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REMOVING HIGH COLOR OF HUMIC SUBSTANCES OR NEUTRALIZING ACIDITY OF ACID RAIN BY FLOTATION-FILTRATION WATER TREATMENT SYSTEM

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ABSTRACT

This publication paper introduces a highly efficient continuous water purification system consisting of flocculation, dissolved air flotation (DAF) and sand filtration. A continuous pilot plant system consisting of a flocculator, a Krofta Supracell DAF Model SPC-3 and three sand filters was operated at 39.62 to 57.23 m^3/hr (9-13 gallons per minute) for water treatment. DAF was controlled at 33.3 percent recycle water flow, and 0.02832 m^3/hr (1 SCFH) air flow. The three continuous sand filters were packed with 28 cm (11 in) of quartz sand (E = 0.35 mm, U = 1.55) and operated at 6.11 to 8.83 m^3/hr/m^2

(A) The first part of this paper demonstrates the feasibility of a DAF-filtration water treatment system for removal of humic substances and 400 color units from a contaminated water. Trihalomethanes are primarily formed by the reaction of free chlorine with humic substances, such as humic acid and fulvic acid, called trihalomethane precursors. A raw water containing 21.5 mg/L of humic acid, 400 units of color and 9 NTU of turbidity was treated by the continuous pilot plant. Over 94 percent of humic acid, 99 percent of color and 93 percent of turbidity were removed when 9.26 mg/L of alum in terms of Al_2O_3 was dosed as coagulant at pH 6.5.

(B) The second part of this paper demonstrates the feasibility of the same DAF-filtration system skid-mounted on a boat for neutralization of acidity in lake water caused by acid rain. High acidity in lake water is primarily formed by dissolution of industrial air pollutants such as, sulfur dioxide (SO_2), nitrogen oxides (NOx) , etc. which are carried by rains to lake water. Actual acidic lake water from Florida-MA having pH 4.9, color 3.5 units, turbidity 2.8 NTU, acidity 24 mg/L as $CaCO_3$, nitrate nitrogen 0.4 mg/L, phosphate 0.1 mg/L as P, sulfate 70 mg/L and total coliforms 160 /100 mL was treated by the same pilot plant continuously for 5 hours under the same operational conditions but using 4.4 mg/L of sodium aluminate as Al_2O_3 and 3.5 mg/L of calcium hydroxide. It was discovered that DAF alone would be sufficient for acid rain neutralization, but the added filtration step would produce an effluent meeting the drinking water standards in terms of pH, color, turbidity, phosphorus, and coliforms.

KEYWORDS:

Memoir, Water Supply, Water Treatment, Innovation, Process, Chemical Coagulation, Flocculation Flotation, Dissolved Air Flotation, Filtration, Water Pollution, Color, Trihalomethane, Humic Acid, Humic Substances, Disinfection-Byproduct, Industrial Air Pollution, Acid Rain, Sulfur Dioxide, Nitrogen Oxides, High Acidity, Low pH, Coliform, Phosphate, Lake Water Restoration, Neutralization, Sodium Aluminate, Calcium Hydroxide, Mobile Boat Plant, Supracell, Sandfloat, AquaDAF, Clari-DAF.

TABLE OF CONTENTS

NOMENCLATURE

ADT: air dissolving tube

DAF: dissolved air flotation

DBP: disinfection by-products

KEC: Krofta Engineering Corporation

LIWT: Lenox Institute of Water Technology

NOx: and nitrogen oxides

SO_2: sulfur dioxide

THM: trihalomethanes

TTHM: Total trihalomethanes

USEPA: U.S. Environmental Protection Agency

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1. ENVIRONMENTAL PROBLEMS, RESEARCH OBJECTIVES AND SUMMARY

1.1 Environmental Problems of Trihalomethanes and Color

On November 29, 1979, the U.S. Environmental Protection Agency (USEPA) promulgated an amendment to the National Interim Primary Drinking Water Regulations establishing a Maximum Contaminant Level of 0.10 mg/L for "Total Trihalomethanes" (TTHM), which is mainly the arithmetic sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform. Other trihalomethanes (THM) containing fluorine and iodine are not common. The reaction for the formation of THM is shown by Equation 1.:

$$\text{Halogens (F, Cl, Br, I)} + \text{THM Precursors (Humic Substances)}$$
$$= \text{THM} + \text{By-Products} \qquad (1)$$

Since chlorine and bromine are used for water and wastewater disinfection, the trihalomethanes (THM) produced from the disinfection reactions are also called disinfection by-products (DBP), which are cancel-causing substances.

