Lenox Institute Press

Newtonville, NY, USA; Auburndale, MA, USA

Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics (STEAM) Series

HUMANITARIAN ENGINEERING EDUCATION OF THE LENOX INSTITUTE OF WATER TECHNOLOGY AND ITS NEW POTABLE WATER FLOTATION PROCESSES

Authored by:

Lawrence K. Wang, PhD, PE, DEE

Retired Acting President and Professor

Lenox Institute of Water Technology

Address: 1 Dawn Drive, Latham, NY 12110-5305, USA

lawrencekwang@yahoo.com

Wang, Lawrence K. (2019). Humanitarian engineering education of the Lenox Institute of Water Technology and its new potable water flotation processes. In: "*Evolutionary Progress in Science, Technology, Engineering, Arts, and Mathematics (STEAM)",* Wang, Lawrence K. and Tsao, Hung-ping (editors). Volume 1, Number 6, June 2019; 160 pages. Lenox Institute Press, Newtonville, NY, 12128-0405, USA. No. STEAM-VOL1-NUM6-JUN2019; ISBN 978-0-9890870-3-2. US Department of Commerce, National Technical Information Service, 5301 Shawnee Road, Alexandria, VA 22312, USA.

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*
15-06-2019

2. REPORT TYPE
TECHNICAL PROGRESS REPORT

3. DATES COVERED *(From - To)*
JAN 1977-JUN 2019

4. TITLE AND SUBTITLE

HUMANITARIAN ENGINEERING EDUCATION OF THE LENOX INSTITUTE OF WATER TECHNOLOGY AND ITS NEW POTABLE WATER FLOTATION PROCESSES

5a. CONTRACT NUMBER NA

5b. GRANT NUMBER NA

5c. PROGRAM ELEMENT NUMBER NA

6. AUTHOR(S)

Wang, Lawrence K.

5d. PROJECT NUMBER STEAM-VOL1-NUM6-JUN2019

5e. TASK NUMBER NA

5f. WORK UNIT NUMBER NA

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

LENOX INSTITUTE PRESS, PO Box 405, Newtonville, NY 12128-0405, USA

LENOX INSTITUTE, 160 Pine Street, Suite 19, Auburndale, MA 02466, USA

8. PERFORMING ORGANIZATION REPORT NUMBER
STEAM-VOL1-NUM6-JUN2019

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Wang, Lawrence K. and Tsao, Hung-ping (editors). "*Evolutionary Progress in Science, Technology, Engineering, Arts, and Mathematics (STEAM)",* Volume 1, Number 6, June 2019; Lenox Institute Press, PO Box 405, Newtonville, NY, 12128-0405, USA

10. SPONSOR/MONITOR'S ACRONYM(S)
LENOX

11. SPONSOR/MONITOR'S REPORT NUMBER
STEAM-VOL1-NUM6-JUN2019

12. DISTRIBUTION / AVAILABILITY STATEMENT

NO RESTRICTION

13. SUPPLEMENTARY NOTES
REGISTRATION ISBN 978-0-9890870-3-2

14. ABSTRACT The histories of the Lenox Institute of Water Technology (LIWT), Krofta Engineering Corporation (KEC), their joint humanitarian engineering education and their step-by-step joint research leading to the development of various flotation drinking treatment processes, including the first drinking water flotation plant in Americas (Lenox Water Treatment Plant) and the once the largest drinking water flotation plant in the world (Pittsfield Water Treatment Plant) are presented. Also documented are their leaders, inventors, educators, co-designers, governmental officers, design concepts, flow diagrams, DAF-filtration (DAFF), plant performance, awards, DAF/DAFF future and related references. The flotation processes invented by LIWT, manufactured by KEC, and financed and collaborated by the above dedicated people are introduced: (a) dispersed air flotation; (b) electroflotation; (c) dissolved air flotation; (d) (e) two stage DAF-DAF clarifier system; (f) sedimentation-DAF clarifier; (g) DAF-filtration, or DAFF; (h) two stage DAF-DAFF clarifier system; (i) sequencing batch dissolved gas flotation; (j) sequencing batch induced gas flotation and (k) DAF-press thickener; (l) two-stage DAF-DAF water softening plant using magnesium carbonate as a recyclable coagulant, etc.

15. SUBJECT TERMS Lenox Institute of Water Technology, Krofta Engineering Corporation, Milos Krofta, Lenox Plant, Pittsfield Plant, DAF, DAFF, electroflotation, 2 stage DAF-DAF, sedimentation-DAF, 2 stage DAF-DAFF; sequencing batch DAF, physical-chemical SBR, DAF-press thickener, 2 stage DAF-DAF water softening, magnesium carbonate coagulant., humanitarian engineering, education

16. SECURITY CLASSIFICATION OF:
UNCLASSIFIED UNLIMITED (UU)

a. REPORT UU	**b. ABSTRACT** UU	**c. THIS PAGE** UU

17. LIMITATION OF ABSTRACT
UU

18. NUMBER OF PAGES
160

19a NAME OF RESPONSIBLE PERSON
Wang, Lawrence K.

19b TELEPHONE NUMBER *(include area code)* (518) 250-0012

HUMANITARIAN ENGINEERING EDUCATION OF THE LENOX INSTITUTE OF WATER TECHNOLOGY AND ITS NEW POTABLE WATER FLOTATION PROCESSES

Authored by:

Lawrence K. Wang, PhD, PE, DEE

TABLE OF CONTENTS

HUMANITARIAN ENGINEERING EDUCATION OF THE LENOX INSTITUTE OF WATER TECHNOLOGY AND ITS NEW POTABLE WATER FLOTATION PROCESSES

Authored by: Lawrence K. Wang (王抗曝)

ABSTRACT

It has been more than 37+ years since the first dissolved air flotation (DAF) drinking water treatment plant in the Americas came on line in Lenox, Massachusetts, USA in 1982. Since that time, the innovative DAF process – long favored for treating a wide variety of waste solids – has grown to become a popular process for drinking water plants in Americas and throughout the entire world .

The story of how the Lenox Water Treatment Plant (LWTP) , and a much larger sister plant, Pittsfield Water Treatment Plant (PWTP), both in Massachusetts, USA, has blazed the trail for the current innovative wave of DAF-based potable water treatment plants. The author has participated in the conceptual development, laboratory tests, patent application, pilot plant demonstration, endless legal battles, State permit applications, and final construction of the awarding winning LWTP and PWTP.   It is the author's honor and also the obligation to record this historical development of one of outstanding innovations of this century.

This book chapter documents the impressive histories of a humanitarian flotation engineering college (Lenox Institute of Water Technology, or LIWT), a flotation manufacturer (Krofta Engineering Corporation, or KEC), the first drinking water

flotation plant in Americas (Lenox Water Treatment Plant, LWTP), once the largest drinking water flotation plant in the world (Pittsfield Water Treatment Plant, PWTP). Also documented are their leader (Dr. Milos Krofta), inventors, educators, co-designers, governmental officers, design concepts, flow diagrams, DAF-filtration (DAFF), plant performance, awards, DAF/DAFF future and related references. The details of flotation process chemistry, material balances, engineering calculations, hydraulics, water quality analysis, energy consumption, cost estimations, etc. can be found from the literature of this book chapter. Many innovative potable water flotation processes jointly invented by LIWT, manufactured by KEC, and financed and collaborated by the above dedicated people are recorded here: (a) dispersed air flotation, or induced air flotation, or Foamer; (b) electroflotation; (c) dissolved air flotation, or DAF, or Supracell; (d) (e) two stage DAF-DAF clarifier system, or Supracell-Supracell system; (f) sedimentation-DAF clarifier, or SediFloat; (g) DAF-filtration, or DAFF, or Sandfloat; (h) two stage DAF-DAFF clarifier system; (i) sequencing batch dissolved gas flotation, (j) sequencing batch induced gas flotation and (k) DAF-press thickener (FloatPress), (l) two-stage DAF-DAF water softening plant using magnesium carbonate as a recyclable coagulant, (m) DAF-membrane process combination, (n) circular automatic backwash filtration for dual-media filtration or GAC filtration; and (0) author’s conceptually developed cream flotation process . This book chapter is intended to be the author’s unofficial memoir which records some author’s lifetime professional experience for reference by future generations. This book chapter is also written in memory of Dr. Milos Krofta, who was the founder and President of both LIWT and KEC as well as the author’s best friend and mentor. Although the academic process names (DAF, DAFF, etc.) and the company brand names (Supracell, Sandfloat, etc.) are used interchangeably throughout the book chapter, the author introduces these new innovative process

ideas in general. The shape of a flotation clarifier can be either circular or rectangular. The unit processes can be either individual process units or the packaged units. It is the author's wish as well as Dr. Krofta's 90th birthday wish that the innovative ideas conceived and the processes developed by LIWT/KEC may be freely adopted or further improved upon by all flotation engineers, scientists, researchers, managers, and manufacturers in the world. The author acknowledges important flotation process contributors, and hopes that the proposed new research directions may be followed and accomplished by young researchers.

Keywords: Milos Krofta, Humanitarian engineering education, Lenox Institute of Water Technology (LIWT), Krofta Engineering Corporation (KEC), Century potable water Innovations, Dissolved air flotation (DAF), Supracell, Flotation-filtration (DAFF), Sandfloat, Drinking water, Lenox Water Treatment Plant (LWTP), Pittsfield Water Treatment Plant (PWTP), Massachusetts, USA, North America, South America, Historical plants, Dispersed air flotation, Induced air flotation, Foamer, Electroflotation, Sedimentation-DAF, SediFloat , Two-stage DAF-DAF system, Two-stage DAF-DAFF system, Sequencing batch sedimentation (Sedimentation-SBR), Sequencing batch dissolved air flotation (DAF-SBR), Flotation-press thickener, FloatPress, Two-stage DAF-DAF softening process, Magnesium carbonate, Recyclable coagulant, Flotation-membrane process combination, Circular automatic backwash filtration for sand filtration, dual-media filtration or GAC filtration, Cream flotation, New research direction, Awards, Flotation process contributors

NOMENCLATURE

$CaCO_3$	calcium carbonate
$Ca(HCO_3)_2$	calcium bicarbonate
$Ca(OH)_2$	calcium hydroxide
$CaSO_4$	calcium sulfate
CDBAC	cetyldimethylbenzylammoniumchloride
CO_2	carbon dioxide
H_2O	water
$MgCO_3$	magnesium carbonate
$Mg(HCO_3)_2$	magnesium bicarbonate
$Mg(OH)_2$	magnesium hydroxide
$MgSO_4$	magnesium sulfate
Na_2CO_3	sodium carbonate
Na_2SO_4	sodium sulfate

HUMANITARIAN ENGINEERING EDUCATION OF
THE LENOX INSTITUTE OF WATER TECHNOLOGY AND
ITS NEW POTABLE WATER FLOTATION PROCESSES

1. LENOX INSTITUTE OF WATER TECHNOLOGY (LIWT) FOR FLOTATION RESEARCH AND EDUCATION AND KROFTA ENGINEERING CORPORATION (KEC) FOR FLOTATION EQUIPMENT MANUFACTURING

The use of old dissolved air flotation (DAF) and dispersed air flotation technologies for solids separation was common in Europe and Asia as early as 1950s (1-78). Old DAF technology became known in North and South Americas in the late 1970s when Dr. Milos Krofta, who was an outstanding mechanical and paper engineer, established Krofta Engineering Corporation (KEC) in Massachusetts, USA, for manufacturing DAF clarifiers to be used in his own areas of expertise, namely de-inking of waste paper pulp and fiber separation. KEC was an international company with branch offices around the world. Dr. Krofta was mainly assisted by Daniel Guss, VP.

In 1978, with the authors' encouragement and assistance, Dr. M Krofta established the not-for-profit Lenox Institute for Research (LIR), and later changed its name from LIR to Lenox Institute of Water Technology (LIWT). The author, Lawrence K. Wang and his wife, Mu-Hao Sung Wang, were initially invited as the LIR/LIWT consultants, and subsequently appointed to be the Institute Director and Adjunct Professor, respectively, with the purposes of: (a) developing flotation process equipment to be used in conjunction with other physical-chemical and biological processes for various applications, such as drinking water treatment, wastewater treatment, algae harvesting, ore separation, sludge thickening, etc. (1-

222); (b) obtaining the US and foreign patents for the Institute, and giving licenses of patent application rights to KEC and other companies or government agencies in exchange of their grants or other types of financial supports to the Institute and students; and (c) developing the Institute as an accredited graduate college offering the degree of "Master of Engineering in Water Technology", Postdoctoral Certificate, and continuing education for educating more qualified flotation engineers, managers or researchers. The LIWT Master's degree program (34 Credit Hour) was licensed by the Commonwealth of Massachusetts, USA. LIWT was also a sponsor of the International Association for Continuing Education and Training and so it awarded CEU credits. An excellent LIWT library had cooperative agreements with the libraries of Rensselaer Polytechnic Institute and the University of Massachusetts. All LIWT graduate credits were accepted by area Universities for their PhD programs.

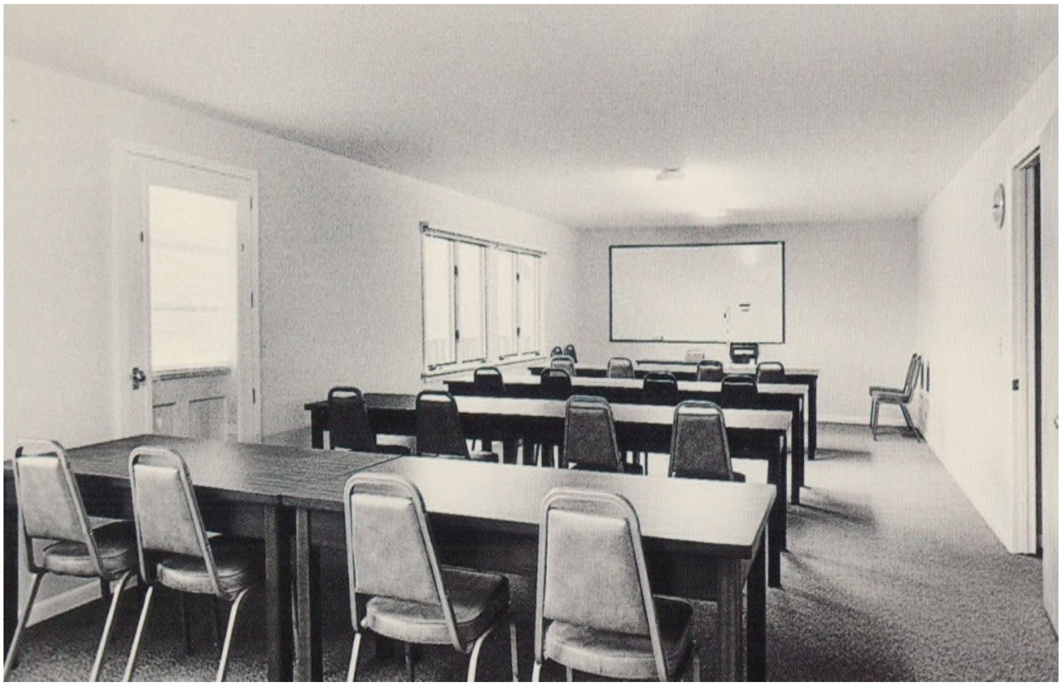
Dr. Krofta, the author, and many other appointed faculty members, such as Dr. Mu-Hao Sung Wang, Dr. Nazih K. Shammas, Dr. Donald B. Aulenbach, Dr. William A. Selke, Dr. Hermann H. Hahn, Dr. James P. Smith, etc. are highly qualified flotation experts. A student admitted to the Master degree program had at least a 4-year BS/BE/BA degree. For an environmental professional who wished to advance his/her career, but did not need a Master degree might receive a Certificated in Water Science and Engineering after he/she completed 14 credit hours (equivalent to 21 Continuing Education Units). All students received full scholarship or Internship (including their living expenses).

