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MICROWAVE-ASSISTED ANALYTICAL METHODS FOR RAPID SOLIDS AND WATER CONTENT DETERMINATION

Authored by

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ABSTRACT

Analytical procedures involving the use of a programmable microwave oven have been developed by the Lenox Institute of Water Technology (LIWT) for rapid and accurate analyses of total solids (TS)(i.e. total residue), total dissolved solids (TDS) (i.e. total filtrable residue), total suspended solids (TSS) (i.e. total nonfiltrable residue), and water content. Based on the LIWT extensive laboratory evaluation, the microwave-assisted methods are comparable to or quicker than the APHA/AWWA/WEF Standard Methods for solids and water content analyses. At present the laboratory equipment manufacturers have not produced the high quality programmable, and temperature controllable microwave ovens for water quality laboratory applications. The authors introduce the microwave-assisted methods as a stepping-stone of environmental research, hoping that (a) operators may use the microwave-assisted methods as the supplemental analytical methods for analyzing the TS, TSS, TDS, and water content under urgent situations and with a standard operating procedure (SOP) for the microwave oven to be used; (b) researchers may develop more similar microwave-assisted technologies for various environmental applications; (c) this microwave-assisted solids and water content methods may one day become a part of the Standard Methods; and (d) the laboratory equipment manufacturers are willing to produce high quality, programmable, and temperature controllable microwave facilities for environmental applications in the near future. Current Standard Methods [7] are: (a) Method 2540B TS dried at 103-105 ^{o}C; (b) Method 2540C TDS dried at 180 ^{o}C; and Method 2540D TSS dried at 103-105 ^{o}C. The Standard Methods allows a material balance mathematical

calculation among the three solids (TS = TSS + TDS) if two solids are known. The authors suggest that the testing temperatures for the three closely related solid tests, (TS, TSS, and TDS) be consistent, either all 103-105 ^{o}C, or all 180 ^{o}C, in order to avoid any errors.

KEYWORDS

Innovation, Research Stepping Stone, Call for Research, Environmental Engineering, Pollution Control, Analysis, Microwave-assisted Methods, Water Quality, Sludge, Total Solids, Total Suspended Solids, Total Dissolved Solids, Water Content, Rapid Field Test Methods, Recommendations, Standard Methods for the Examination of Water and Wastewater..

ACRONYM

APHA: American Public Health Association

AWWA: American Water Works Association

FS: Fixed solids

FSS: Fixed suspended solids (fixed nonfiltrable residue)

LIWT: Lenox Institute of Water Technology

SOP Standard operating procedure

TDS: Total dissolved solids (total filtrable residue)

TS: Total solids

TSS : Total suspended solids (total nonfiltrable residue)

VS: Volatile solids

VSS: Volatile suspended solids (volatile nonfiltrable residue)

SS: Settleable solids

WC: Water content

WEF: Water Environment Federation

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PREFACE AND ACKNOWLEDGMENT

Solids refer to matter suspended or dissolved in potable, surface, and saline waters, as well as wastewaters and sludge. There are different kinds of solid tests, such as total solids (TS), total suspended solids (TSS), total dissolved solids (TDS), fixed solids (FS), volatile solids (VS), settleable solids (SS), etc. [1-8], which are defined in the Glossary section of this publication. This publication discusses only TS, TSS, TDS and water content.