Many toxic organics similar to THM in nature, such as methylene chloride, 1,1 dichloroethylene, 1,1 dichloroethane, 1,2 transdichloroethylene, 1,2 dichloroethane, 1,1,1 trichloroethane, carbon tetrachloride, trichloroethylene, tetrachloroethylene, etc., can also be produced depending on the type of precursors present in water.

Theoretically if the precursors can be removed from water by an appropriate treatment system, no THM can be formed.

1.2 Environmental Problems of Acid Rain and Acidic Lake Water

Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulfuric and/or nitric acid that fall to the ground from the atmosphere in wet or dry forms. Broadly used to include both wet and dry deposition. This can include rain, snow, fog, hail or even dust that is acidic. Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NOx) are emitted into the atmosphere and transported by wind and air currents. The SO_2 and NOx react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground. While a small portion of the SO_2 and NOx that cause acid rain is from natural sources such as volcanoes, most of it comes from the burning of fossil fuels. The major sources of SO_2 and NOx in the atmosphere are: (a) Burning of fossil fuels to generate electricity. Two-thirds of SO_2 and one-fourth of NOx in the atmosphere come from electric power generators. (b) Vehicles and heavy equipment. (c) Manufacturing, oil refineries and other industries. Winds can blow SO_2 and NOx over long distances and across borders making acid rain a problem for everyone and not just those who live close to these sources.[18-20]

The ecological effects of acid rain are most clearly seen in aquatic environments, such as streams, lakes and marshes where it can be harmful to fish and other wildlife. As it flows through the soil, acidic rain water can leach aluminum from soil clay particles and then flow into streams and lakes. The more acid that is introduced to the ecosystem, the more aluminum is released. Some types of plants and animals are able to tolerate acidic waters and moderate amounts of aluminum. Others, however, are acid-sensitive and will be lost as the pH declines. Generally, the young of most species are more sensitive to environmental conditions than adults. At pH 5, most fish eggs cannot hatch. At lower pH levels, some adult fish die. Some acidic lakes have no fish. Even if a species of fish or animal can tolerate moderately acidic water, the animals or plants it eats might not. For example, frogs have a critical pH around 4, but the mayflies they eat are more sensitive and may not survive pH below 5.5. [19]

Walking in acid rain, or even swimming in a lake affected by acid rain, is no more dangerous to humans than walking in normal rain or swimming in non-acidic lakes. However, when the pollutants that cause acid rain — SO_2 and NOx , as well as sulfate and nitrate particles — are in the air, they can be harmful to humans. SO_2 and NOx react in the atmosphere to form fine sulfate and nitrate particles that people can inhale into their lungs. Many scientific studies have shown a relationship between these particles and effects on heart function, such as heart attacks resulting in death of people with increased heart disease risk, and effects on lung function, such as breathing difficulties for people with asthma.

1.3 Research Objectives

The objectives of this research were: (a) to investigate the feasibility of removing humic acid and its associated high color concentration from water by an innovative water treatment system consisting of chemical coagulation/flocculation, dissolved air flotation (DAF) and sand filtration. Humic acid is a common color-causing substance, and also a THM precursor; (b) to investigate the feasibility of neutralizing sulfuric acid and nitric acid and their associated low pH in lake water by the same innovative flocculation-DAF-filtration water treatment system, which was skid-mounted on a boat.

1.4 Summary

This publication paper introduces a highly efficient continuous water purification system consisting of flocculation, dissolved air flotation (DAF) and sand filtration. A continuous pilot plant system consisting of a flocculator, a Krofta DAF Model SPC-3 and three sand filters was operated at 39.62 to 57.23 m^3/hr (9-13 gallons per minute) for water treatment. DAF was controlled at 33.3 percent recycle water flow, and 0.02832 m^3/hr (1 SCFH) air flow. The three continuous sand filters were packed with 28 cm (11 in) of quartz sand (E = 0.35 mm, U = 1.55) and operated at 6.11 to 8.83 $m^3/hr/m^2$.