Figure 1 to 6 document the LIWT campus, facility, and program curriculum. The Institute occupied over 18,000 square feet of classroom (Figures 1, 2 and 3), laboratory and supporting research equipment and facilities (Figures 4, 5 and 6). Its research facilities featured advanced testing ad bench equipment to support faculty and student work, as well as the Institute's R&D functions. A fully staffed and equipped machine shop (Figure 5) was available to build, modify or test experimental devices. The authors and Betty C. Wu (MS), developed the Institute's modern chemical and microbiological laboratories which were equipped with AA, GC, MS, TOC, COD, BOD, spectrophotometers, turbidity meters, toxicity analyzers, ozone generators, ovens, digesters, incubators, balances, Jar Tester, DAF tester, particle counter, coliform tester, counters, sand filters, GAC filters, settlers, vacuum filters, stereoscopic microscopes, dryers, monitoring instrument, etc. The LIWT laboratory (Figures 4) was certified by the States of New England and the States of NY, PA and NJ, where the LIWT and KEC had flotation projects. The LIWT laboratory's functions included: (a) providing external public services at minimum charges as a not-for-profit organization; and (b) performing internal sample analyses and bench-scale tests, in turn, suggesting optimum methods for water and wastewater treatment, process improvement, system monitoring, pollution control, and sample analyses. Students were educated to understand all aspects of physical-chemical and biological processes (including flotation technology), their process monitoring, cost estimation, process control and influent/effluent/sludge analyses. (74-79, 94-168, 172-178, 180-189)

An array of pilot plant units (Figures 5 and 6) offered students experience with crucial aspect of effective training in the flotation applications. These pilot plant units included: dissolved air flotation clarifiers, dispersed air foam flotation clarifiers (or dispersed air flotation clarifiers), sedimentation-flotation clarifier, fractionators (spray filters), plastic media filtration pilot plant, flocculation pilot plant, sand filter pilot plant, granular activated carbon pilot plant, cooling tower, gas stripper, belt press, and ozone generators.

[Insert Figure 1. Lenox Institute of Water Technology (LIWT), Massachusetts, USA]

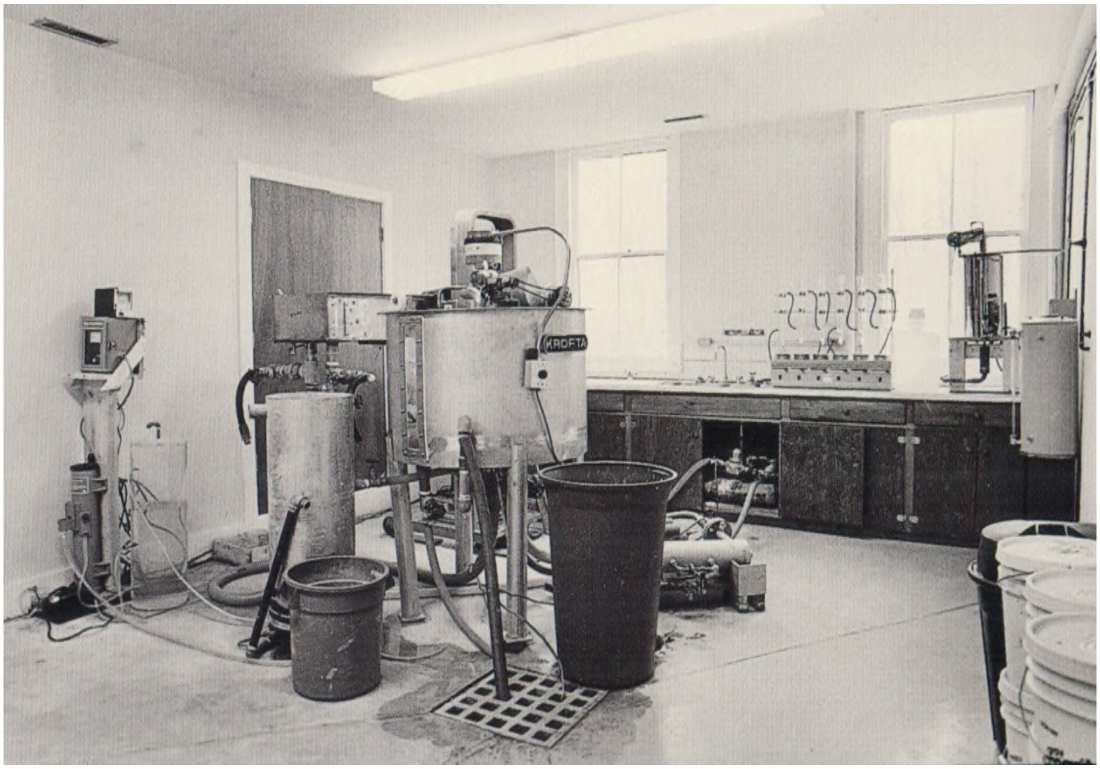
[Insert Figure 2. Beautiful Lenox Institute campus with a lake]



[Insert Figure 3. A Lenox Institute classroom (shown) and a computer room (not shown)]

[Insert Figure 4. A chemical laboratory (shown), an instrumentation room (not shown) and a microbiology laboratory (not shown)]

[Insert Figure 5. Lenox Institute machine shop and pilot plant rooms]



[Insert Figure 6. One of Lenox Institute pilot plant room for testing flotation processes]

Each student required completion of at least 34 credit hours (Table 1) toward graduation with a Master degree. The Institute did fulfill its noble mission - - Between 1981 and 2002, it educated over 200 highly qualified flotation engineers, scientists and managers who are now proudly serving their home countries around the world, . Dr. Krofta passed away soon after he celebrated his 90th birthday, and his beloved LIWT also ended its 100% tuition-free graduate program. Figure 7 shows Dr. LK Wang awarded the Master degree diploma to one of the graduate students. Figure 8 is a photo of Dr. and Mrs. Krofta and Dr. MHS Wang. After LIWT's mission completion, the faculty members (the author, Dr. Mu-Hao Sung Wang, Dr. Nazih K. Shammas, Dr. Donald B. Aulenbach, Dr. William A. Selke, Dr. Hermann H. Hahn, Daniel Guss, Betty C. Wu) of LIWT have continuously maintained this Institute's spirit (also Dr. Krofta's 90th birthday wish) in offering educational seminars and workshops, conducting R&D investigations, and publishing academic papers and books. Their important publications include hundreds of US Federal government reports, the Handbook of Environmental Engineering series (Springer/Humana Press, Switzerland), the Advances in Industrial and Hazardous Wastes Treatment series (CRC Press/Taylor & Francis Group, USA), Water and Wastewater Engineering textbook series (John Wiley, USA), and the Handbook of Environment and Waste Management series (World Scientific, Singapore). Most of the books published by the LIWT faculty members are the updated versions of previous LIWT lecture materials. Typical examples of the LIWT textbooks are listed in below in comparison with the course numbers listed in Table 1:

(a) Wang, LK, NC Pereira, YT Hung, Biological Treatment Processes, Humana Press, 818 pages, 2009. (BIO-501)

(b) Wang, LK, NK Shammas, YT Hung, Advanced Biological Treatment Processes, Humana Press, 738 pages, 2009. (BIO-501)

(c) Wang, LK, NK Shammas, YT Hung, Biosolids Treatment Processes, Humana Press, 820 pages, 2007. (BIO-502)

(d) Wang, LK, NK Shammas, YT Hung, Biosolids Engineering and Management, Humana Press, 800 pages, 2008. (BIO-503)

(e) Wang, LK, YT Hung, NK Shammas, Physicochemical Treatment Processes, Humana Press, 723 pages, 2005. (PHC-561)

(f) Wang, LK, YT Hung, NK Shammas, Advanced Physicochemical Treatment Processes, Humana Press, 690 pages, 2006. (PHC-562)

(g) Wang, LK, YT Hung, NK Shammas, Advanced Physicochemical Treatment Technologies, Humana Press, 710 pages, 2007. (PHC-562)

(h) Wang, LK, NK Shammas, WA Selke, and DB Aulenbach, Flotation Technology, Humana Press, 680 pages, 2010. (FLO-541, FLO-542 and FLO-543)

(i) Krofta, M. and LK Wang. Flotation Engineering. Lenox Institute of Water Technology, Lenox, MA, USA. Technical Manual No. Lenox-1-06-2000/368. (2000) (FLO-541, FLO-542 and FLO-543)

(j) AWWA, WEF, APHA, Standard Methods for the Examination of Water and Wastewater. (LAB-551)

(k) Shammas, NK and LK Wang, Water Supply and Wastewater Removal. John Wiley & Sons. 820 pages, 2011. (LAB-551)

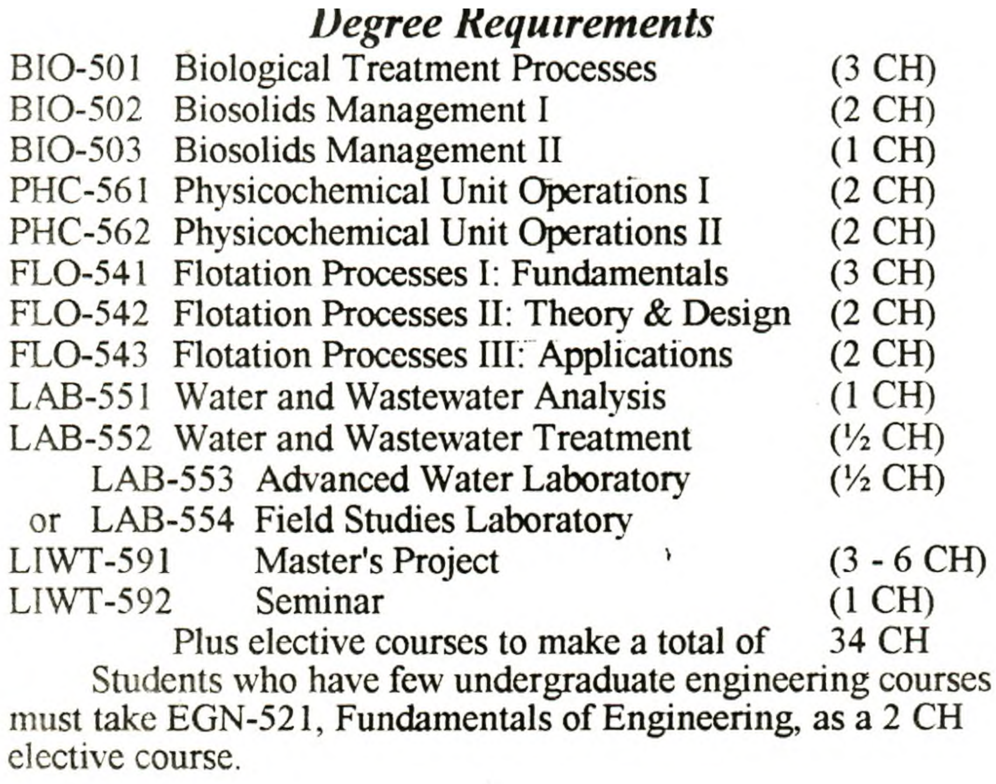
(l) Shammas, NK and LK Wang, Water Engineering. John Wiley & Sons. 806 pages, 2016. (LAB-552)

(m) Krofta, M, LK Wang, and MHS Wang. Laboratory Simulation and Optimization of Physical-Chemical Treatment Processes. US Dept. of

Commerce, National Technical Information Service, NTIS-PB86-188794/AS, 42 pages, 1985. (LAB-553)

(n) Wang, LK, MHS Wang, YT Hung, and NK Shammas. Natural Resources and Control Processes. Springer, 632 pages, 2016. (LAB-554)

The above typical LIWT textbooks indicate the caliber of Lenox professors (M Krofta, LK Wang, MHS Wang, NK Shammas, WA Selke and DB Aulenbach) and the quality of advanced education that the LIWT provided to the students. The mission of the Lenox Institute of Water Technology was completed in terms of : (a) developing many flotation technologies as well-established processes for water purification, domestic sewage treatment, industrial effluent treatment, sludge thickening, algae harvesting, ore mining, fiber recovery, fish powder recovery, arsenate removal, groundwater remediation, etc. in the world; (b) obtaining many process equipment patents in the US and foreign countries based on the Institute's research; (c) collaborating with KEC and other companies for pilot plant demonstrations, process equipment manufacturing, and commercialization of Lenox inventions; (d) transferring Lenox technologies in exchange of financial supports to the Institute and its faculty and students; (e) training of plenty flotation engineers, scientists and managers who can and are willing to work in the field of environmental flotation technology ; and (f) distributing the well-established environmental flotation knowledge to the general public through academic presentations and publications.



Degree Requirements

BIO-501	Biological Treatment Processes	(3 CH)
BIO-502	Biosolids Management I	(2 CH)
BIO-503	Biosolids Management II	(1 CH)
PHC-561	Physicochemical Unit Operations I	(2 CH)
PHC-562	Physicochemical Unit Operations II	(2 CH)
FLO-541	Flotation Processes I: Fundamentals	(3 CH)
FLO-542	Flotation Processes II: Theory & Design	(2 CH)
FLO-543	Flotation Processes III: Applications	(2 CH)
LAB-551	Water and Wastewater Analysis	(1 CH)
LAB-552	Water and Wastewater Treatment	(½ CH)
LAB-553	Advanced Water Laboratory	(½ CH)
or LAB-554	Field Studies Laboratory	
LIWT-591	Master's Project	(3 - 6 CH)
LIWT-592	Seminar	(1 CH)
	Plus elective courses to make a total of	34 CH

Students who have few undergraduate engineering courses must take EGN-521, Fundamentals of Engineering, as a 2 CH elective course.

[Insert Table 1. Lenox Institute of Water Technology's Curriculum of Master of Engineering in Water Technology]

[Insert Figure 7. Dr. Lawrence K. Wang, Dr. Nazih K. Shammas, Dr. Donald B. Aulenbach of LIWT with some graduating students on Lenox campus]

[Insert Figure 8. Dr. and Mrs. Milos Krofta with Dr. Mu-Hao Sung Wang who learned Dr. Krofta's 90th birthday wish]

2. REVIEW OF ALL POSSIBLE FLOTATION TECHNOLOGIES FOR WATER PURIFICATION

2.1 Introduction

The Lenox Institute of Water Technology (LIWT) began to review all possible flotation technologies which may be used for water purification.

In all flotation processes, micro air bubbles attach to flocculated particles, suspended solids, surface active substances, etc. carrying them to the surface where they are collected and removed. The flotation process is particularly effective for lighter particles, such as in algae, which are more easily floated to the top of the treatment structure than they are weighted to the bottom.

There are several different kinds of flotation separation technologies, of which DAF is one. Depending on the influent water and the contaminants involved, a flotation treatment operation may use any of the following methods. The results of their reviews are presented in the following sections.

2.2 Review of Dissolved Gas Flotation (DGF)

DGF 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 non-selective flotation (i.e. Save-All). Since dissolved gas flotation is achieved using any kinds of extremely fine gas bubbles generated from a gas dissolving tube or tank under high pressure and laminar hydraulic conditions; DGF becomes DAF when using air bubbles; DAF was finally selected for construction of water purification plants; DAF is suitable for both small and large communities.

2.3. Review of Dispersed Gas Flotation

Dispersed gas flotation (or induced gas flotation IGF, or foam separation, or froth flotation) is a process involving introduction of gas directly into the water through a revolving impeller, a diffuser system, or an ejector, or a combination of them, at low pressure (slightly higher than one atm) for generating big gas bubbles (80 microns to over one mm) in large volume under turbulent hydraulic flow conditions. The gas flow rate is about 400 percent of the influent water flow rate. Physical entrapment and electrochemical attraction play minor roles in an induced gas flotation system. The attachment of gas bubbles to the impurities is mainly a result of surface adsorption, gas stripping and oxidation. Surface active substances (inks, detergents, ores, soaps, etc.) together with impurities are selectively separated in a foam phase at the water surface. The foam containing the surfactant and the impurities are removed by suction device, Volatile substances are removed by gas stripping action. The clarified waster is discharged from the flotation clarifier’s bottom. Reducing agents, such as ferrous ions, can be oxidized to ferric ions for subsequent separation in ferric hydroxide form if air is used as a gas.