The original concept of using a microwave-assisted technology for rapid solids analysis and disinfection was conceived by Krofta and Wang at the Lenox Institute of Water Technology (LIWT) (formerly Lenox Institute for Research) in 1980-1981 [1], when a new process equipment, FloatPress (i.e. a combination of dissolved air flotation thickener and sludge press) was being developed, and there was an urgent need of rapid solids analysis for the FloatPress operational adjustments, and process improvement. [2, 3] The early research was sponsored by Blandford Foundation of Hoboken, NJ, USA, under a grant 34050-Blandford

The LIWT microwave-assisted methods are not developed as a replacement of the Standard Methods [4-8], but as a mobile plant's rapid research methods to be used in the field and when immediate results are needed. The Standard Methods for solids determinations have changed several times (including solid name changes and temperature range changes) since 1980 [4-7], LIWT researchers have used both the microwave-assisted methods and the

Standard Methods simultaneously for many years. Duplicate samples were taken in the field (a) for immediate field analyses of total solids (TS), total suspended solids (TSS), total dissolved solids (TDS) and water content (WC) using the microwave-assisted methods, and (b) for further verification analyses of extra set of samples in the government certified laboratory using the Standard Methods [4-7]. The results obtained from the microwave-assisted methods (i.e. introduced in this publication) and that from the Standard Methods [4-7] were very close.

Current commercially available microwave ovens are for kitchen applications, not for laboratory applications. The microwave-assisted methods will not become the Standard Methods until the laboratory equipment manufacturers are willing to produce high quality, programmable, and temperature controllable microwave ovens (similar to but better than Ward's Combined Microwave-Convection Oven shown in Figure 1) that may reproduce the results. The microwave part of the Ward's oven quickly and periodically reaches the specified temperature, and the convection part of the oven keeps the temperature for a programmed period of time based on a prepared Standard Operating Procedure (SOP).. Combination of both microwave and convection will speedy up the solids or water content testing time. The laboratory equipment manufacturers, however, are not encouraged to produce such expensive high quality, programmable, and temperature controllable microwave-convection ovens until the microwave-assisted technology is formerly accepted as the Standard Methods. So it is a chicken-and-the-eggs situation.

The authors introduce the microwave-assisted methods as a small stepping-stone of environmental research, hoping that (a) operators may use the microwave-assisted methods as the supplemental analytical methods for analyzing the TS, TSS, TDS, and WC under urgent situations and with a standard operating procedure (SOP) for the microwave oven to be used; (b) researchers may develop more similar microwave-assisted technologies for various environmental applications; (c) this microwave-assisted solids and water content methods may one day become a part of the Standard Methods; and (d) the laboratory equipment manufacturers are willing to produce high quality, programmable, and temperature controllable microwave-convection ovens for environmental applications in the near future.

MICROWAVE-ASSISTED ANALYTICAL METHODS FOR RAPID SOLIDS AND WATER CONTENT DETERMINATION

Mu-Hao Sung Wang and Lawrence K. Wang, Lenox Institute of Water Technology

1. TOTAL SOLIDS (TOTAL RESIDUE) DETERMINATION

1.1. Principle

A well-mixed sample is evaporated in a weighed non-metal microwave-oven-proof container and dried to constant weight in a microwave oven at a controlled temperature near boiling point. (103-105 ^{o}C). The increase in weight over that of the empty container represents the total solids (TS) or total residue. Although the results may not represent the weight of actual dissolved and suspended solids in wastewater samples, the determination is useful for plant control. In some instances, correlation may be improved by adding 1 N sodium hydroxide (NaOH) to wastewater samples with a pH below 4.3 and maintaining the pH of 4.3 during evaporation. Correct final calculation for added sodium hydroxide.

1.2. Interferences:

Exclude large floating particles or submerged agglomerates of non homogeneous materials from the sample. Disperse visible floating oil and grease with a blender before withdrawing a sample portion for analysis.

1.3. Apparatus:

1.3.1 Evaporating Containers

Dishes or beakers of at least 250 mL capacity and 8 cm height made of the following materials: (a) porcelain; (b) ; high-silica glass; or (c) polymethylpentene.

1.3.2 Desiccator

It should be provided with a desiccant containing a color indicator of moisture concentration.

1.3.3. Analytical Balance

It should have a 200-g capacity, capable of weighing to 0.1 mg.

1.3.4 Microwave Oven

It should be programmable with ability to vent humidity. Sears Microwave Oven Model No. 99911 or equivalent, or better.