The first part of this paper demonstrates the feasibility of this innovative system for removal of humic substances and 400 color units from a contaminated water. Trihalomethanes are primarily formed by the reaction of free chlorine with humic substances, such as humic acid and fulvic acid, called trihalomethane precursors. A raw water containing 21.5 mg/L of humic acid, 400 units of color and 9 NTU of turbidity was treated by the continuous pilot plant. Over 94 percent of humic acid, 99 percent of color and 93 percent of turbidity were removed when 9.26 mg/L of alum in terms of Al_2O_3 was dosed as coagulant at pH 6.5. Related academic references are cited [1-15] and related terminologies are presented in the Glossary section of this publication.

The second part of this paper demonstrates the feasibility of the same DAF-filtration system skid-mounted on a boat for neutralization of acidity in lake water caused by acid rain. High acidity in lake water is primarily formed by dissolution of industrial air pollutants such as, sulfur dioxide (SO_2), nitrogen oxides (NOx) , etc. which are carried by rains to lake water. Actual acidic lake water from Florida-MA having pH 4.9, color 3.5 units, turbidity 2.8 NTU, acidity 24 mg/L as $CaCO_3$, nitrate nitrogen 0.4 mg/L, phosphate 0.1 mg/L as P, sulfate 70 mg/L and total coliforms 160 /100 mL was treated by the same pilot plant continuously for 5 hours under the same operational conditions but using 4.4 mg/L of sodium aluminate as Al_2O_3 and 3.5 mg/L of calcium hydroxide. It was discovered that DAF alone would be sufficient for acid rain neutralization, but the added filtration step would produce an effluent meeting the drinking water standards in terms of pH, color, turbidity, phosphorus, and coliforms. The readers are referred to the cited literatures [16-20] and the Glossary section for additional technical information.

This research has demonstrated that a water treatment system consisting of chemical coagulation-flocculation, dissolved air flotation (DAF), and filtration will be feasible for (a) removal humic substances and their associated high color form contaminated water , and (b) neutralizing the acidity and its associated low pH in acidic lake water. The flocculation, DAF and filtration units can be individual process equipment [10], [11], or can be combined together as a package plant, know as DAFF or Krofta Sandfloat [8], [10], [21]. Either water system described above will have the same technical feasibility and water treatment efficiency.

2. INNOVATIVE FLOCCULATION, FLOTATION AND FILTRATION WATER TREATMENT SYSTEM

2.1 Conventional Water Treatment System

The most common conventional water treatment system includes chemical coagulation-flocculation, sedimentation clarification, multimedia filtration, disinfection and corrosion control. [13]

2.2 Innovative Water Treatment System

An innovative water treatment system introduced in this publication is similar to the conventional water treatment system except that sedimentation clarification is replaced by dissolved air flotation (DAF). [8-15] Specifically an innovative water system includes chemical coagulation-flocculation, DAF clarification, multimedia filtration, disinfection and corrosion control.

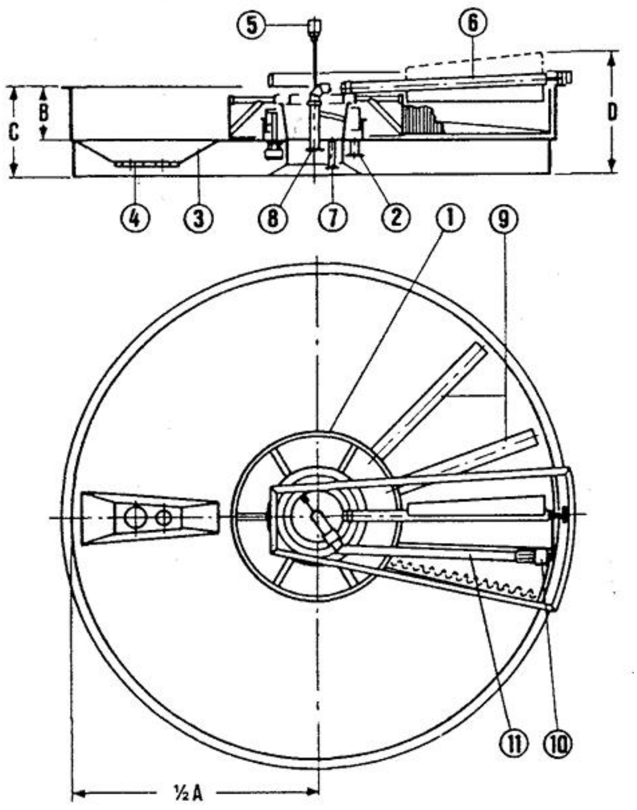
3. CONTINUOUS PILOT PLANT AND ITS OPERATIONAL PROCEDURES

The pilot plant system which was fully documented by elsewhere[1][2] was set up at the Lenox Institute of Water Technology (LIWT), Massachusetts, USA, for this research.