Since this flotation is achieved using lost cost coarse gas bubbles generated under low pressure and turbulent hydraulic conditions, this process was initially selected for investigation and demonstration, but was not selected for full scale plant construction because the surfactant to be used in the process as a collector would require the review and approval by the US Environmental Protection Agency (USEPA) and local governments.

2.4 Review of Electroflotation

Electroflotation is a process involving the generation of hydrogen and oxygen bubbles in a dilute electrolytic aqueous solution by passing a direct current between two electrodes (a) anode and (b) cathode. Anode reaction generates oxygen bubbles and hydrogen ions; while cathode reaction generates hydrogen bubbles and hydroxide ions. Either aluminum or steel sacrificial electrodes can be employed for generating the gas bubbles as well as coagulants at the same time. Non-sacrificial electrodes are employed for generating the gas bubbles only, and can be mode of titanium (as the carrier material) and lead dioxide (as the coating material). Electrical power is supplied to the electrodes at a low voltage potential of 5 to 20 volts DC by means of a transformer rectifier. Small bubbles in the range of 20-50m microns are produced under laminar hydraulic flow conditions feasible for flotation separation of fragile flocs from water in a small system. The floats on the water surface are the impurities/pollutants removed from water. The clarified water is discharged from the flotation clarifier’s bottom. There can be unexpected advantages and disadvantages when electroflotation is employed. For instance, chlorine bubbles may be generated as a water disinfectant if the water contains significant amount of chloride ions. Certain unexpected gas bubbles may be generated and may be undesirable. (151) Since electroflotation is achieved using hydrogen and oxygen (or chlorine when many chlorides are present) bubbles generated between anode and cathode electrodes, this more complex process was selected for research and development. A small potable water electroflotation process unit was developed for small communities. (102, 134)

2.5 Review of Vacuum Flotation

In a vacuum flotation system, the influent process water to be treated is usually almost saturated with air at atmospheric pressure. There is an air-tight enclosure on the top of the flotation chamber in which partial vacuum is maintained. The fine air bubbles (20-80 microns) are generated under laminar hydraulic flow conditions by applying a vacuum (negative pressure) to the flotation chamber. The theory is that the lower the pressure, the lower the air solubility in water. The soluble air originally in water is partially released out of solution as extremely fine bubbles due to a reduction in air solubility caused by negative vacuum pressure. The bubbles and the attached solid particles rise to the water surface to form a scum blanket, which can be removed by a continuous scooping or skimming mechanism. Grit and other heavy solids that settle to the bottom are raked to a central sludge sump for removal. Auxiliary equipment includes an aeration tank for saturating the water or wastewater with air, vacuum pumps, and sludge pumps. (151) Since vacuum flotation is achieved using the gas bubbles generated by negative vacuum pressure that suck out the soluble gas in water originally; the process is not suitable for potable water treatment because the dissolved gas in water usually is not high due to low solubility of air. Vacuum flotation works for the gases (such as carbon dioxide) with high solubility in water.

2.6 Review of Biological Flotation

In a biological flotation system, fermentations take place in the presence of anaerobic bacteria, nitrates and substrates under anaerobic environment, anaerobic bacteria in waste sludge convert nitrate and the substrate with carbon source (such as methanol, or residual BOD) to nitrite, water and carbon dioxide fine bubbles. Nitrite further reacts with a substrate (such as methanol or residual BOD) in the same waste sludge, producing fine nitrogen bubbles, more fine carbon dioxide bubbles, water and hydroxide ions. The biological waste sludge, such as activated sludge can then be floated to the surface by the fine nitrogen and carbon dioxide bubbles and be thickened (i.e. concentrated). The thickened sludge which are the final products of the biological flotation thickening process are skimmed or scooped off from the liquid sludge surface; while the subnatant clarified water is discharged from the biological flotation thickener’s bottom. The energy consumption of this process is low. Its detention time is long. More research is needed for this newly developed sludge thickening process (151). Since biological flotation is accomplished using mainly nitrogen and carbon dioxide bubbles (and under extreme anaerobic conditions, some methane and/or hydrogen sulfide gas) generated under anaerobic conditions in the presence of organics (Figure 9) ; it is obviously not suitable for potable water treatment.

2.7 Review of Deep Shaft Flotation

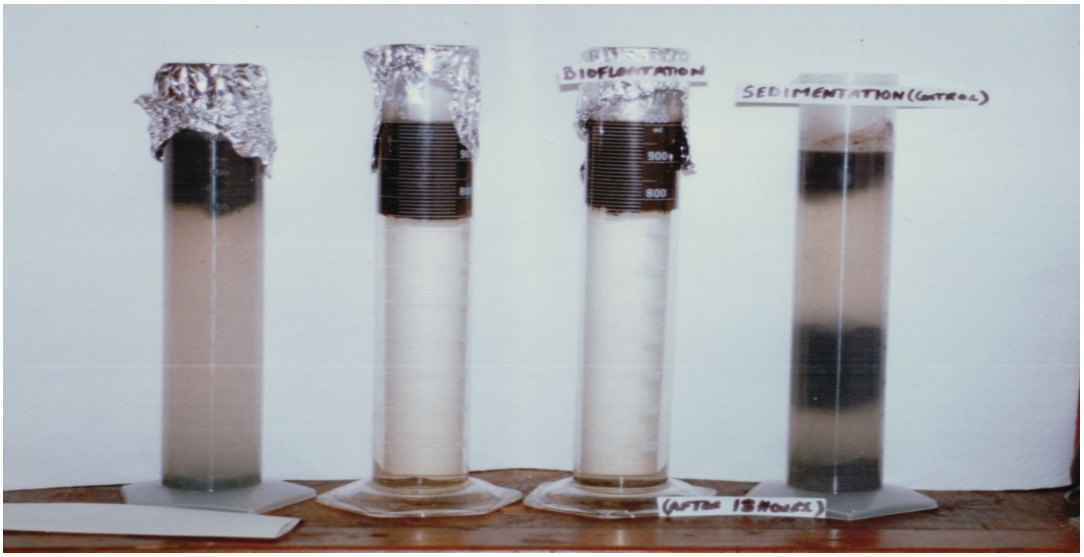
In a deep shaft flotation system (or micro-flotation system, or vertical shaft flotation system), the entire volume of water to be treated is subjected to the increased pressure by passing the water down and up a shaft approximately 10 meters deep. At the bottom of the shaft, on the down-comer side, air is injected by one air blower under low pressure (20 psig) . Un-dissolved air rises up the shaft against the flow thus increasing the saturation of the water. As the water rises in the up-flow section, the hydrostatic pressure decreases. Some of the soluble air is then released out of solution in the form of fine air bubbles due to a reduction in air solubility caused by pressure reduction. Floc agglomeration and bubble generation occur simultaneously and gently; providing good attachment of the air bubbles to the flocs. The amount of air which can be dissolved is limited by the depth of shaft (e.g. hydrostatic pressure provided). The saturation of the water with air at that depth is dependent on the way the air is introduced to the system. (e.g. size of air bubbles produced at point of injection.). Similarly the floats collected on water surface are the impurities/pollutants removed from the water. The floats are collected by a rotating sludge collection scoop or equivalent. The bottom flotation clarified water is discharged as the treated water (151). Since this deep shaft flotation is accomplished using the gas bubbles generated high pressure and laminar hydraulic conditions within an extremely long water column (such as a 500 ft. deep water well), it is not suitable for potable water treatment unless there is an existing water well available..

2.8 Review of Plain Gravity Flotation

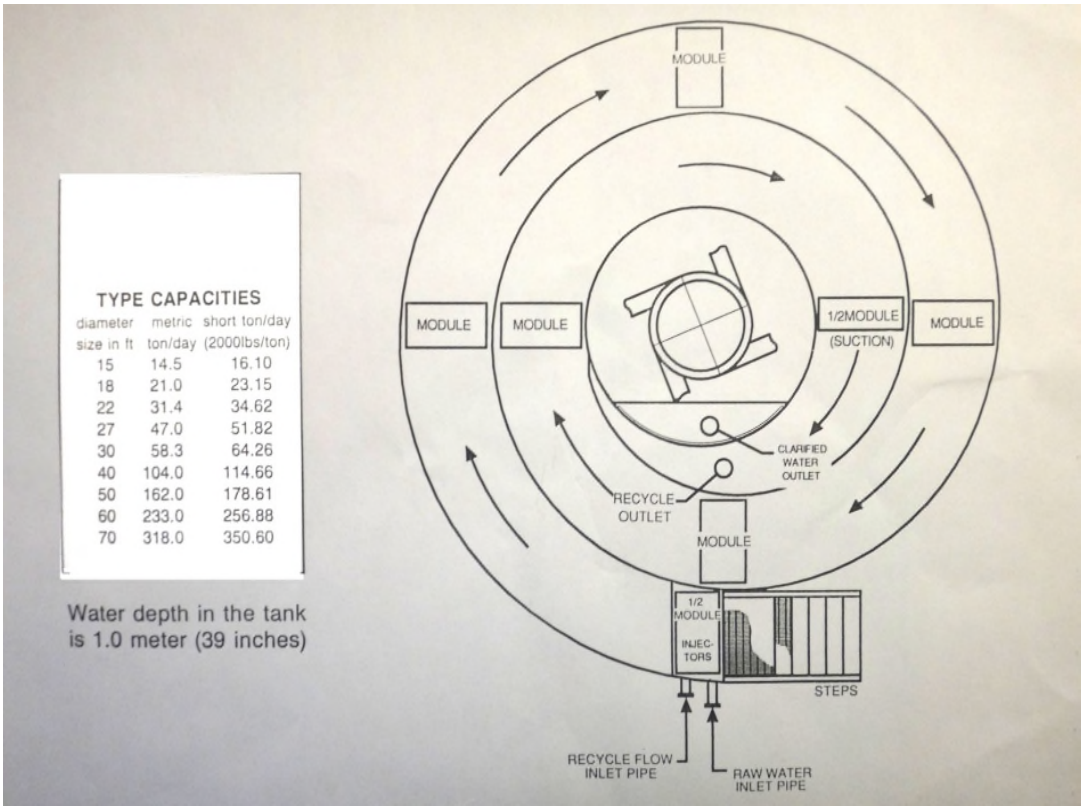
In natural gravity flotation, oil, grease, wax, fiber, or other substances lighter than water (specific gravity is less than 1) are allowed to rise naturally to the water surface of quiescent tank, where they are skimmed off or scooped off. The bottom clean water is discharged as the treated water. The floats skimmed off or scooped off from the water surface are either the impurities/pollutants to be removed, or the resources (such as fibers, or oils) recovered for reuse. Since gravity flotation is accomplished by gravity without any bubbles if the solids to be floated to the water surface are lighter than water (i.e. density is less than one), it is not suitable for potable water treatment. It is only good for oil-water separation, or wax-water separation, or fiber recovery.

.

The following are the author's view on the final process selection : (a) Dissolved gas flotation (DGS) is a nonfoaming process that can also feature several different catalysts. Ozone and carbon dioxide can also be used selectively in drinking water treatment. (b) DAF is one of DGF processes, and air is the gas of choice in the DAF drinking water treatment process due to the fact that air is sufficient to achieve the goals of the process and is the least expensive alternative; (c) The nature of all DGS (including DAF) methods involves creating a laminar flow, thereby avoiding turbulence and foam. This uniform upward flow is achieved by pressurizing, gas dissolving and then gas releasing into the clarification reactor for formation of fine gas bubbles, which account for only about 1 percent of the total flow (gas flow to water flow). (d) DAF is a non-selective process, because all contaminants that can be attached onto the gas bubble surface are separated. These contaminants include all suspended matter, colloids, chemical and microbial flocs, plant fibers, hardness solids, turbidity, color substances and precipitated heavy metals. (e) dispersed air flotation (or induced air flotation, or foam separation) needs a surfactant (such as CDBAC, or equivalent) as a collector or foaming agent, thus may not be suitable for potable water treatment until the surfactant is approved by the Federal and local governments for water purification. (f) electroflotation is suitable for potable water applications in individual homes or by small communities. (g) vacuum flotation, biological flotation, deep shaft flotation and plain gravity flotation are not suitable for potable water applications, therefore they were not studied by the LIWT for water purification research. Although biological flotation was not selected for further study, Figure 9 introduces this interesting process by an experiment using waste activated sludge. It can be seen that the carbon dioxide and methane gas bubbles generated under anaerobic condition successfully float the sludge to the water surface, and clarify the subnatant water phase. The following sections show the



[Insert Figure 9. Biological flotation of activated sludge under covered anaerobic condition, using uncovered gravity sedimentation as a control test.]



TYPE CAPACITIES

diameter size in ft	metric ton/day	short ton/day (2000lbs/ton)
15	14.5	16.10
18	21.0	23.15
22	31.4	34.62
27	47.0	51.82
30	58.3	64.26
40	104.0	114.66
50	162.0	178.61
60	233.0	256.88
70	318.0	350.60

Water depth in the tank is 1.0 meter (39 inches)

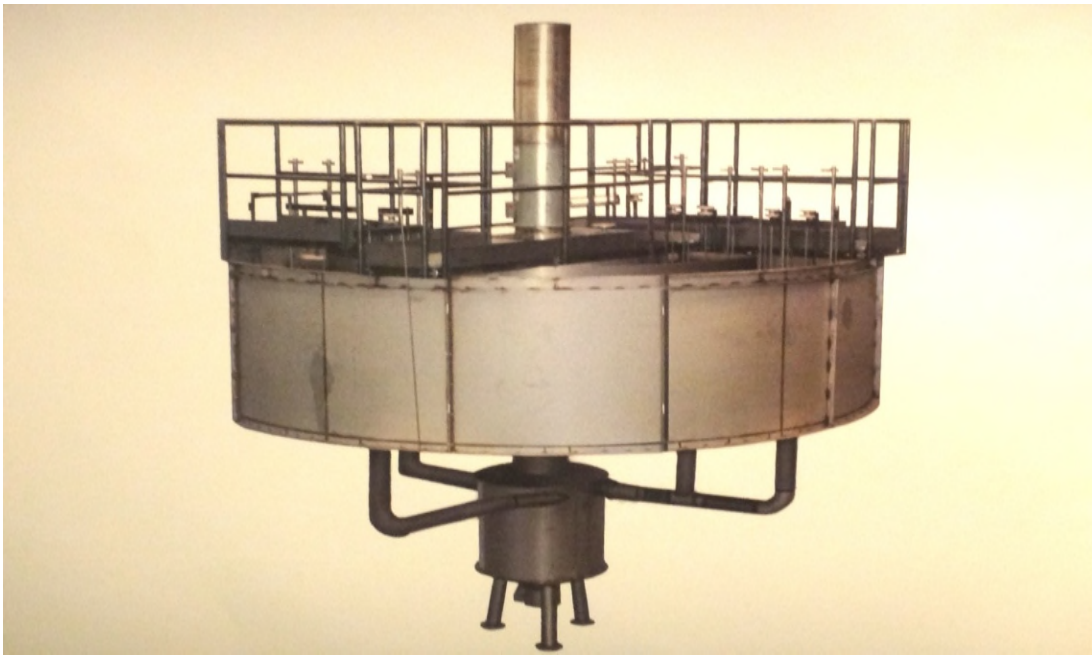
[Insert Figure 10. Flow diagram of a simplified dispersed air flotation clarifier (Foamer)]

step-by-step R&D projects conducted by the LIWT toward the final selection of DAF for the first two potable water flotation plants in Americas.

