More recently, as the merits of the microfiltration and ultrafiltration processes have been recognized and costs of the process equipment have become more affordable, ways have been sought to extend the use of these processes that simply strain particulate matter out of water but do not remove dissolved constituents. Again chemical coagulation has been recognized as a process that could pretreat water prior to membrane filtration and thus extend the range of water quality that can be treated this way. Coagulation for removal of NOM, when the NOM is susceptible to removal by this technique, has proven to be an excellent pretreatment for use in conjunction with membrane filtration to control both particulate contaminants and organic matter that can serve as the precursor to DBPs.

Coagulation is important for many goals of water treatment, so chapter 1, "Particle and Natural Organic Matter Removal in Drinking Water Treatment," deals extensively with this topic. The influence of NOM on coagulation is explained, along with the role of pH and solubility of metal coagulants.

Determining the appropriate chemical conditions, coagulant, and sometimes polymer dosages for coagulation and flocculation is a necessary step at plants where coagulation is practiced. Chapter 2, "Jar Testing," presents extensive information on procedures for using jar tests to determine the conditions needed for successful treatment full-scale.

Chapter 3, "Online Sensors for Monitoring and Controlling Coagulation and Filtration," was prepared because numerous measurements, both chemical and physical, are needed in water treatment plants on a daily basis. This is especially so for plants treating surface water, as the Surface Water Treatment Rule and its subsequent modifications have imposed a significant regulatory requirement for monitoring. In addition, the quality of some surface waters can change substantially over one working shift, or even more rapidly. To maintain the careful process control over chemical coagulation and subsequent treatment steps, online monitoring devices are available and can greatly reduce the burden on operators who would otherwise have to perform many analytical procedures manually. With the convenience of online monitoring, however, comes the necessity to maintain an excellent quality control program so the operations staff and management know that they can have confidence in the results being obtained from the online instruments. Online monitoring can be especially helpful in plants that employ high-rate clarification processes or direct filtration, as the residence time in such plants is often much shorter than the residence time in conventional water filtration plants. For continuing effective water treatment at plants with shorter residence times, online monitoring is needed to alert operators to any adverse changes in raw or treated water quality so prompt corrective action can be taken or so operators can verify that management of chemical feeds by online instrumentation has been done correctly and treated water quality goals continue to be met.

Treatment of coagulated water to create floc growth and to remove suspended solids by clarification is discussed in chapter 4, "Flocculation and Clarification Processes." Information is presented on a wide range of traditional and newer clarification processes in this chapter.

Even as new applications are found for coagulation, the main purpose for which it is used is to condition water for clarification followed by filtration in rapid rate granular media filters. Even if coagulation is done properly, mismanagement of granular media filters still can result in impaired filtered water quality. In order to optimize filter performance, operators need to understand how to manage tasks such as filter backwashing, returning filters to service, and imposing rate increases on filters. These topics are addressed in chapter 5, "Filtration," along with a discussion of particle removal mechanisms in granular media filters and biological filtration.

Chapter 6, "Pilot Testing for Process Evaluation and Control," presents information for those who are considering undertaking pilot filter column or pilot plant water treatment studies to evaluate process modifications or new treatment approaches on an existing water source or to explore treatment options for a new source of water. This chapter also presents a description of the use of pilot filter columns as an online process control tool for assessing the adequacy of coagulation in the full-scale plant.

Practical examples related to information presented in earlier chapters may be found in chapter 7, "Case Studies." When the topic of a case study in chapter 7 is relevant to text in an earlier chapter, it is mentioned in the earlier chapter.

Even with all of the instrumentation, mechanization, and computerization of operations in water treatment plants, the human factor remains vitally important. In a 1989 Awwa Research Foundation (now Water Research Foundation) report entitled *Design and Operation Guidelines for Optimization of the High-Rate Filtration Process: Plant Survey Results,* John L. Cleasby and his co-authors emphasized the human factor. Among their conclusions about the key factors contributing to successful high-rate filtration resulting in low-turbidity finished water were the following:

1. Management must adopt a low turbidity goal, convince the operators that this is a serious goal to be met, and budget adequate funds for whatever chemical dosages are required to achieve the goal. Chemical pretreatment prior to filtration is more critical to success than the physical facilities at the plant. However, good physical facilities may make achievement of the goal easier and more economical. …

7. Good operator training and the building of operator pride in quality of the treated water are important steps in producing the best filtered water. Some plants utilize 12 hour operating shifts to give more continuity to plant operation, and a short period of shift overlap to provide for intershift communication related to the current treatment strategy.

The advice given by Cleasby and his co-authors is sound. Water treatment plant operators work to produce the drinking water that is supplied to them and their relatives, friends, neighbors, and community in general. The health protection of all in the community is a function of those who operate and oversee water treatment plants. Over the last 100 years or more, the drinking water industry in the United States has made great progress in diminishing health risks related to drinking water. The incidence of waterborne disease is much, much lower than it was in the 1890s, thanks to the many improvements in water treatment that have been implemented in the United States. An important purpose of this manual is to promote the continued improvement in drinking water treatment in future years by providing current information on this topic.

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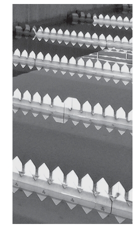

Chapter 1

Particle and Natural Organic Matter Removal in Drinking Water

Kwok-Keung (Amos) Au, Scott M. Alpert, and David J. Pernitsky

INTRODUCTION

One of the most basic processes in the treatment of raw source waters to meet drinking water standards is the solid/liquid separation process to remove particulate material. Particulate material originating in raw water or contributed by addition of treatment chemicals is physically separated from source water during drinking water treatment by clarification and filtration processes. These processes target not only removal of particulate material itself but also contaminants that are associated with the particulate material. Clays, sands, colloids, and so on all may comprise typical particulates to be removed; however, removal of other particle classes, such as microorganisms and particulate forms of natural organic matter (NOM), is beneficial for efficient treatment. Further, other contaminants (e.g., arsenic, iron, manganese, or dissolved NOM) may be associated with particulate matter via coprecipitation, sorption, or other physicochemical mechanisms. Disinfection by-products (DBPs) have been a primary driver for specific focus on NOM removal. In fact, although much research has been devoted to the coagulation of inorganic particles, coagulant dosages for many surface waters are controlled by the NOM concentration rather than by turbidity. During coagulation, dissolved-phase NOM is converted into a solid phase, allowing removal in subsequent clarification/filtration processes. Finally, chemical and/or physical disinfection is also dependent on effective removal of particulate matter that may shield microorganisms from disinfectant contact and/or reduce the effectiveness of disinfection chemicals.