The pilot plant system consisted of (a) a rectangular static hydraulic flocculator (L x W x H = 102 in x 16 in x 10 in = 259.08 cm x 40.64 cm x 25.40 cm); (b) a dissolved air flotation unit (Krofta Model SPC-3; Diameter = 0.91 m = 3 ft; Depth = 55.88 cm = 22 in); and (c) three sand filters (28 cm of quartz sand as filter bed).

Figure 1 shows only the continuous pilot dissolved air flotation unit (Krofta DAF Model SPC-3) which was the heart of the entire pilot plant system [2].

Figure 1. Dissolved air flotation clarifier (Krofta DAF Model SPC-3) [2]



A DIAMETER of SUPRACELL
B DEPTH of SUPRACELL TANK
C DEPTH of SUPRACELL TANK with BOTTOM SUPPORT
D MINIMUM OVERALL HEIGHT of SUPRACELL

1 ROTATING CENTER SECTION
2 CLARIFIED WATER OUTLET
3 SETTLED SLUDGE SUMP
4 SETTLED SLUDGE OUTLET
5 (KROFTA) ROTARY CONTACT
6 (KROFTA) SPIRAL SCOOP
7 FLOATED SLUDGE OUTLET
8 UNCLARIFIED WATER INLET
9 CLARIFIED WATER EXTRACTION PIPES
10 GEAR MOTOR
11 DISTRIBUTION DUCT

4. EXPERIMENTAL AND OPERATIONAL CONDITIONS

4.1 Flotation and Filtration Water Treatment for Removal of Extremely High Color Caused by Humic Substances

The following were the experimental and operational conditions:

1. Raw water: Lenox Town water, Lenox, Massachusetts, USA, containing 21.5 mg/L of artificially added: humic acid (Color = 400 units; Turbidity = 9 NTU);
2. Chemical dosage: 9.26 mg/L of alum in terms of Al_2O_3;
3. Continuous water influent flow rate: 39.62 m^3/hr (9 gpm);
4. Continuous DAF water recycle flow rate: 13.21 m^3/hr (3 gpm);
5. Pressure of air dissolving tube: 90 psig;
6. Air flow rate to air dissolving tube (ADT): 0.02832 m^3/hr;
7. Sand filtration rate: 6.11 m^3/hr/m^2 (2.5 gpm/sf);
8. Sand specifications: Effective Size = 0.35 mm and Uniformity Coefficient = 1.55;
9. Sand depth: 28 cm (11 in) of quartz sand;
10. Sand filter backwash rate: 28.12 m^3/hr/m^2 (11.5 gpm/sf)

4.2 Flotation and Filtration Water Treatment for Neutralization of Acidity Caused by Acid Rain

The following were the experimental and operational conditions:

1. Raw lake water: South Pond water, Florida, Massachusetts, USA, having pH 4.9, color 3.5 units, turbidity 2.8 NTU, acidity 24 mg/L as $CaCO_3$, nitrate nitrogen 0.4 mg/L, phosphate 0.1 mg/L as P, sulfate 70 mg/L and total coliforms 160 /100 mL ;
2. Chemical dosages: 94.4 mg/L of sodium aluminate as Al_2O_3 and 3.5 mg/L of calcium hydroxide as $CaCO_3$;
3. Continuous water influent flow rate: 57.23 m^3/hr (13 gpm);
4. Continuous DAF water recycle flow rate: 19.08 m^3/hr (4.33 gpm);
5. Pressure of air dissolving tube: 90 psig;
6. Air flow rate to air dissolving tube (ADT): 0.02832 m^3/hr;
7. Sand filtration rate: 8.83 m^3/hr/m^2 (3.6 gpm/sf);
8. Sand specifications: Effective Size = 0.35 mm and Uniformity Coefficient = 1.55;
9. Sand depth: 28 cm (11 in) of quartz sand;
10. Sand filter backwash rate: 28.12 m^3/hr/m^2 (11.5 gpm/sf)

5. RESULTS AND DISCUSSIONS

5.1 Flotation and Filtration Water Treatment for Removal of Extremely High Color Caused by Humic Substances

After start-up, the DAF-filtration pilot plant reached steady state condition within 12 minutes. In 5 hours of continuous operation, the plant consistently produced a filter effluent containing only 0.6 NTU of turbidity, 2 units of color, and 1 mg/L of humic acid. Original influent containing 21.5 mg/L of humic acid was in dark brown color (400 color units). The treated product water (filter effluent) became crystal clear.