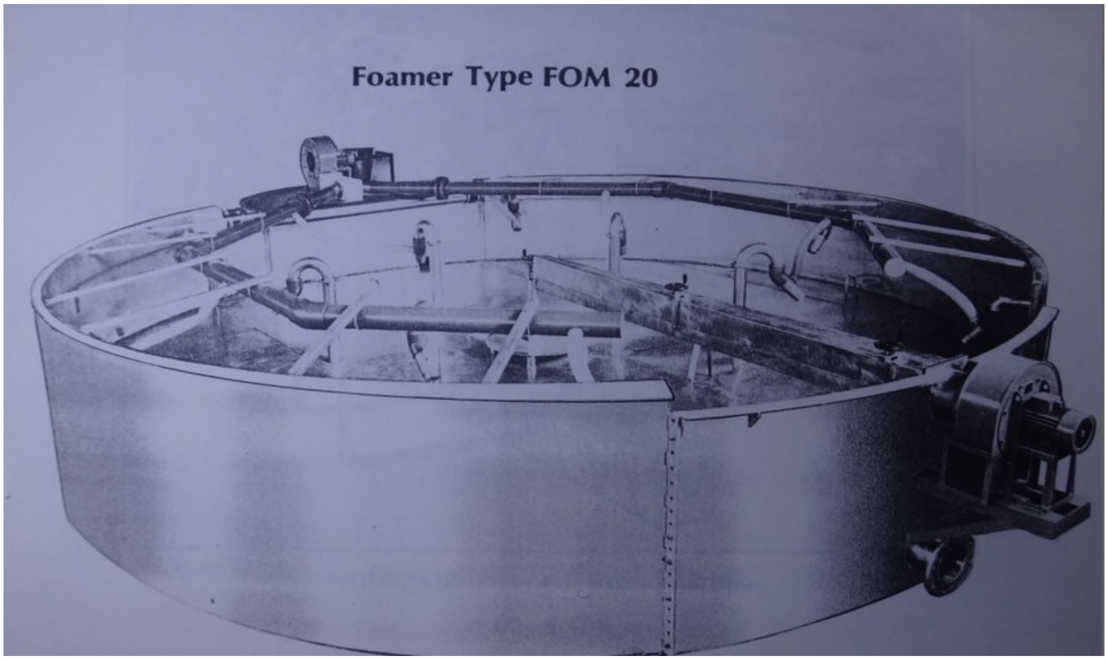
3. INITIAL SELECTION OF DISPERSED AIR FLOTATION (OR INDUCED AIR FLOTATION, OR FOAM SEPARATION) AS A WATER PURIFICATION PROCESS

Dispersed air flotation (or induced air flotation, or foam separation) was initially selected for developing as an innovative water purification process. Specifically dispersed air flotation is a process involving introduction of air directly into the water through a revolving impeller, a diffuser, or an ejector at low pressure (slightly higher than 1 atm) for generating large air bubbles (normally 80 microns to over 1 mm) in large volumes under turbulent conditions. The air flow rate is about 400% of influent liquid flow rate. Physical entrapment and electrochemical attraction play minor roles in a dispersed air flotation system. The attachment of air bubbles to the impurities is mainly a result of surface adsorption, gas stripping, and oxidation. Surface-active substances (CDBAC, inks, detergents, and so on) are selectively separated in foam phase. (20-21, 97, 107). Volatile substances are simultaneously removed gas stripping. Reducing agents, such as ferrous ions, can be simultaneously oxidized to ferric ions by air for subsequent separation in ferric hydroxide form. Dispersed air flotation can be used in ore separation, coal purification, fiber de-inking, surfactant separation, lignin separation, and so on. (30-31). Since CDBAC was developed as an effective organic disinfectant for environmental control (71), the authors combined both CDBAC and dispersed air flotation and developed: a sequencing batch dispersed air flotation (or sequencing batch foam separation) process, shown in a figure in the literature (107, 210, 228-229), and a continuous dispersed air flotation (or continuous foam separation) process, shown in Figures 10-12, which are potentially suitable for water purification or other applications. Krofta and Wang's research data were published by the US National Technical Information Service in 1983 (107).

Figure 10 shows the top view of a full scale dispersed air flotation (or induced air flotation, IAF; or Foamer; or foam separation), shown in Figure 11. Efficiency of the IAF clarifier (Figures 10-11) for foam separation is proportional to the surface area and not the depth of the clarifier depth. The full scale IDF clarifier has very low water head (1 meter or 39 inches) and surface area requirement is proportional to the water flow. The optimum foaming is achieved in a spiral formed channel where the influent is treated six times by repeatedly injecting the air through special jets and then aspirating the formed foam away. The IAF clarifier installed in one room recycles the air with minimum discharge.



[Insert Figure 11. A full-scale dispersed air flotation clarifier (Foamer) developed and manufactured by LIWT/KEC]



[Insert Figure 12. Another full-scale dispersed air flotation clarifier (Foamer) developed and manufactured by LIWT/KEC]

Figure 12 shows another full-scale IAF clarifier (Foamer) developed and commercialized by LIWT/KEC with a 20-ft. diameter and multiple air injectors. It is equally effective as a foam separation clarifier.

A sequencing batch dispersed air flotation (or sequencing batch induced air flotation, or sequencing batch foam separation) was also developed and patented (107, 189, 210, 229)

A complete continuous water treatment plant involving the use of a dispersed air flotation clarifier will include: screening, influent pumping, chemical feeding, pre-disinfection, coagulation, dispersed air flotation (Foamer) , filtration, carbon adsorption, post-disinfection, corrosion control. Carbon adsorption is needed for removal of any residual surfactant (CDBAC) that is used in dispersed air flotation clarifier (130). The entire innovative water purification system's flow diagram will be similar to a conventional water system, except that a dispersed air flotation clarifier is used for replacing a conventional sedimentation clarifier.

The Institute's initial research data related to the potable water dispersed air flotation system were published in JAWWA (71, 79) and by AIChE and US National Technical Information Service (107). The dispersed air flotation process is technically feasible for water purification because CDBAC is a chemical approved by FDA for human consumption. However, the water purification field is controlled by the USEPA and local governments. It would be very time-consuming and difficult for CDBAC to be approved as a drinking water treatment chemical by both the Federal and local governments. The invention is not wasted, however, CDBAC and its similar cationic surfactants are widely adopted later by the industry as an effective disinfectant for spray-can disinfectant, swimming pool algae control, roof moss control, and many other environmental control applications.

4. SUBSEQUENT SELECTION OF ELECTROFLOTATION FOR WATER PURIFICATION

The gas bubbles used in electroflotation consists of hydrogen and oxygen bubbles produced by the electrolysis of water (230). The chemical reactions occurring at the electrodes to produce these gas bubbles are:

(a) Anode reaction: $2\ H_2O = 4\ H^+ + O_2$ (bubbles) $+ 4\ e^-$

(b) Cathode reaction: $4\ e^- + 4\ H_2O = 2\ H_2$ (bubbles) $+ 4\ OH^-$

(c) Total reaction: $2\ H_2O = 2\ H_2$ (bubbles) $+ O_2$ (bubbles)

From the above reactions, it can be seen that for each flour electrons of current passed between the anode and cathode electrodes, one molecule of oxygen bubbles and two molecules of hydrogen bubbles are produced. Or in more specific terms, 0.174 mL of gas bubbles, measured at standard temperature and standard pressure, is produced by each coulomb of electric current. The extremely fine bubbles in the order of about 100 microns are formed at the electrodes of the electroflotation clarifier, and the bubbles rise to the clarifier's water surface as fine mist . Generation of fine hydrogen and oxygen bubbles through electrolysis reactions has many advantages: (a) Purity: since the gas bubbles are created from water and no actual handling or transport of the gases occurs before their use, gass bubbles remains uncontaminated; (b) Process control: controlling the rate of generation is easy because the more current applied, the more gas generated. Conversely, the less current applied, the less gas generated. (c) Simplicity: the resulting unit is easy to manufacture and simple in operation.

Figure 13 is a flow diagram of the LIWT/KEC potable water electroflotation-filtration plant. Figure 14 shows a small electroflotation-filtration water treatment plant commercially developed by LIWT/KEC for serving individual home owners, apartments, or small lake communities.

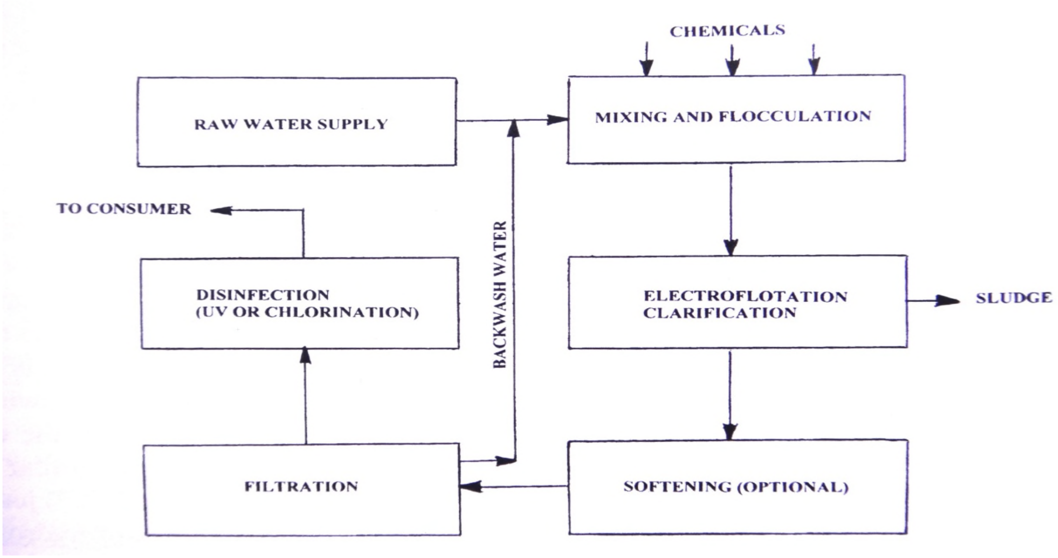
Figure 15 is an operational diagram showing how a complete electroflotation-filtration package plant is operated. It is noted from Figure 15 that raw water influent is pumped (Figure 15 # 4) into the plant through an influent pipeline. As this fluid enters the alum flocculation cylinder (Figure 15 # 10), it is mixed with a concentrated solution of alum which is pumped (9) to this point from the alum storage cylinder. The alum solution and the fluid swirl in this tank to form a precipitate called alum flocs. The liquid and floc emerge from the cylinder where another chemical, polyelectrolyte or sodium aluminate, is added in a similar fashion (Figure 15 # 11). The fluid then flows through a mixing cylinder (Figure 15 # 12) to a point in the tank (Figure 15 # 13) just below the electroflotation unit (Figure 15 # 14). This unit electrically separates the molecules of hydrogen and oxygen in the water and, thereby, forms gaseous bubbles which immediately rise to the water surface. These bubbles attach themselves to the flocs, which have now entrapped the foreign matter in the fluid, and rise to the surface. Being buoyant, the sludge floats on the water surface and is collected (Figure 15 # 16) and returned to the front section of the influent storage tank by the sludge discharge pump (Figure 15 # 17). Gaseous materials are removed through a vent and fan (Figure 15 # 39) . The fluid, which now fills the tank (Figure 15 # 13), is drawn down through the bottom of the tank by means of the discharge pump (Figure 15 # 32). As water flows down the tank, it passes through a layer of sand (Figure 15 # 24) and a fine screen where unfloated particulates are filtered out. The water then passes through an ultra violet (UV) disinfection unit (Figure 15 # 38) where pathogens are killed. The purified potable water product is now fit for domestic consumption.

Water flow from the filter is controlled by a flow meter (Figure 15 # 33). Water flow into the system from the influent pump (Figure 15 # 4) which is in excess of the purified outflow is bypassed back to the influent storage tank through a bypass line (Figure 15 # 7).

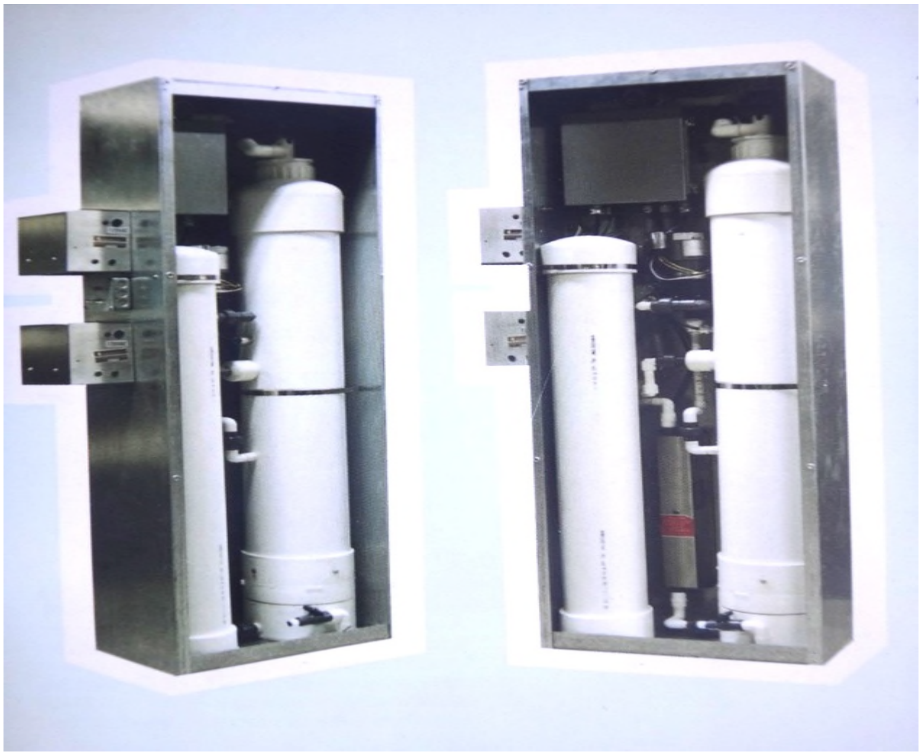
As material builds up in and on the surface of the sand, the flow through the sand decreases. In order to maintain the design flow in the water system over an extended period of time, the sand must be cleansed periodically. This is accomplished by a timer, which shuts off the influent flow and energizes the backwash cycle. During this short (20 seconds) cycle, water is pumped (Figure 15 # 28) back through the sand (Figure 15 # 24) from the clearwell (Figure 15 # 30). This backwash flow lifts the foreign matter from the sand. To facilitate this process, a small portion of the backwash water is diverted through a surface wash pipe (Figure 15 # 23) to help in the cleansing of the sand surface. The backwashed material is then collected (Figure 15 # 19) and discharged back to the influent storage tank by means of a wastewater recycle pump (Figure 15 # 20).

The excellent performance of the LIWT/KEC jointly developed electroflotation-filtration package plant can be found from the literature (134, 230). It has been used successfully for treating well water, lake water, and highly contaminated water. Due to high energy cost, the system was ruled out to be used for the City of Pittsfield, which had a population over 50,000.