1.4. Preparation Procedure

a. Clean evaporating container (such as a 400-mL polymethylpentene beaker), and dry it at maximum power for 10 minutes, in a microwave oven (Note:

Use the power setting of MAX POWER if Sears Microwave Oven Model No. 99911 is used). Cool and store in desiccator until needed. Weigh immediately before use.

b. Sample size: Choose a sample volume that will yield a residue between 2.5 mg and 200 mg on a 4.7 cm diameter filter pad. The upper limit is extended to 1100 mg when an 11.0 cm diameter filter is used. Volume required may be estimated from conductivity. If necessary, add successive sample portions to the same container.

1.5. Analytical Procedure

a. Transfer a measured volume of sample to a pre-weighed container.

b. Place the container in microwave oven. Enter power setting at maximum power until boiling. Immediately reduce the power setting for evaporation at a temperature which is slightly below boiling to prevent splattering. (Note: Use the power setting of FIVE if Sears Microwave Oven Model No. 99911 is used) . Continue the evaporation in the oven until sample is totally evaporated except for residual condensation on the container walls.

c. Increase the power setting of microwave over to maximum power for 10 minutes in final drying step.

d. Remove container and cool it in the desiccator to balance temperature, and weigh.

e. Repeat cycle of drying by microwave oven cooling, desiccating, and weighing until a constant weight is obtained or until loss of weight is less than 4% of the previous weight, or 0.5 mg, whichever is less.

f. Calculation of Total Solids (Total Residue):

mg/L total solids (TS) = [(A - B) x 1000] / (mL sample)

where A = weight of dried sample and container (mg); B = weight of clean and dry container (mg)

1.6. Precision and Accuracy

Precision is about ±5 %, when the residue from a 50-mL to 100-mL of water sample was weighed

2. TOTAL DISSOLVED SOLIDS (TOTAL FILTRABLE RESIDUE) DETERMINATION

2.1 Principle

Total dissolved solids (TDS), or total filtrable residues, are the water sample materials that pass through a standard glass fiber filter and remain after evaporation and drying to constant weight at a controlled temperature (180 °C) in a microwave oven.

The filtrate from the total suspended solids (TSS) (or total nonfiltrable residue) determination may also be used for determination of total dissolved solids (TDS) (or total filtrable residue)

2.2 Interferences:

Highly mineralized waters with a considerable calcium, magnesium, chloride, and/or sulfate content may be hygroscopic and require prolonged drying, proper desiccation, and rapid weighing.

2.2 Apparatus

All of the apparatus listed in Total Residue Determination is required and in addition:

2.3.1. Glass-Fibre Filters, Circular, Without Organic Binder.

Suitable filters include: Whatman grade 934AH and 984H; Gelman type A/E, Millipore type AP40; or equivalent. They are available in diameters of 2.2 cm to 11.0 cm.

2.3.2. Filtration Apparatus Suitable For Filter Selected

2.3.2.1 Filter Holder.

Gooch crucible adapter or membrane filter funnel, or buchner filter funnel.

2.3.2.2 Gooch Crucible.

25-mL to 40-mL capacity, suitable for filter size selected. (Optional)

2.3.2.3. Suction Flask

500 mL capacity.

2.4 Preparation Procedure

a. Preparation of glass-fiber filter: Place filter either on membrane filter apparatus or bottom of a suitable Gooch crucible. Apply vacuum and wash filter with three successive 20-mL volumes of distilled water. Continue suction to remove all traces of water. Discard washings.

b. Preparation of evaporating non-metal microwave-oven-proof container: Clean evaporating container and dry it at maximum power for 10 minutes in a microwave oven (Sears Microwave Oven Model No. 999111 or equivalent) Cool and store in desiccator until needed. Weigh immediately before use.

c. Sample size: Because excessive residue in the evaporating container may form a water-entrapping crust, use a sample yielding between 2.5 mg and 250 mg total filtrable residue. If sample contains less than 10 mg/L total dissolved solids (total filtrable residue), use 250 mL.