The humic acid (sodium salt) was supplied by Aldrich Chemical Company, Inc., Milwaukee, Wisconsin, 53233, U.S.A. Its concentrations were measured according to a method developed by Dr. Lawrence K. Wang and coworkers and can be found from the literature [3], [4].

Color and turbidity were measured according to the "Standard Methods for the Examination of Water and Wastewater" [5]

The entire pilot plant system consisting of flocculation, dissolved air flotation and sand filtration was manufactured by Krofta Engineering Corporation (KEC), Massachusetts, U.S.A.

The first full scale DAF-filtration water treatment plant in America (with 1 MGD or 3785 cubic meters per day design capacity) has successfully serving the Town of Lenox, Massachusetts, U.S.A. since 1982. The Lenox plant also consists of the unit processes of flocculation, dissolved air flotation and sand filtration. [7], [8], [9]. Today DAF-filtration has become the main stream water treatment technology around the world [10], [11], [12]. This publication has demonstrated that a water treatment plant consisting of DAF and filtration is feasible for removal of humic substances and extremely high color from a contaminated water.

5.2 Flotation and Filtration Water Treatment for Neutralization of Acidity Caused by Acid Rain

Under the experimental conditions listed in Section 4.2, the continuous pilot plant consisting of chemical coagulation-flocculation, dissolved air flotation (DAF), and sand filtration successfully treated the acidic lake water . Three separate sets of samples were taken for water quality analyses: (a) raw lake water before treatment; (b) DAF effluent from the first stage treatment; and (c) the sand filtration effluent from the second stage treatment.

Table 1 lists the experimental results. It appears that even the DAF treatment alone will be sufficient for treatment and neutralization of acidic lake water. After DAF treatment, pH value was neutral at 7, and the percent removals of color (91 %), turbidity (71.4%), acidity (91.7 %), nitrate-N (25 %), phosphate-P (100 %), sulfate (85.7%), and coliform bacteria (99.99 %) were all satisfactory. Additional filtration treatment produced an effluent meeting drinking water quality because the color, turbidity, and coliform bacteria were further reduced to 0.1 color units, 0.1 NTU, and 0 coliform bacteria count , respectively.

It is understood that for acidic lake water neutralization alone, the coagulant/flocculant, such as sodium aluminate may not be needed for coagulation and chemical flocs generation. Lime such as calcium hydroxide will be sufficient for neutralization. Addition of sodium aluminate will not only neutralize the acidic lake water, but also purify it for removal of color, turbidity, phosphate and total coliform, etc.

Figure 2 presents the mobile floating pilot water treatment boat specifically designed by the Lenox Institute of Water Technology (LIWT) and Krofta Engineering corporation (KEC) for lake water restoration. The boat plant includes the process equipment of flocculator, dissolved air flotation clarifier, and sand filters. In addition, the process equipment of disinfection, sludge thickening, and sludge storage are also available on the boat plant. The treated filter effluent was discharged into the lake.

Table 1. Treatment of acidic lake water using dissolved air flotation

Parameters	Raw Lake Water (Before)	Flotation Effluent (1st Stage)	Filtration Effluent (2nd Stage)
pH, unit	4.9	7.0	7.1
Color, unit	3.5	0.3	0.1
Turbidity, NTU	2.8	0.8	0.5
Acidity mg/L $CaCO_3$	24.0	1.9	1.8
Nitrate-N, mg/L	0.4	0.3	0.2
Phosphate-P, mg/L	0.1	0	0
Sulfate, mg/L	70.0	10.0	9.0
Coliforms, #/100 mL	160	1	0