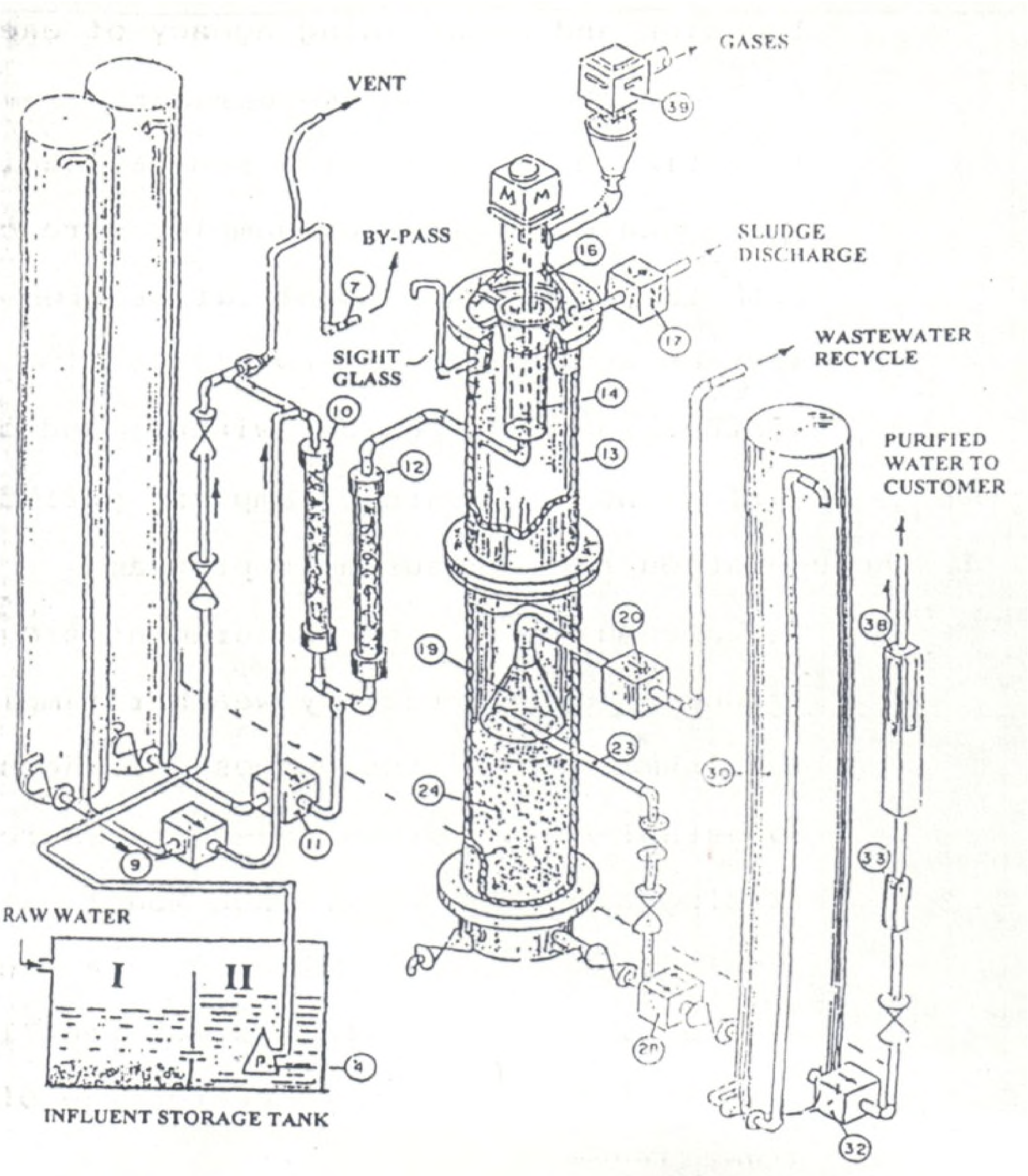
Other electroflotation application has been reported by Krofta and the author (102).



[Insert Figure 13. A flow diagram of the LIWT/KEC developed potable water electroflotation-filtration plant]



[Insert Figure 14. A small electroflotation-filtration water treatment plant developed by LIWT/KEC for serving individual home owners, apartments, or small lake communities.]



.

[Insert Figure 15. Operation of a complete electroflotation-filtration package plant.]

5. FINAL SELECTION DISSOLVED GAS FLOTATION AS A WATER PURIFICATION PROCESS

For developing an innovative water treatment system for large communities, the authors and the Institute dropped dispersed air flotation and electroflotation for water purification, and began investigation of dissolved gas flotation process for water purification instead. (221)

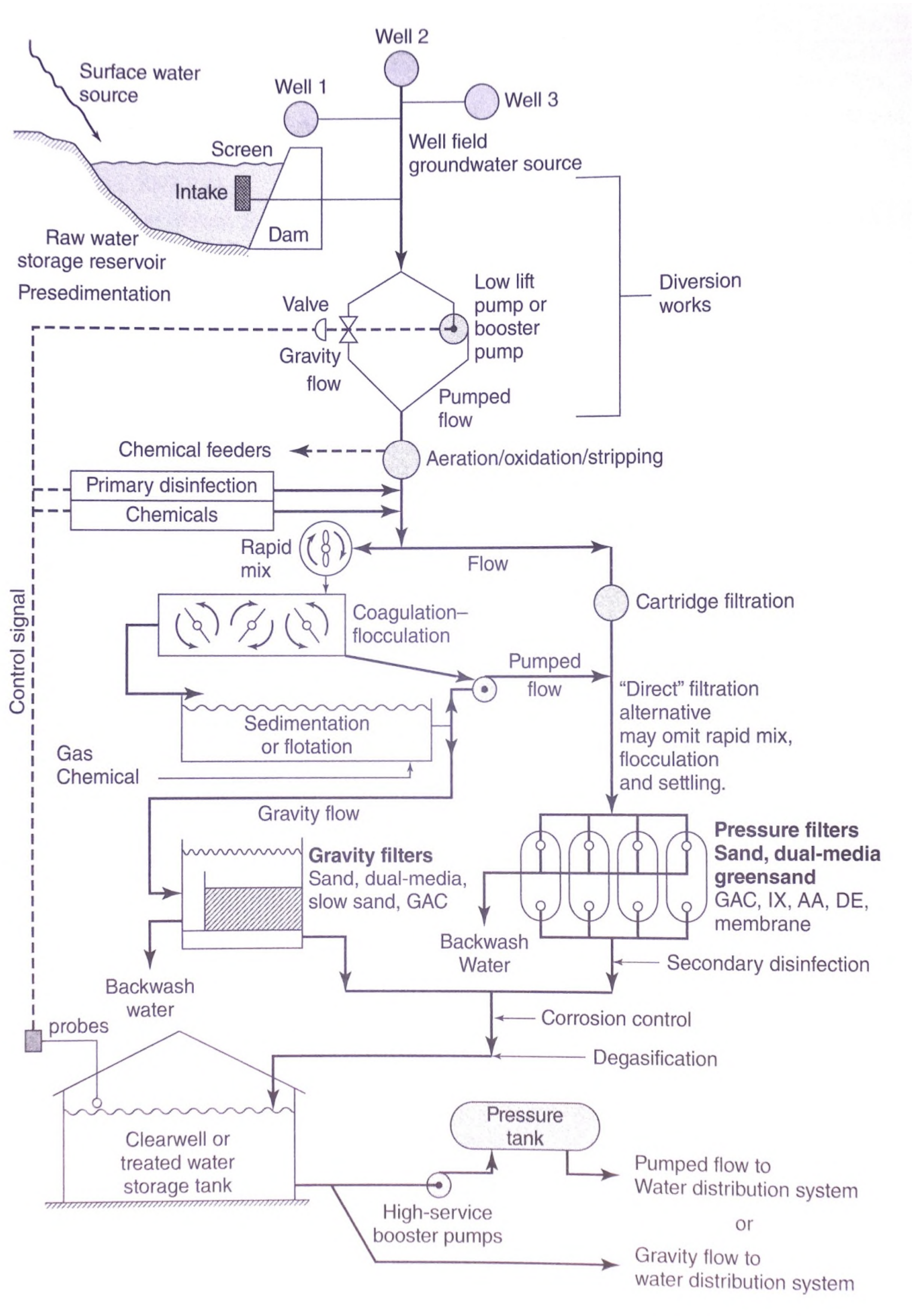
Basically dissolved gas flotation (DGF) is a process involving pressurization of air at 25 to 95 psig for dissolving gas into water, and subsequent release of pressurized water to a clarifier under normal atmospheric pressure (1 atm) and laminar hydraulic flow conditions for generating extremely fine gas bubbles (normally 20 to 80 microns in diameter), which become attached to the impurities to be removed. The gas flow rate is about 1 % 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 agglomerates is less than 1, resulting in buoyancy or non-selective flotation (i.e., a save-all process). The LIWT's standard textbook, Flotation Technology (LK Wang, NK Shammas, WA Selke and DB Aulenbach, Humana Press, 680 pages, 2010) presents theory, principles, operation, maintenance, design criteria, costs, chemical additives, process control, tests, and design examples. (226)

DGF becomes: (a) dissolved air flotation (DAF) if air is used; (b) dissolved nitrogen flotation (DNF) if nitrogen gas is used; (c) dissolved carbon-dioxide flotation (DCDF) if carbon dioxide is used; (d) dissolved ozone flotation (DOF) if ozone is used, etc. In the past, DAF was mainly used for sludge thickening and fiber recovery. The authors and other LIWT researchers work together to develop it as a water purification process. Our efforts and laboratory experimental results, pilot plant demonstrations can be found from the literature (90-100, 105-106, 112-114, 117, 119, 122-128, 221).

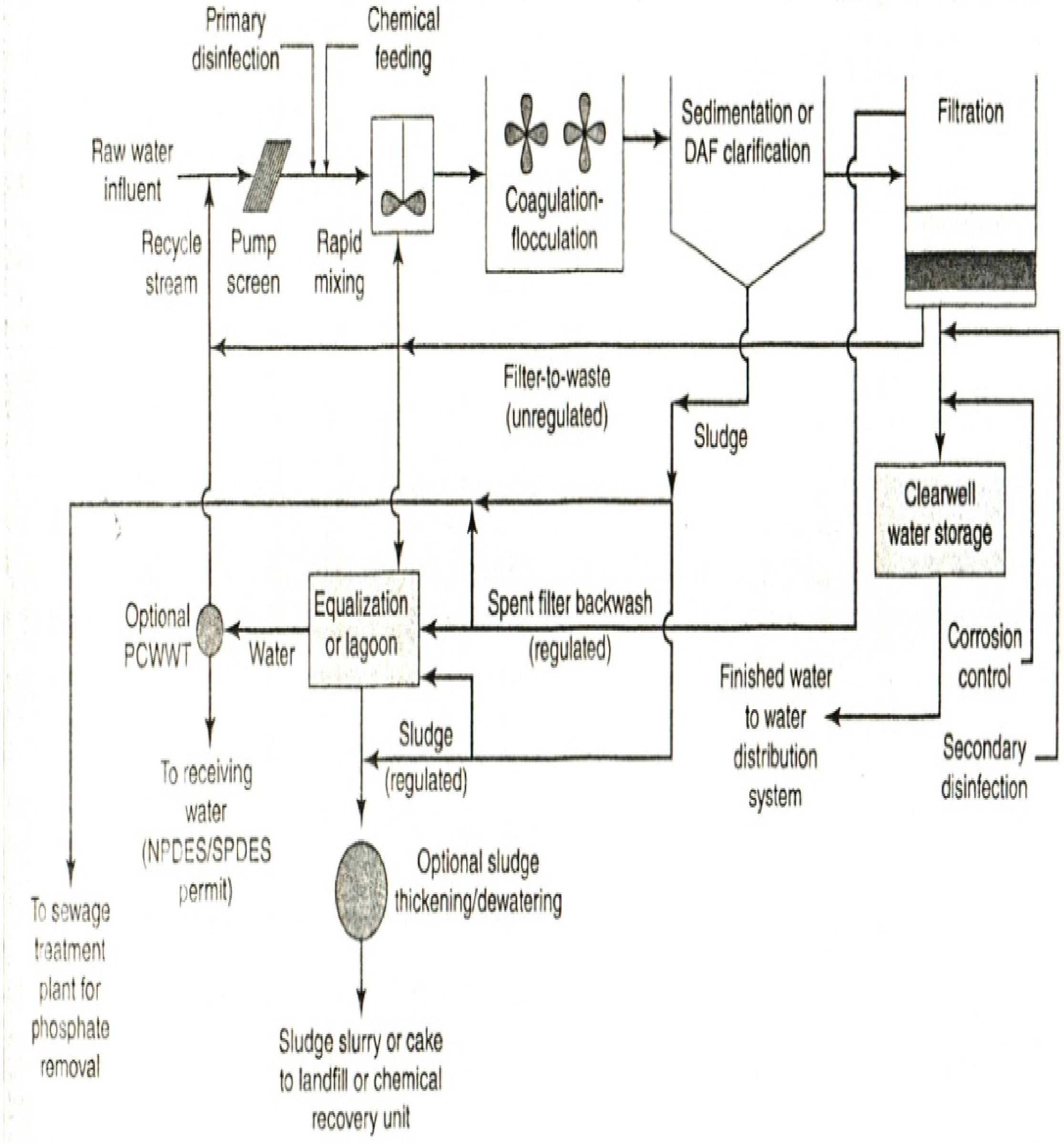
6. DEVELOPMENT OF A POTABLE WATER DAF SYSTEM BY REPLACING CONVENTIONAL SEDIMENTATION CLARIFIER WITH INNOVATIVE DAF

The very first innovative DAF water purification system adopted Krofta Engineering Corporation's existing DAF clarifier, Supracell . A complete water treatment plant (Potable Water DAF System 1) involving the use of a the existing DAF (Supracell) will include the individual unit processes of influent screening/pumping, chemical feeding, predisinfection, coagulation, DAF (Supracell), filtration, post-disinfection, and corrosion control. This entire innovative water purification system's flow diagram will be similar to conventional water system, except that DAF clarifier is used for replacing conventional sedimentation clarifier. (Figure 16). (231)

The LIWT/KEC developed high rate DAF (shown in Figures 18 and described in Table 2) has many advantages: (a) very low retention time of 2 minutes 30 minutes, or say 3 minutes means a much smaller total volume; (b) high specific clarification capacity (4 to 5 gpm per square foot) means a much smaller surface area; (c) installation cost is low because the clarifier is delivered fully prefabricated, no heavy supports are needed, and the weight is as low as 150 lbs per square foot; (d) the clarifier maintains value because it can be easily relocated when/if necessary; (e) space requirement, or foot print, is minimal because of its low headroom, and being able to be erected above ground level (such as on the second floor, on the roof top, or on top of an existing sedimentation basin, etc.); (f) easy to clean because the clarifier is completely open, bottom is self-cleaning during operation; (g) water clarification to below 20 to 30 ppm of filterable solids in the clarified effluent, and sludge thickening to above 2 to 3 percent in consistency. Figure 19 shows a high rate DAF (Supracell 62) installed in UK. It had a diameter of 62 ft. and 9,265 gpm (35.2 M^3/min) was installed on the second floor with extremely small foot print due to its extremely shallow tank depth of B = 29.5 in. and its low weight. Figure 20 shows the flow diagram of a complete water treatment plant in which (a) a dissolved air flotation clarifier (Supracell or equivalent) replaces a conventional sedimentation clarifier; and (b) a dissolved air flotation clarifier replaces a conventional gravity thickener for overall cost saving and foot-print reduction.