2.5 Analytical Procedure

a. Under vacuum, filter well-mixed sample through glass-fiber wash with three successive 10-mL volumes of distilled water, and continue suction for about 3 min. after filtration is complete.

b. Transfer filtrate to a weighed evaporating container and evaporate to dryness in microwave oven according to the Total Residue Determination Procedures (Sections 1.5a through 1.5c). Remove container from microwave oven and cool it in a desiccator to balance temperature, and weigh.

c. Repeat drying cycle until a constant weight is obtained or until weight loss is less than 4% of previous weight or 0.5 mg, whichever is less. Base calculation on original sample volume because all filtrate is evaporated.

d. Calculation of Total Dissolved Solids (TDS), or Total Filtrable Residue:

mg/L total dissolved solids (TDS) = [(A - B) x 1000] / (mL sample)

where: A = weight of dried residue and container (mg); B = weight of clean and dry container (mg)

3. TOTAL SUSPENDED SOLIDS (TOTAL NONFILTRABLE RESIDUE) DETERMINATION

3.1 Principle

Total suspended solid (TSS), or nonfiltrable residue, is the retained material on a standard glass-fiber filter after filtration of a well-mixed sample. The residue is dried at controlled temperature (103-105°C) in a microwave oven. If the suspended material clogs the filter and prolongs filtration, the difference between the total solids (total residue) and the total dissolved solids (total filtrable residue) provides an estimate of the total non-filtrable residue (TSS). The equation for calculation is TSS = TS - TDS.

Volatile nonfiltrable residue (volatile suspended solids, VSS) and fixed nonfiltrable residue (fixed suspended solids, FSS) can be determined on the material retained on the glass-fiber filters in the Gooch crucibles on completion of the drying in microwave oven.

3.2 Apparatus

Apparatus listed in Sections 1.3 and 2.3 is required.

3.3 Preparation Procedure:

a. Preparation of glass-fiber filter: Place filter on membrane filter apparatus or buchner funnel filter apparatus, or the bottom of a suitable Gooch crucible. Apply vacuum and wash filter with three successive 20-mL portions of distilled water. Continue suction to remove all traces of water, and discard washings. Remove filter from filter apparatus and transfer to a non-metal planchet as a support. (Remove crucible and filter combination if a Gooch crucible is used.) Dry in a microwave oven for 15 minutes on maximum power. Store in desiccator until needed. Weigh immediately before use.

b. Sample size: Because excessive residue on the filter may entrap water and extend drying time, take for analysis a sample volume that will yield between 2.5 mg and 200 mg total suspended solids (nonfiltrable residue) on a 4.7 cm diameter filter pad. The upper limit is extended to 1100 mg when an 11.0 cm diameter filter is used.

3.4 Analytical Procedure

a. As a practical limit, filter at least 100 mL of well-mixed sample under vacuum through a pre-weighed filter. Wash filter with three successive 10 mL protions of distilled water. Carefully remove filter from membrane or buchner filter funnel assembly and transfer to a non-metal planchet as a support. (Alternatively remove crucible and filter combination from crucible adapter if a Gooch crucible is used.)

b. Dry the filter in microwave oven for 15 minutes on maximum power. Remove the filter from microwave oven and cool it .in a desiccator to balance temperature, and weigh.

c. Repeat drying cycle until a constant weight is attained or until weight loss is less than 4% of previous weight, or 0.5 mg, whichever is less. (Note: Suppose the crucible container is used, the dried residue in the Gooch crucible may be used for determining volatile and fixed matter at 550 ^{o}C.)

d. Calculation of Total Suspended Solids (TSS) or Nonfiltrable Residue::

mg/L total suspended solids (TSS) = [(A - B) x 1000] / (mL sample)

where: A = weight of filter and residue (mg); B = weight of filter (mg).