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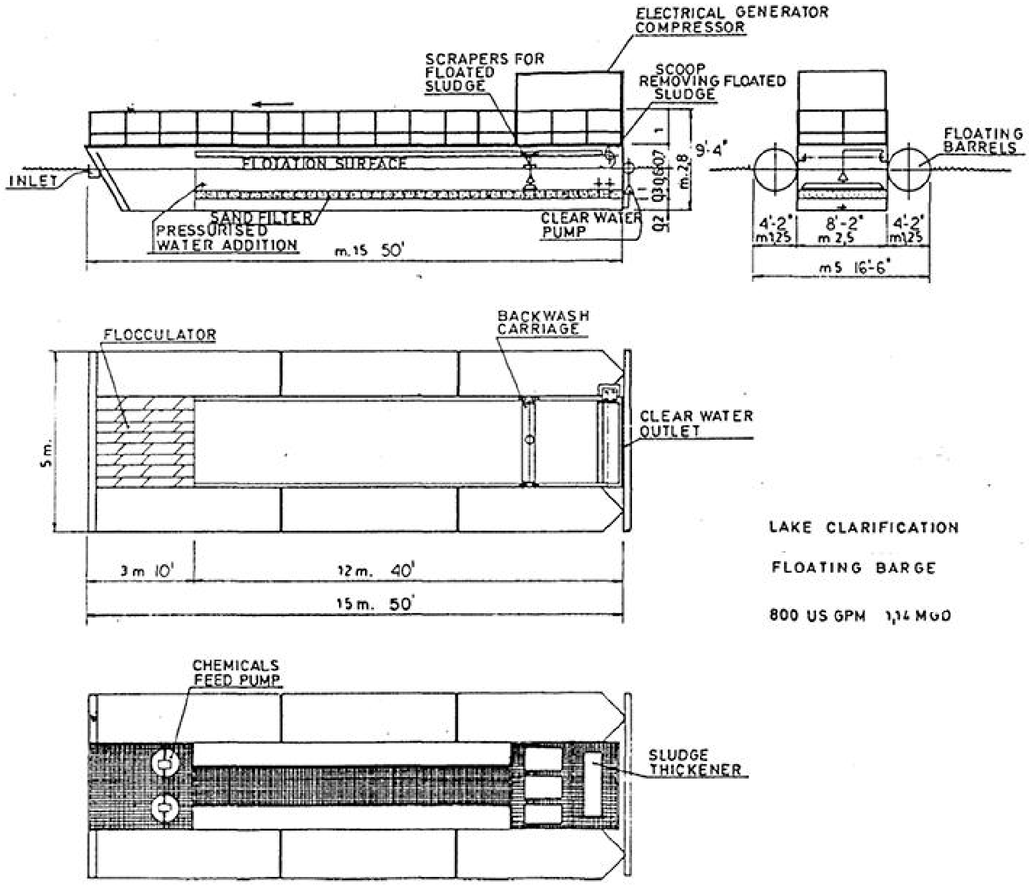
Figure 2. The top view, side view, and cross-sectional view of a boat water treatment plant consisting of the process equipment for chemical coagulation-flocculation, dissolved air flotation, sand filtration, disinfection, sludge thickening, sludge storage for lake water treatment



GLOSSARY

Acid rain: Acid rain, or acid deposition, is a broad term that includes any form of precipitation with acidic components, such as sulfuric and/or nitric acid that fall to the ground from the atmosphere in wet or dry forms. Broadly used to include both wet and dry deposition. This can include rain, snow, fog, hail or even dust that is acidic. Acid rain results when sulfur dioxide (SO_2) and nitrogen oxides (NO_x) are emitted into the atmosphere and transported by wind and air currents. The SO_2 and NO_x react with water, oxygen and other chemicals to form sulfuric and nitric acids. These then mix with water and other materials before falling to the ground. While a small portion of the SO_2 and NO_x that cause acid rain is from natural sources such as volcanoes, most of it comes from the burning of fossil fuels. The major sources of SO_2 and NO_x in the atmosphere are: (a) Burning of fossil fuels to generate electricity. Two-thirds of SO_2 and one-fourth of NO_x in the atmosphere come from electric power generators. (b) Vehicles and heavy equipment. (c) Manufacturing, oil refineries and other industries. Winds can blow SO_2 and NO_x over long distances and across borders making acid rain a problem for everyone and not just those who live close to these sources.

AquaDAF: A rectangular dissolved air flotation clarifier (DAF) manufactured by and commercially available from SUEZ Water Technologies and Solutions, 8007 Discovery Drive, Richmond, VA 23229, USA

Clari-DAF: A rectangular dissolved air flotation clarifier (DAF), manufactured by and commercially available from Xylem Water & Wastewater, 227 S. Division St, Zelienople, PA 16063, USA

Dissolved air flotation (DAF): It is one of dissolved gas flotation (DGF) processes when air is used for generation of gas bubbles. See dissolved gas flotation (DGF).