[Insert Figure 16. The flow diagram of a general water treatment system. (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016; pp. 326) (231)]



[Insert Figure 17. The flow diagram of a simplified water treatment system (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016; pp. 667) (231)]

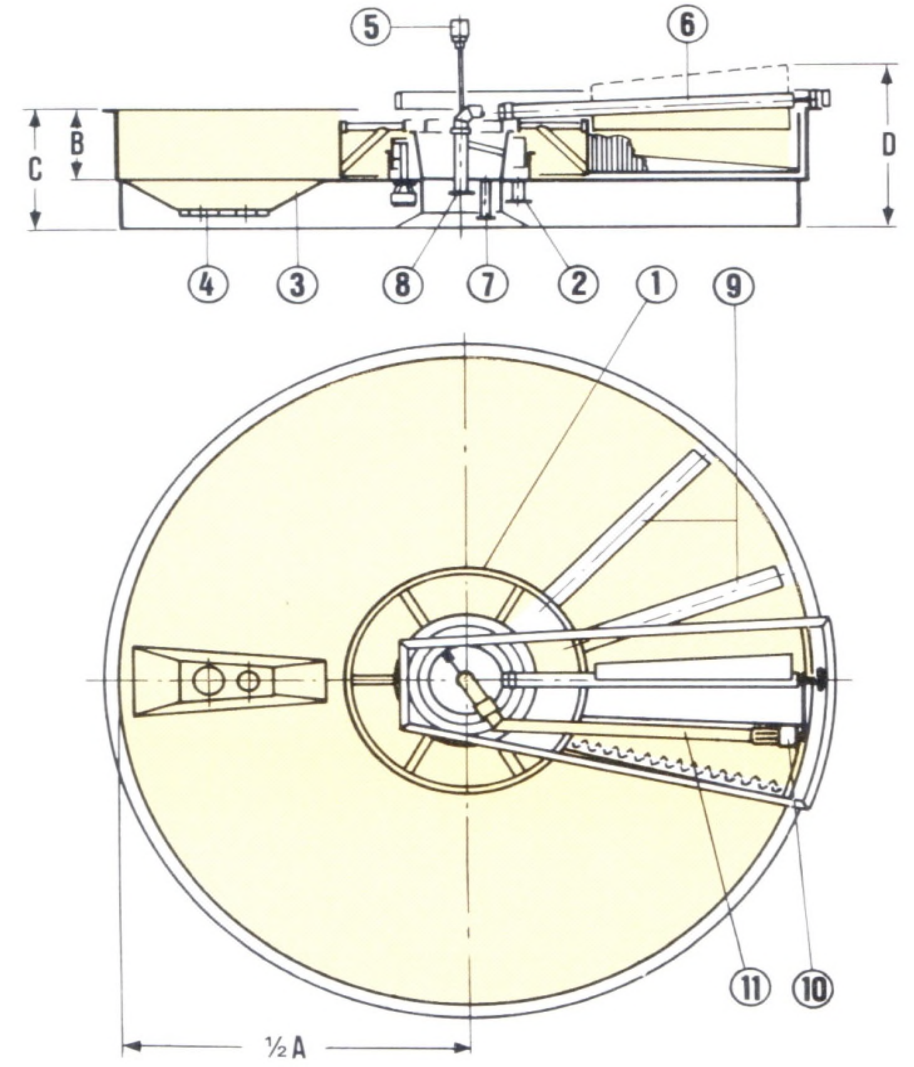
Although there are so many advantages for the newly developed water system, Dr. Milos Krofta and KEC did accept this new water system for the City of Pittsfield and Village of Lenox, because Dr. Krofta was a mechanical engineer (not a civil engineer), thus he preferred to have an all-in-one package water treatment plant. This can be an excellent totally new water treatment system, or it can be extremely useful for improving an existing conventional water treatment plant by simply installing a shallow, high rate DAF (Supracell) on the top of an existing sedimentation basin. (145)

7. DEVELOPMENT OF A POTABLE WATER DOUBLE DGF-DGF SYSTEM BY REPLACING CONVENTIONAL DOUBLE SEDIMENTATION-SEDIMENTATION CLARIFIERS WITH INNOVATIVE DOUBLE DGF-DGF CLARIFIERS

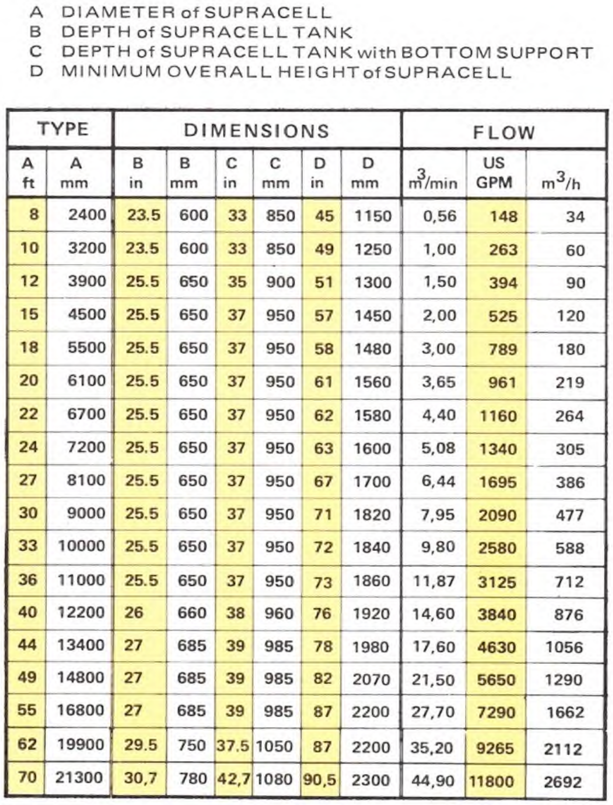
Recarbonation is frequently applied to a "two-stage lime-soda ash softening process system", shown in Figures 21 and 22. Figure 21 shows mainly the softening chemicals used and the precipitates produced in the system, while Figure 22 is the flow diagram of a typical lime-soda ash softening water treatment plant. Because different chemicals must be used and different pH condition must be controlled in each stage, two clarifiers will be required for the two-stage process system. Normally two sedimentation clarifiers are adopted.

LIWT/KEC developed a double DGF-DGF clarification system shown in Figure 23. It is noted that this highly efficient, and commercially available double DGF-DGF clarification system has extremely small foot-print, and very low detention time. For removing hardness in a water softening process system, the double DGF-DGF clarification system can be dissolved carbon dioxide flotation (DCDF) and/or dissolved air flotation (DAF) depending on whether or not separate recarbonation units will be used. In case ozone will be used for predisinfection, dissolved ozone flotation (DOF) may be adopted in the first stage for cost saving because a separate ozonation unit may not be needed. The double DGF-DGF clarifier (double Supracell) system is delivered fully prefabricated. Larger units are delivered in parts which flange together. No heavy foundation or support structure is needed as the total load factor when filled with water weights less than 150 lbs per square foot for each DGF (Supracell) unit. The unique compact and efficient design is made possible by use of the principle of “zero velocity”. Each DGF water level in the tank is extremely low (16 inches). This means reduced size and weight as well as low retention time (3 minutes for each DGF). The DGF is smaller in surface area for its capacity because a very high specific clarification degree is attained at 4 to 5 gpm per square foot.

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



[Insert Figure 18. An Innovative high rate dissolved gas flotation clarifier (Supracell)]

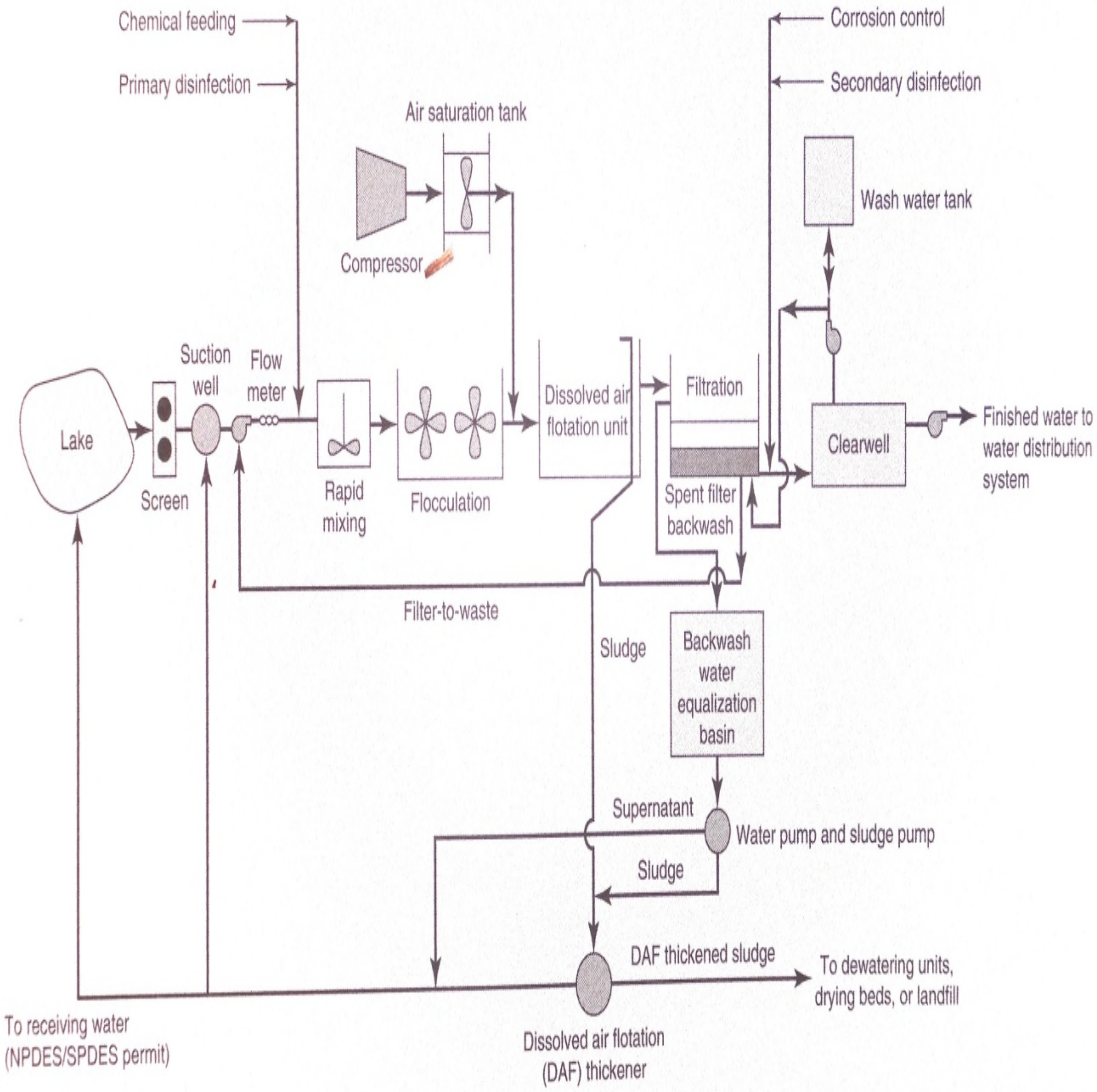


A DIAMETER of SUPRACELL
B DEPTH of SUPRACELL TANK
C DEPTH of SUPRACELL TANK with BOTTOM SUPPORT
D MINIMUM OVERALL HEIGHT of SUPRACELL

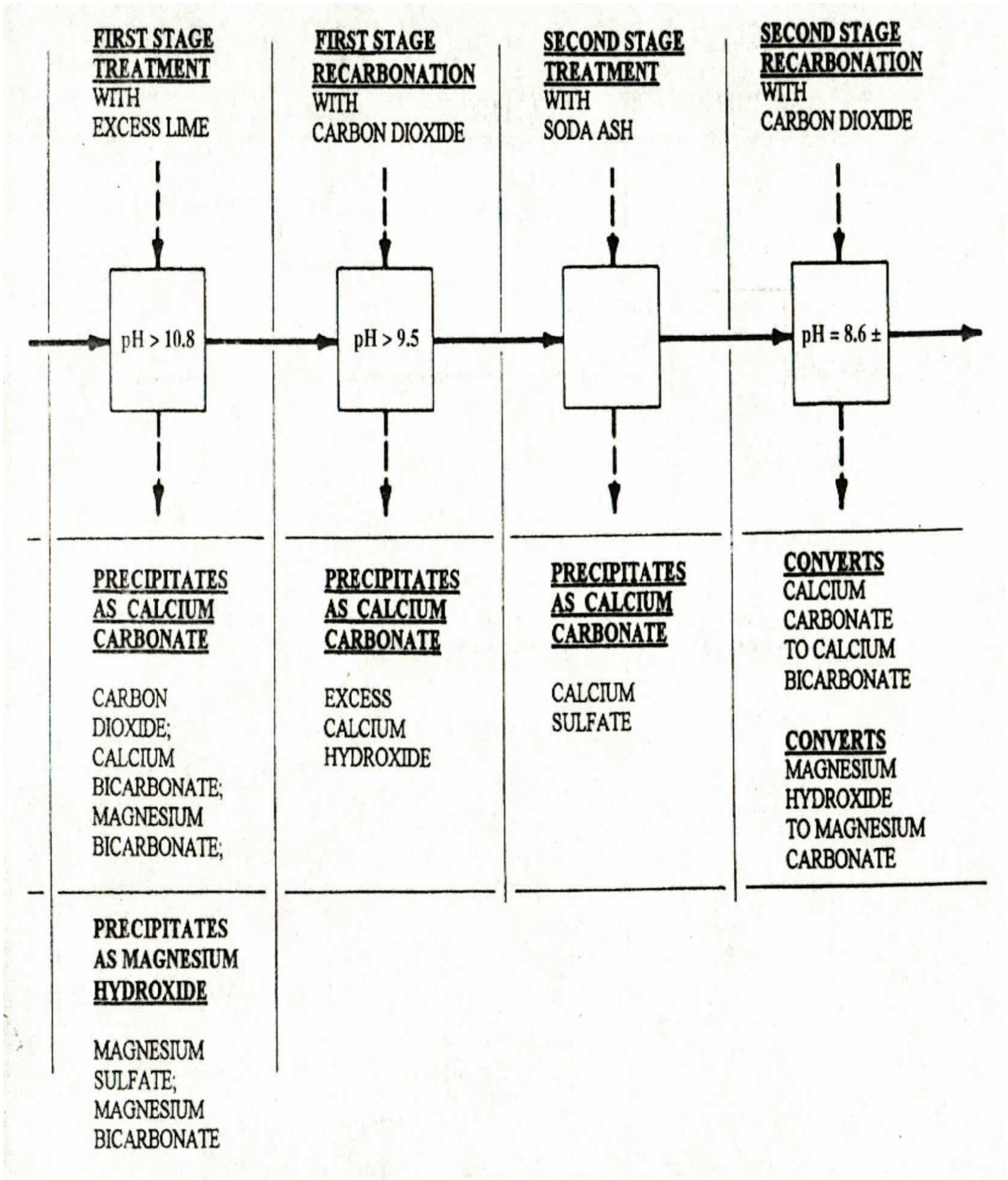
TYPE		DIMENSIONS						FLOW		
A ft	A mm	B in	B mm	C in	C mm	D in	D mm	m^3/min	US GPM	m^3/h
8	2400	23.5	600	33	850	45	1150	0,56	148	34
10	3200	23.5	600	33	850	49	1250	1,00	263	60
12	3900	25.5	650	35	900	51	1300	1,50	394	90
15	4500	25.5	650	37	950	57	1450	2,00	525	120
18	5500	25.5	650	37	950	58	1480	3,00	789	180
20	6100	25.5	650	37	950	61	1560	3,65	961	219
22	6700	25.5	650	37	950	62	1580	4,40	1160	264
24	7200	25.5	650	37	950	63	1600	5,08	1340	305
27	8100	25.5	650	37	950	67	1700	6,44	1695	386
30	9000	25.5	650	37	950	71	1820	7,95	2090	477
33	10000	25.5	650	37	950	72	1840	9,80	2580	588
36	11000	25.5	650	37	950	73	1860	11,87	3125	712
40	12200	26	660	38	960	76	1920	14,60	3840	876
44	13400	27	685	39	985	78	1980	17,60	4630	1056
49	14800	27	685	39	985	82	2070	21,50	5650	1290
55	16800	27	685	39	985	87	2200	27,70	7290	1662
62	19900	29.5	750	37.5	1050	87	2200	35,20	9265	2112
70	21300	30,7	780	42,7	1080	90,5	2300	44,90	11800	2692

[Insert Table 2.. Dimensions versus capacities of high rate dissolved gas flotation clarifier (Supracell)]