4. WATER CONTENT DETERMINATION

4.1 Principle

A wet water or sludge sample is evaporated in a weighed non-metal microwave-oven-proof container and dried to constant weight in a microwave oven at a controlled temperature near water's boiling point. The decrease in weight from that of the original wet raw sample represents the water content.

4.2 Apparatus

All of the apparatus listed in Total Residue Determination (Section 1.3) is required.

4.3 Preparation Procedure:

Same as Section 1.4 (Preparation procedure for the Total Residue Determination)

4.4 Analytical Procedure:

a. Transfer an appropriate amount of wet sample to a pre-weighed non-metal microwave-oven-proof container, and weigh (To determine C value)

b. Place the container together with the sample in microwave oven.

cl. If it is a watery sample, enter power setting maximum power until boiling. Then immediately reduce the power setting at a temperature which is slightly below boiling point to prevent splattering (Note: Use the power setting of FIVE for sears Microwave Oven Model No. 99911). Continue the evaporation in the oven until sample is totally evaporated except for residual condensation on the container walls. Finally increase the power setting of microwave oven to maximum Power for 10 minutes in total drying step.

c2. Alternatively if it is a sludge cake sample, enter power setting maximum power for 20 minutes in a microwave oven for evaporation and drying. (Use porcelain or high-silica glass container; Do not use polymethylpentene container when evaporation/drying process is over 10 minutes.)

d. Remove container and cool it in desiccator to balance temperature and weigh (To determine A value).

e. Repeat cycle of drying by microwave oven at cooling, desiccating, and weighing until a constant weight is obtained or until loss of weight is less than 4% of the previous weight, or 0.5 mg, whichever is less.

f. Calculation of Water Content (WC):

% water content = (C - A) x l00 / (C - B)

where: A = weight of dried sample and container (mg); B = weight of clean and dry container (mg); C = weight of wet raw sample and container (mg)

5. STANDARD OPERATING PROCEDURE (SOP): PROPER USE OF A SEARS KENMORE MICROWAVE OVENZ MODEL NO. 99911 FOR SOLIDS ANALYSIS

(Note: This section is for readers' reference only. In the near future, the analytical equipment manufacturers may produce high quality standard microwave ovens for all microwave-assisted analytical methods or process testing. For the time being, each water quality laboratory shall prepare a special note (similar to this Section 5) for the laboratory's specific microwave oven that will be used for determination of solids and water content)

A. <u>Always</u> arrange filter pads and containers in a circular fashion around the center of the oven. This is to assure even drying.

B. Leave the provided glass tray in the oven bottom for total residue (total solids, TS) and total filtrable residue (total dissolved solids, TDS) analyses. The tray heats during use and facilitates even drying.

C. Remove the provided glass tray in the oven bottom in evaporation/drying process when a filter paper (i.e. not a glass fibre filter) is used for determination of total nonfiltrable residue (total suspended solids, TSS).

D. <u>Never</u> heat the polymethylpentene plastic containers on HI power for more than 10 minutes continuously after they are dry. This is to avoid melting. However, after cooling in a desiccator and weighing, the containers may be re-dried as many times as is necessary, but still not more than 10 minutes each time.

E. Filter pads and containers should be re-dried on HI power for an additional 10 minutes during both pre-weight and final weight determinations. This is to assure complete drying.

F. A control and/or blank determination should be performed simultaneously. Appropriate sample weight corrections may then be made if required.

G. During total solids (TS) determination never let the samples boil continuously and rapidly. To do this a low power level of 5 is recommended for evaporation of samples. This is to: (a) Avoid foaming over of samples, and (b) Avoid volatilization of sample constituents other than water.

H. Preweight determination of filter pads (flass fibre filter or paper filter): (a) pre-wash filter pads with 100 ml distilled water; (b) dry pads on hi power for 15 minutes; and (c) cool in desiccator and weigh to nearest 0.1 mg.