Dissolved air flotation-filtration (DAFF): It is a package plant including both dissolved air flotation and filtration, such as Sandfloat, developed by the Lenox Institute of Water Technology (LIWT), and manufactured by Krofta Engineering Corporation (KEC) and their associated companies around the world. The filtration portion of DAFF can be sand filtration, multiple-media filtration, or granular activated carbon (GAC) filtration.

Dissolved gas flotation (DGF): It is a process involving pressurization of gas at 25 to 95 psig for dissolving gas into water, and subsequent release of pressure (to one atm) under laminar flow hydraulic conditions for generating extremely fine gas bubbles (20-80 microns) which become attached to the impurities to be removed and rise to the water surface together. The impurities or pollutants to be removed are on the water surface are called float or scum which scooped off by sludge collection means. The clarified water is discharged from the flotation clarifier's bottom. The gas flow rate is about one percent of influent liquid flow rate. The attachment of gas bubbles to the impurities can be a result of physical entrapment, electrochemical attraction, surface adsorption, and/or gas stripping. The specific gravity of the bubble-impurity agglomerate is less than one, resulting in buoyancy or flotation (i.e. Save-All).

Filtration: It is usually a granular medial filtration process which involves the passage of wastewater or water through a bed of filter media with resulting deposition f suspended solids. Eventually the pressure drop across the bed becomes excessive or the ability of the bed to remove suspended solids is impaired. Cleaning is then necessary to restore operating head and effluent quality. The time in service between cleanings is termed the filter run time or run length. The head loss at which filtration is interrupted for cleaning is called the terminal head loss, and this head loss is maximized by the judicious choice of media sizes. Dual media filtration involves the use of both sand and anthracite as filter ,media, with anthracite being placed on top of the sand. Gravity filters operate by either using the available head from the previous treatment unit, or by pumping to a flow split box after which the wastewater flows by gravity to the filter cells. Pressure filters utilize pumping to increase the available head. A filter unit generally consists of a containing vessel, the filter media, structures to support the media, distribution and collection devices for filter influent, effluent, and backwash water flows, supplemental cleaning devices, ad necessary controls for flows, water levels and backwash sequencing. Backwash sequences can include air scour or surface wash steps. Backwash water can be stored separately or in chambers that are integral parts of the filter unit. Backwash water can be pumped through the unit or can be supplied through gravity head tanks. Filtration may also include granular activated carbon (GAC) filtration and pressure filtration.

Floc: Collections of smaller particles that have agglomerated together into larger, more separable (floatable or settleable particlks as result of the coagulation process.

Flocculation: A water treatment unit process followibg coagulation that uses gentle stirring to bring suspended particles together so they will form largr, more separable (floatable or settleable) floc.

Humic substances (HS): They are organic compounds, including humic acid, fulvic acid, their salts, etc. that are important components of humus, the major organic fraction of soil, peat, and coal.

Krofta Engineering Corporation (KEC): It is an equipment manufacturer and engineering design company in Lenox, Massachusetts, USA, working closely with the Lenox Institute of Water Technology (LIWT) for develop, production, sales, installation and operation of innovative water and wastewater treatment processes, monitoring devices and analytical methods.

Lenox Institute of Water Technology (LIWT): It is a non-profit college in Massachusetts, USA, with expertise in environmental STEAM (science, technology, engineering, arts and mathematics) education, R&D, invention, process development, monitoring system/methods development, patent application, licensing, fund raising, engineering design and project management. LIWT teams up with Krofta Engineering Corporation (KEC), for technology transfer, equipment design, and voluntary humanitarian global service through free education, training, and academic publications.

Sandfloat: It is the combination of a circular high-rate dissolved air flotation clarifier and a circular automatic backwash granular filtration (DAFF) developed by the Lenox Institute of Water Technology (LIWT), and manufactured by Krofta Engineering Corporation (KEC) and its associated companies. The granular filtration can be sand filtration and/or granular activated carbon (GAC) filtration.

Supracell: It is a circular high-rate dissolved air flotation (DAF) clarifier developed by the Lenox Institute of Water Technology (LIWT), and manufactured by Krofta Engineering Corporation (KEC) and its associated companies.

Total coliform (TC): Bacteria of the family Enterobacteriaceae including all aerobic and facultative anaerobic, gram-negative, nonspore-forming, rod shaped bacteria that ferment lactose in 24-48 hours at 35 degree C. Coliform bacteria are commonly found in the intestinal tracts of warm-blooded animals, therefore, total coliform is used as an indicator of possible bacterial or fecal contamination. The number of Total Coliform includes both Fecal Coliform and Escherichia coli.