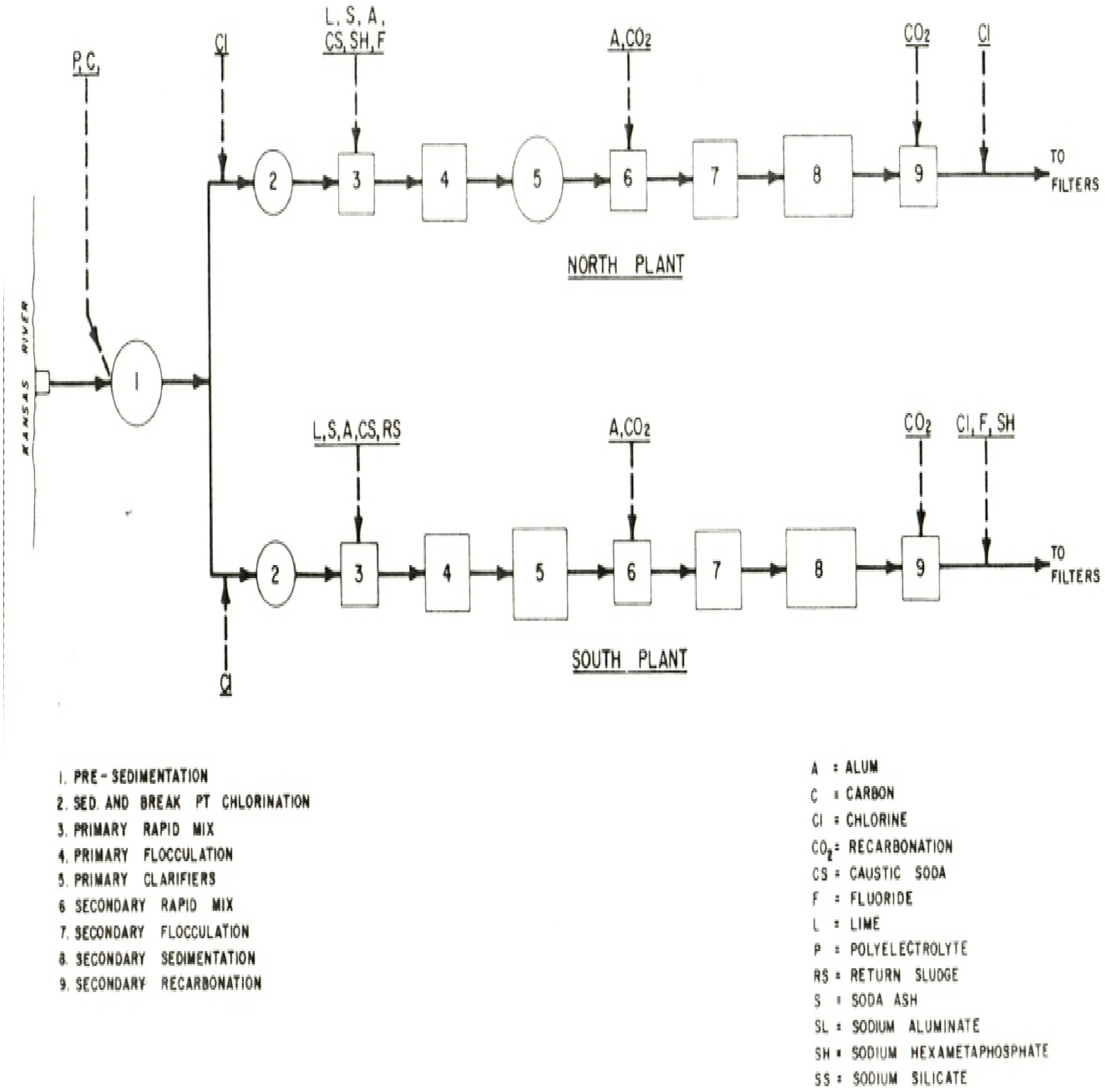
[Insert Figure 19. A high rate dissolved gas flotation clarifier in UK (Supracell 62; tank depth = 750 mm; flow = 35.2 m^3/min; diameter = 62 ft = 19,900 mm)]



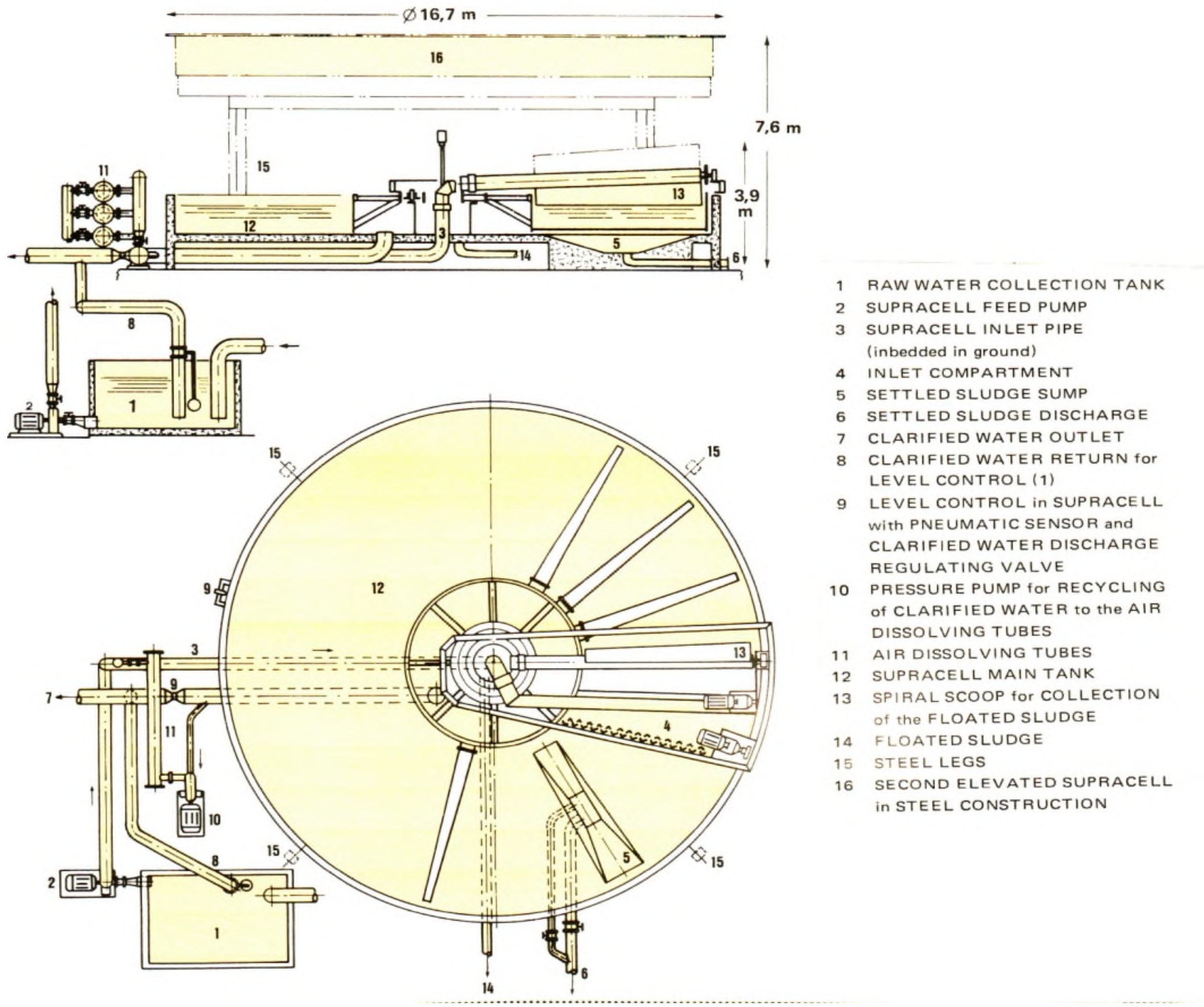
[Insert Figure 20. A flow diagram of a complete water treatment plant in which (a) a dissolved air flotation clarifier (Supracell or equivalent) replaces a conventional sedimentation clarifier; and (b) a dissolved air flotation clarifier replaces a conventional gravity thickener for overall cost saving and foot-print reduction. (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016) (231)]



[Insert Figure 21. Water treatment for hardness removal using two-stage lime/soda ash softening process (Credit: LK Wang, YT Hung and NK Shammas, Physicochemical Treatment Processes, Humana Press, NJ, USA, pp. 221, 2004) (232)]



[Insert Figure 22. Flow diagram of lime-soda ash softening plant in Topeka, Kansas, USA (Credit: CW Reh, Lime-soda softening processes, Water Treatment Plant Design, RL Sanks, editor, Ann Arbor Science, MI, USA, 1979; pp. 583)]



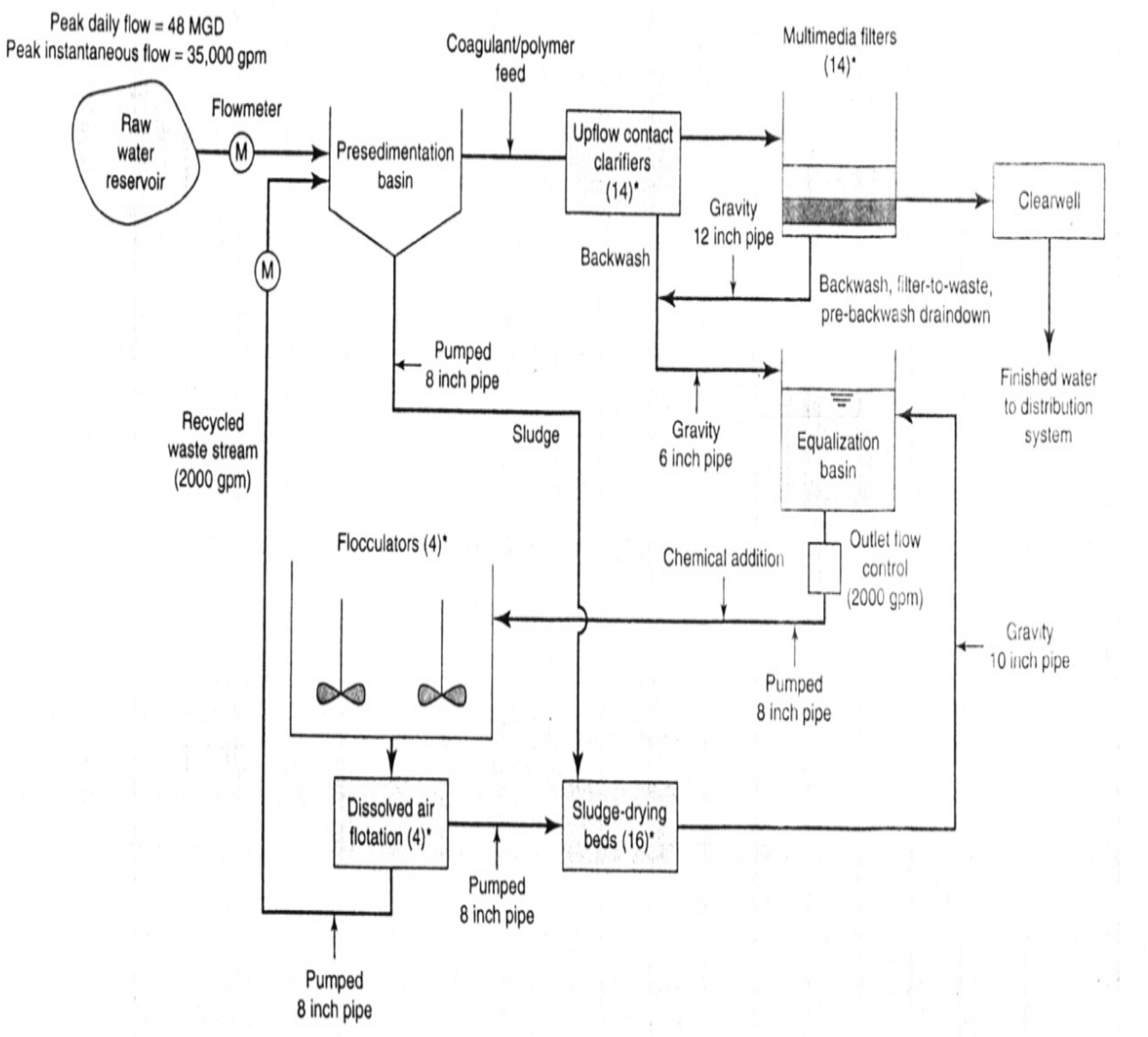
[Insert Figure 23. Top view and side view of a double DGF-DGF clarifier (Double Supracell)]

8. DEVELOPMENT OF A POTABLE WATER SEDIMENTATION-DAF SYSTEM BY REPLACING A CONVENTIONAL DOUBLE PRE-SEDIMENTATION-SEDIMENTATION WATER CLARIFICATION WITH AN INNOVATIVE COMBINED SEDIMENTATION-DAF CLARIFICATION

The quality of reservoir raw water usually is poor (having high turbidity, color and silt) soon after a big storm. Under this engineering situation, a pre-sedimentation step is needed prior to normal water treatment, as shown in Figure 24. Upflow contact clarifier in Figure 24 is one of conventional sedimentation clarification processes. DAF in Figure 24 is for the plant's wastewater treatment and waste sludge thickening. The conventional system shown in Figure 18 works fine in terms of its product water (plant water effluent) quality, and waste management. Almost all wastewater is treated by DAF and recycled to the pre-sedimentation basin for reprocessing and reproduction of drinking water. Both construction costs and O&M costs of this fine process system are very expensive.

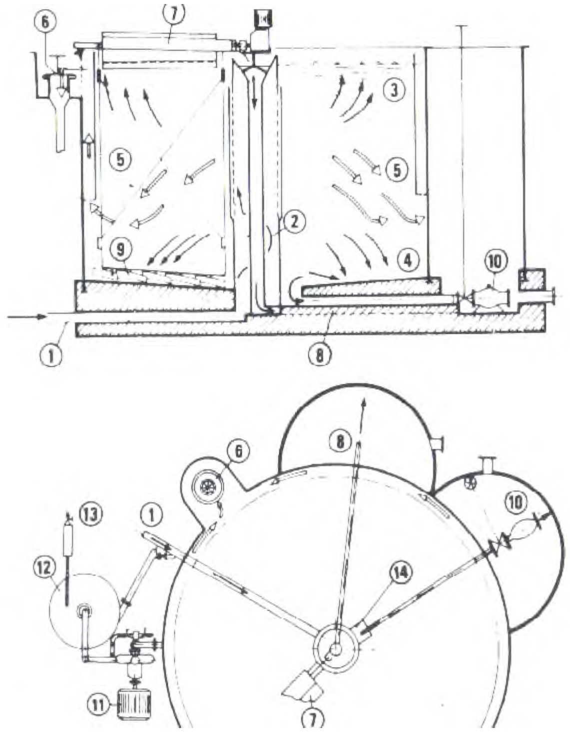
LIWT/KEC developed and manufactured an innovative and very cost-effective sedimentation-DAF clarifier (Figure 25; SediFloat or SDF) for replacing both pre-sedimentation and upflow contact sedimentation clarifier shown in Figure 24. The sedimentation-DAF clarifier is much smaller (in terms of equipment volume and foot-print) than the combined pre-sedimentation clarifier and upflow contact clarifier when processing the same water flow. A complete water treatment plant involving the use of a the innovative sedimentation-DAF clarifier will include: screening, influent pumping, chemical feeding, predisinfection, coagulation, sedimentation-DAF clarifier, filtration, post-disinfection, and corrosion control. This entire innovative water purification system's flow diagram will be similar to conventional water system (Figure 24), except that a much smaller sedimentation-DAF clarifier replaces both pre-sedimentation and upflow contact clarifier. Figure

25 shows the engineering design and operation procedures of a Sedimentation-DAF clarifier. Figure 26 shows a full scale sedimentation-DAF Clarifier (SDF-36FT; diameter = 36 ft.) which was built with acid-resistant tiles in Holland; while Figure 27 shows the construction of two sedimentation-DAF clarifiers (SDF-55FT; each diameter = 55 ft.) in Italy. Although the sedimentation-DAF is fully developed and has been widely applied in waste treatment, its excellent potable water application in Americas needs more promotion by water engineers and managers. With the authors' collaboration and the UNIDO (United Nations Industrial and Development Organization) cooperation, LIWT/KEC technologies have been distributed to many developing and industrial countries (207). Figure 28 shows how Dongshin EnTech has successfully used a combined Sedimentation-DAF clarifier for potable water treatment in South Korea. (145, 200) For transferring the DAF technology to South Korea, Dr. LK Wang received an engineering award from Korean Society of Water Pollution Research and Control and South Korean government. (200)



* Number in parenthesis indicates number of treatment units.