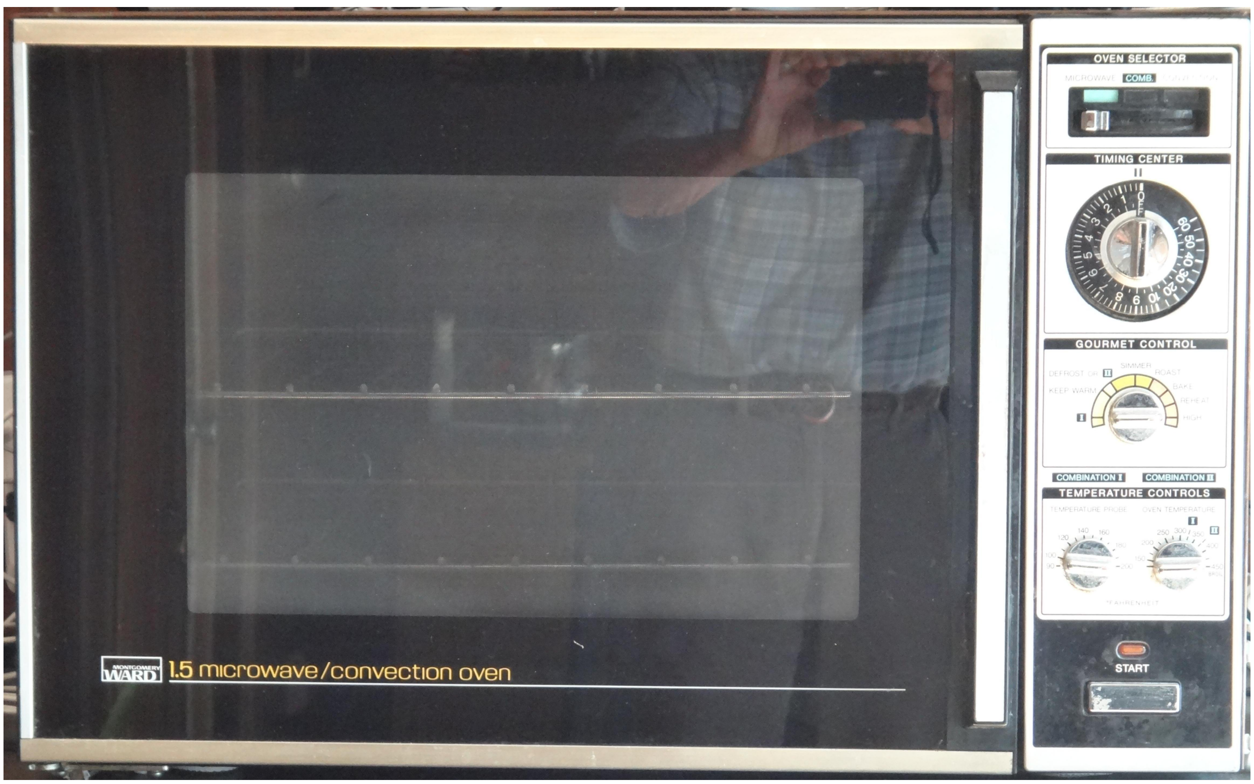
I. Preweight determination of non-metal microwave-oven-proof containers: (a) dry containers on HI power for 10 minutes; and (b) cool in desiccator and weigh to nearest 0.1 mg.

J. Limits of detection of glass fibre filter pads : (a) Accepted standard methods limits for loading Glass Fibre filter pads are 2.5 mg to 200 mg of solids on a 4.7 cm diameter pad. The upper limit (200 mg) is to avoid entrapment of water by excess residue; (b) Using an 11.0 cm diameter filter pad in conjunction with a 11.0 cm diameter buckner funnel increases the filtration area by a factor of 5.5. Given this factor it is suggested that the upper weight limit could be extended to 1100 mg as long as the pad is loaded evenly.