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APPENDIX

INTRODUCTION OF THE EDITORS OF ENVIRONMENTAL SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS (STEM) SERIES

1. Editor Lawrence K. Wang

Editor Lawrence K. Wang has served the society as a professor, inventor, chief engineer, chief editor and public servant (UN, USEPA, New York State) for 50+ years, with experience in entire field of environmental science, technology, engineering and mathematics (STEM). He is a licensed NY-MA-NJ-PA-OH Professional Engineer, a certified NY-MA-RI Laboratory Director, a licensed MA-NY Water Operator, and an OSHA Instructor. He has special passion, and expertise in developing various innovative technologies, educational programs, licensing courses, international projects, academic publications, and humanitarian organizations, all for his dream goal of promoting world peace. He is a retired Acting President/Professor of the Lenox Institute of Water

Technology, USA, a Senior Advisor of the United Nations Industrial Development Organization (UNIDO), Vienna, Austria, and a former professor/visiting professor of Rensselaer Polytechnic Institute, Stevens Institute of Technology, University of Illinois, National Cheng-Kung University, Zhejiang University, and Tongji University. Dr. Wang is the author of 750+ papers and 50+ books, and is credited with 29 invention patents. He holds a BSCE degree from National Cheng- Kung University, Taiwan, ROC, a MSCE degree from the University of Missouri, a MS degree from the University of Rhode Island and a PhD degree from Rutgers University, USA. Currently he is the book series editor of CRC Press, Springer Nature Switzerland, Lenox Institute Press, World Scientific Singapore, and John Wiley. Dr. Wang has been a Delegate of the People to People Internatonal Foundation, a Diplomate of the American Academy of Environmental Engineers, a member of ASCE, AIChE, ASPE, WEF, AWWA, CIE and OCEESA, and a recipient of many US and international engineering and science awards.

2. Editor Mu-Hao Sung Wang

Editor Mu-Hao Sung Wang has been an engineer of the New York State Department of Environmental Conservation, an editor of CRC Press, Springer Nature Switzerland, and Lenox Institute Press, and a university professor of the Stevens Institute of Technology, National Cheng-Kung University, and the Lenox Institute of Water Technology. Totally she has been a government official, and an educator in the USA and Taiwan for over 50 years. Dr. Wang is a licensed Professional Engineer, and a Diplomate of the American Academy of Environmental Engineers (AAEE). Her publications have been in the areas of water quality, modeling, environmental sustainability, solid and hazardous waste management, NPDES, flotation technology, industrial waste treatment, and analytical methods. Dr. Wang is the author of over 50 publications and an inventor of 14 US and foreign patents. She holds a BSCE degree from National Cheng-Kung University, Taiwan, ROC, a MS degree from the University of Rhode Island, RI, USA, and a PhD degree from Rutgers University, NJ, USA. She is the Co-Series Editor of the Handbook of Environmental Engineering series (Springer Nature Switzerland), Coeditor of the

Advances in Industrial and Hazardous Wastes Treatment series (CRC Press of Taylor & Francis Group) and the Coeditor of the Environmental Science, Technology, Engineering and Mathematics series (Lenox Institute Press). She is a member of AWWA, NYWWA, NEWWA, WEF, NEWEA, CIE and OCEESA.

3. Editor Yuriy I. Pankivskyi

Dr. Yuriy I. Pankivskyi has 25 years of professional experience of scientific research and environmental education. He has expertise in strategic environmental assessment, environmental impact assessment, drinking water treatment, waste waters treatment, water and air pollution control, solid waste management. He works as environmental consulting engineer for industrial enterprises, state administrations of cities and towns of Western Ukraine, communities, private firms and institutions and as researcher, educator for state universities. He is the Associate Professor and Deputy Head of Department of Ecology of Ukrainian National University of Forestry. His research and publications have been in areas of water and air quality control, waste water treatment, environmental sustainability and education, analytical methods, investigations of multifunctional material for optoelectronics and environment testing. Dr. Pankivskyi is author of over 70 scientific publications. He earned his Specialist degree from Lviv State Ivan Franko University (Ukraine), ME degree from Lenox Institute of Water Technology (MA, USA), and his PhD degree from Lviv National Ivan Franko University (Ukraine). He is a member of National Ecological Center of Ukraine (Lviv Department).