K. For determination of total solids (TS) and total dissolved solids (TSS), a non-metal screen may be placed on the top of an evaporation/drying container in final drying stage to prevent any splattering of solids.

Figure 1.

A HIGH QUALITY, PROGRAMMABLE, TEMPERATURE CONTROLLABLE COMBINED MICROWAVE-CONVECTION OVEN



GLOSSARY

Fixed solids (FS): The total, suspended, or dissolved solids remaining in a sample after ignition for a specified time at a specified temperature. Determinations of fixed and volatile solids do not distinguish precisely between inorganic and organic matter because some inorganic compounds can be lost during ignition. Organic matter can be better characterized via total organic carbon (TOC).

Settleable solids (SS): The material in a sample that settles out of suspension within a defined period. This may include floating material, depending on the technique used..

Solids: Solids refer to matter suspended or dissolved in potable, surface, and saline waters, as well as wastewaters and sludge.

Total dissolved solids (TDS): (a) In a Total Solids (TS) test, the portion of solids in a water sample that passes through a specified testing filter is the Total Dissolved Solids (TDS). Total Dissolved Solids (TDS) = Total Solids (TS) - Total Suspended Solids (TSS); (b) The portion of total solids in a water sample that passes through a filter with a nominal pore size of 2.0 um (or smaller) under specified conditions.

Total solids (TS): (a) It is the term applied to the material residue left in the vessel after evaporation of a sample and its subsequent drying in an oven at a defined temperature. Total Solids (TS) = Total Dissolved Solids (TDS) + Total Suspended Solids (TSS); (b) The material left in a sample vessel after evaporation and subsequent oven drying at a defined temperature (such as 103-105 ^{o}C). Total solids includes both total suspended and total dissolved solids, which are physically separated via filtration. Whether a solids particle is filtered into the “suspended” or “dissolved” portion principally depends on a filter’s thickness, area, pore size, porosity, and type of holder, as well as the physical nature, particle size, and amount of solids being filtered.

Total suspended solids (TSS): (a) In a total solids (TS) test, the portion of total solids in a water or sludge sample that is retained by a specified testing filter is the Total Suspended Solids (TSS). Total Suspended Solids (TSS) = Total Solids (TS) - Total Dissolved Solids (TDS); (b) The portion of total solids in an aqueous sample retained on the 2-um filter. NOTE: Some suspended clays and suspended colloids will pass through a 2-um filter.

Volatile solids (VS): The total, suspended, or dissolved solids lost from a sample after ignition for a specified time at a specified temperature. Determinations of fixed and volatile solids do not distinguish precisely between inorganic and organic matter because some inorganic compounds can be lost during ignition. Organic matter can be better characterized via total organic carbon (TOC)

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APPENDIX

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

1. Editor Lawrence K. Wang

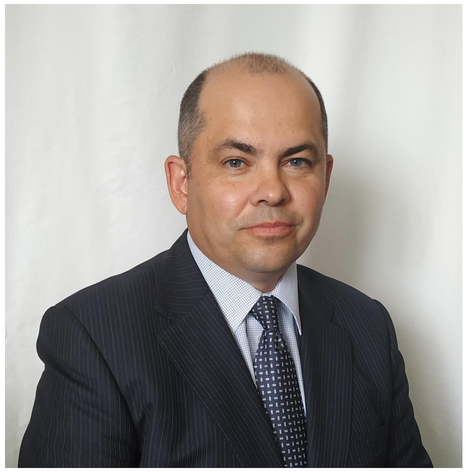
Editor Lawrence K. Wang has served the society as a professor, inventor, chief engineer, chief editor and public servant (UN, USEPA, New York State) for 50+ years, with experience in entire field of environmental science, technology, engineering and mathematics (STEM). He is a licensed NY-MA-NJ-PA-OH 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).