[Insert Figure 24. A conventional water treatment plant involving the use of pre-sedimentation and upflow contact sedimentation clarifiers (231)]



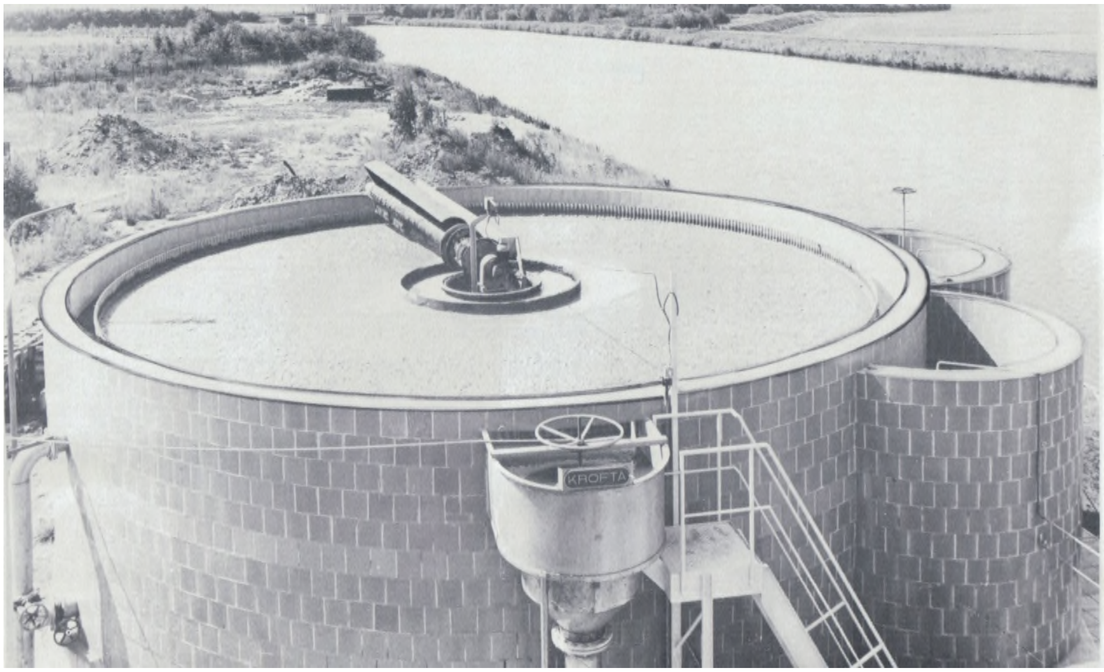
The untreated effluent (1) is fed by gravity or pump to the center distributor (2) where it mixes with the air released from the recycled air carrier water and then enters the tank. Fine air bubbles lift the suspended, flocculated solids to the water surface (3). Heavier particles settle rapidly to the tank floor (4). The zone of clear water formed between the floated and settled solids is then discharged into the outlet annulus (5) where it overflows through an adjustable outlet weir (6). Adjustment of this weir controls the water level in the tank.

Floated matter is removed by the rotating spiral scoop (7) which discharges the sludge through the sludge pipe in the center distributor (2) to a sludge well (8) at the tank perifery.

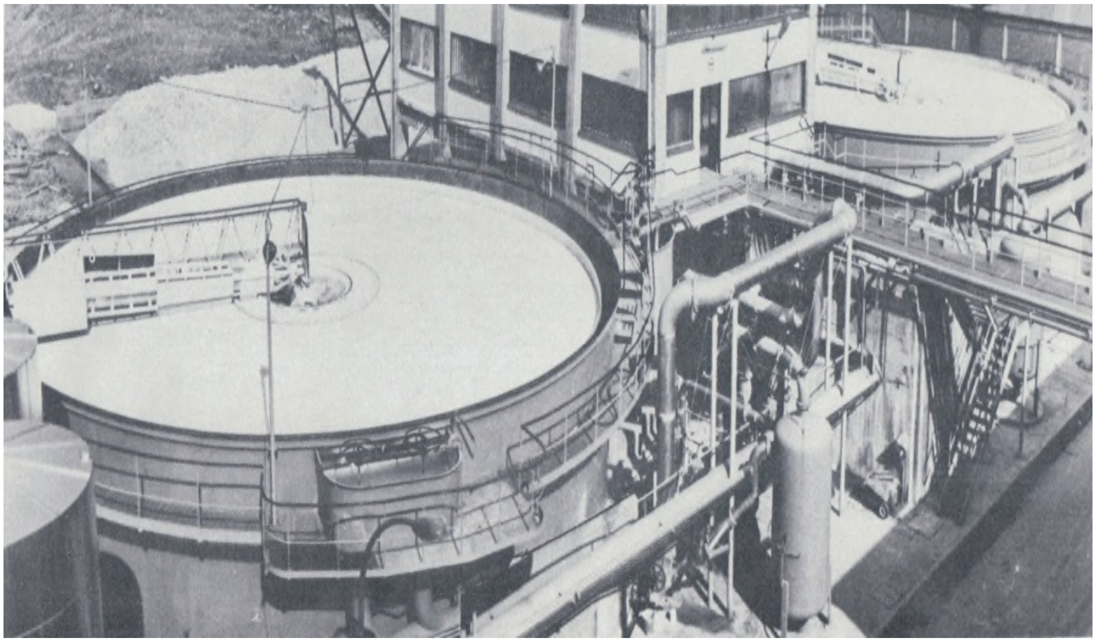
A suspended bottom scraper (9) is supported from the scoop structure and moved forward by the scoop drive. The settled sludge is scraped to the center of the tank and into a sludge pit (14) constructed in the foundation. From here, the sludge is removed intermittently through an automatically operated pneumatic valve (10). The scraper is so constructed as to allow it to rise and slip over any excessive obstructing sludge build-up in order to prevent any damage to the scoop drive.

The recycled air carrier water is pumped (11) at a pressure of about 80 psi into the retention tank (12). Compressed air (13) enters the retention tank directly. The air carrier water is then released into the center distributor after mixing with the raw influent. For small installations, it may be more economical to pressurize the whole of the effluent inflow.

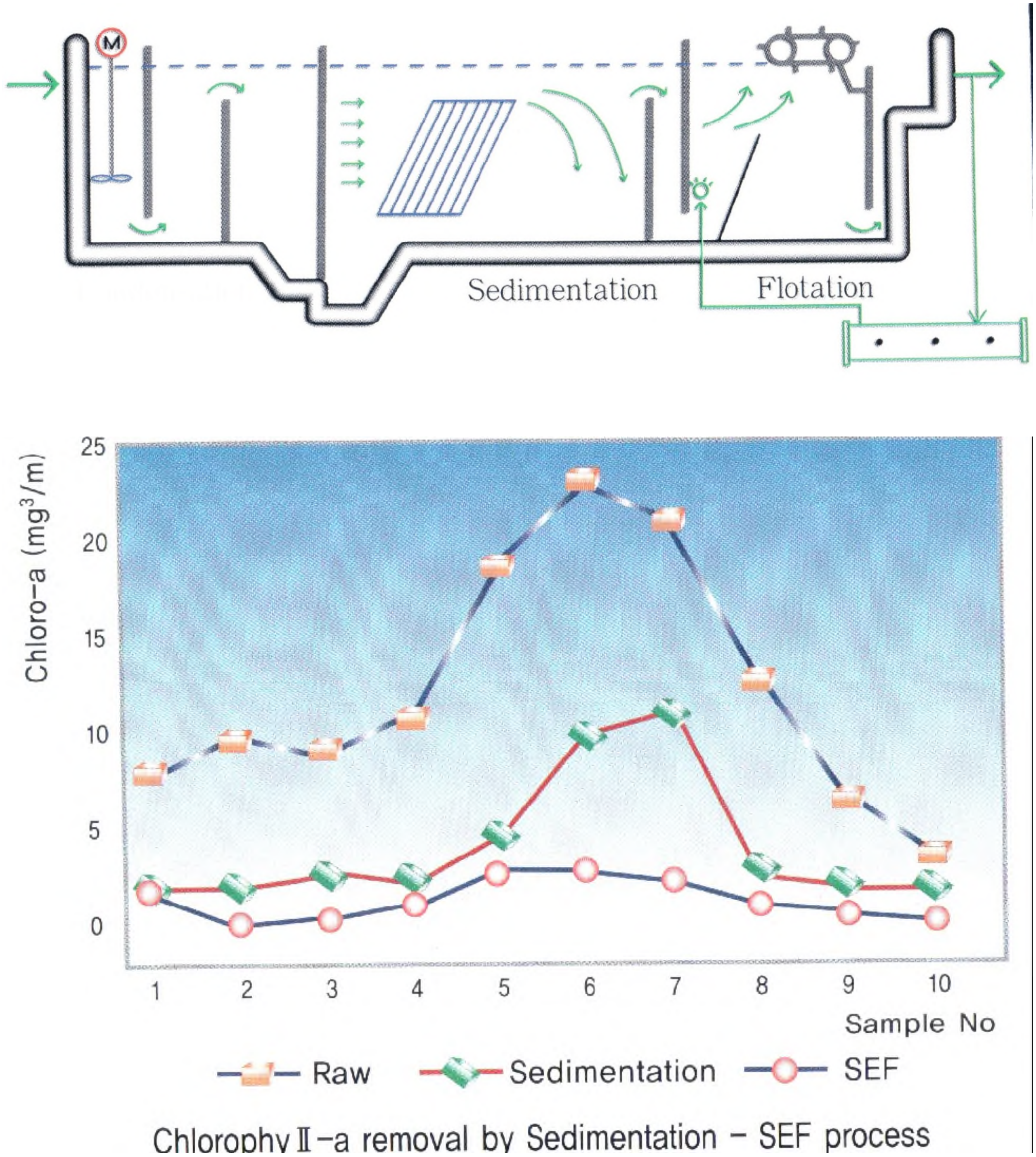
[Insert Figure 25 . Design and Operation of a Sedimentation-DAF Clarifier (SDF; or SediFloat)]



[Insert Figure 26 . Construction of Sedimentation-Flotation Clarifier (SDF-36FT) in Acid-Resistant Tiles (Holland)]



[Insert Figure 27 . Construction of Two Sedimentation-DAF Clarifiers (SDF-55FT) in Italy]



[Insert Figure 28. Removal of Chlorophy II-a by sedimentation alone and combined sedimentation-DAF (Credit: Dongshin EnTech, South Korea) (145, 200)]

9. DEVELOPMENT OF A POTABLE WATER DAF-FILTRATION CLARIFIER BY REPLACING CONVENTIONAL SEDIMENTATION-FILTRATION SYSTEM WITH INNOVATIVE DAF-FILTRATION SYSTEM

9.1. Decision and Advantages of Having a DAF-Filtration (DAFF or Sandfloat) Package Plant

Selection of a The reason for DAF's or DAFF's absence from drinking water treatment in the New World in early 1980s was a combination of plentiful land, relatively strong municipal finances and reliance on a tried-and-true sedimentation process that was familiar to owners, and profitable for municipal engineering designers and equipment suppliers.

DAF got its chance in the Americas in the late 1970s to early 1980s, sparked by the authors' flotation doctoral theses and the authors' research that caught the attention and imagination of Dr. Milos Krofta, a prominent paper industry expert and engineering firm owner. Previous sections have introduced many possible potable water treatment systems developed by LIWT/KEC., but only the dissolved air flotation-filtration (DAFF) package system, also known as Sandfloat system (Figures 29-32) are adopted by LIWT/KEC for the Lenox Water Treatment Plant (LWTP) and the Pittsfield Water Treatment Plant (PWTP).

Why did Dr. Krofta and KEC want to have the all-in-one package water treatment plants for the LWTP and PWTP? The authors gave the answer before: Dr. Krofta was a mechanical engineer whose products should be like a mechanical unit, such as a car, a machine, a crane, or a mechanical package plant.

The author then visited Lowell Water Treatment Plant in Massachusetts, USA, finding out the details of their rectangular Automatic Backwash Sand Filtration

(ABSF) System. Later, finally a DAF-ABF (also known as DAFF plant, or Sandfloat plant) was developed and commercialized.

In a new Sandfloat package water treatment system (Figure 29), the unit processes of chemical feeding, coagulation, DAF clarification, automatic backwash sand filtration (ABF), disinfection and corrosion are all included. It is important to note that a patented circular ABF was used instead of Lowell Water Treatment Plant's rectangular ABF.

Since both the Americas' first two DAF-filtration (DAFF) plants (LWTP and PWTP) were identical in their Sandfloat design, the design features of both LWTP and PWTP are introduced together in this Section.

Other than floating the clarified contaminants rather than settling them, a DAF-filtration plant's flow diagram is essentially the same as a conventional water filtration plant's flow diagram, except the clarification-filtration portion. For instance, the unit processes of an innovative DAF-filtration plant includes rapid mixing, flocculation, DAF clarification, filtration, disinfection and corrosion control, while the unit processes of a conventional water filtration plant includes rapid mixing, flocculation, sedimentation clarification, filtration, disinfection and corrosion control. The rest unit processes can be identical, and even the types and dosages of water treatment chemicals may be identical. Accordingly the total treatment ultimately results in a drinking water product of equal quality. Figure 29 shows the flow diagram of a typical DAFF plant.

Figures 30-32 introduces the package unit of DAFF (Sandfloat) itself. Specifically Figure 30 is a bird's view of DAFF, Figure 31 presents DAFF's top view, side view and various sizes; and Figure 32 shows the internal flow diagram within the DAFF clarifier.

The primary advantage of DAFF technologies is the reduction in water clarification detention time. Conventional sedimentation-filtration treatment requires 2 to 4 hours of detention time, while DAFF clarification requires only 3 to 15 minutes of detention time for achieving identical water clarification-filtration efficiency. This drives other benefits, including less infrastructure required, small foot-print, and lower initial cost, building heating cost and lifecycle costs.

Figure 33 shows a DAF clarifier side-by-side with a sedimentation clarifier each treating about the same flow, and the DAF is so small in terms of volume, and can be installed on the second plant floor (meaning zero ground floor foot-print), but the comparable sedimentation clarifier is huge in volume. For the DAFF construction, the flotation compartment is installed on the top of an automatic backwash filter, so the foot-printer becomes even smaller. Figure 34 shows a 30-ft. diameter Sandfloat (SASF 30FT; DAFF) which was installed on an existing settler's top in Berlin, Germany because of limited space in the plant.

Figure 35 illustrates why and how the foot-print and volume of a package DAF-filtration clarifier (DAFF, or Sandfloat) over that of a conventional sedimentation clarifier and a conventional sand filter. The Krofta Sandfloat (DAFF clarifier)with its compact design and water treatment in one unit by chemical flocculation, dissolved air flotation and filtration, has received more and more acceptance, due to its high clarification, low total installation cost , low O&M cost, and extremely small space requirement.

9.2 Engineering Design Criteria and Costs of DAF-Filtration (DAFF or Sandfloat) Package Clarifier

Modem flotation clarifiers produce 6 gallons per minute of clarified water per square foot of surface area, (6 GPM per square foot; 240 L/min per square meter). Sedimentation clarifiers only produce 0.2 to 1.0 GPM per square foot, (10-20 L/min per square meter). Flotation clarifies process approximately 10 times more water with the same surface area in comparison with sedimentation.

Flotation clarifiers operate with only 16 inches of depth. (0.4 M), with a retention time of 2-3 minutes. Sedimentation requires a depth of approximately 80 inches, (2.0 M), and a retention time of 2 to 4 hours.

Flotation requires a clarifier with a volume of 1.67 gallons to clarify 1.0 GPM. (1.0 cubic meter per minute). Sedimentation requires a clarifier with a volume of 75 gallons to clarify water at the same rate, (1 GPM). The volume of sedimentation clarifiers is more than 45 times larger than flotation clarifiers.

Initial construction cost is reduced by 30 - 50 %. Compact clarifiers are less costly to build than large conventional settling tanks. Enclosing the system in a building and the use of corrosion resistant materials offer odor control and lower maintenance. Land use is substantially reduced.

Operational costs are reduced by approximately 30%. Operational costs are composed of three almost equal parts:

(a) Repayment of investment costs. The repayment of principal and interest, is proportionally reduced by the reduced total investment cost;

(b) Cost of chemicals and power. Less flocculating chemicals are required for flotation as only a small floc is necessary, compared with the large floc size necessary for settling. New flotation techniques operate with low power requirements, normally reducing power consumption by approximately 30%.

(c) Labor and maintenance costs. Advanced flotation plants are fully automated in an enclosed building and require only a few hours daily of attendance, reducing labor costs by 50 % or more.

Flotation technology allows the building of a plant that is profitable, facilitates financing and reduces the need for government grants or privatization schemes.

Flotation clarifiers are extremely compact allowing the system to be completely enclosed in a building, preventing odor and noise. The old concept of locating wastewater treatment plants as far away as possible from inhabited areas of towns and cities is no longer necessary. Long pipelines can be avoided, and valuable buildings, land and expanding areas can be saved.

Several individual plants can be built where collection sewers would otherwise be difficult or impossible to locate.

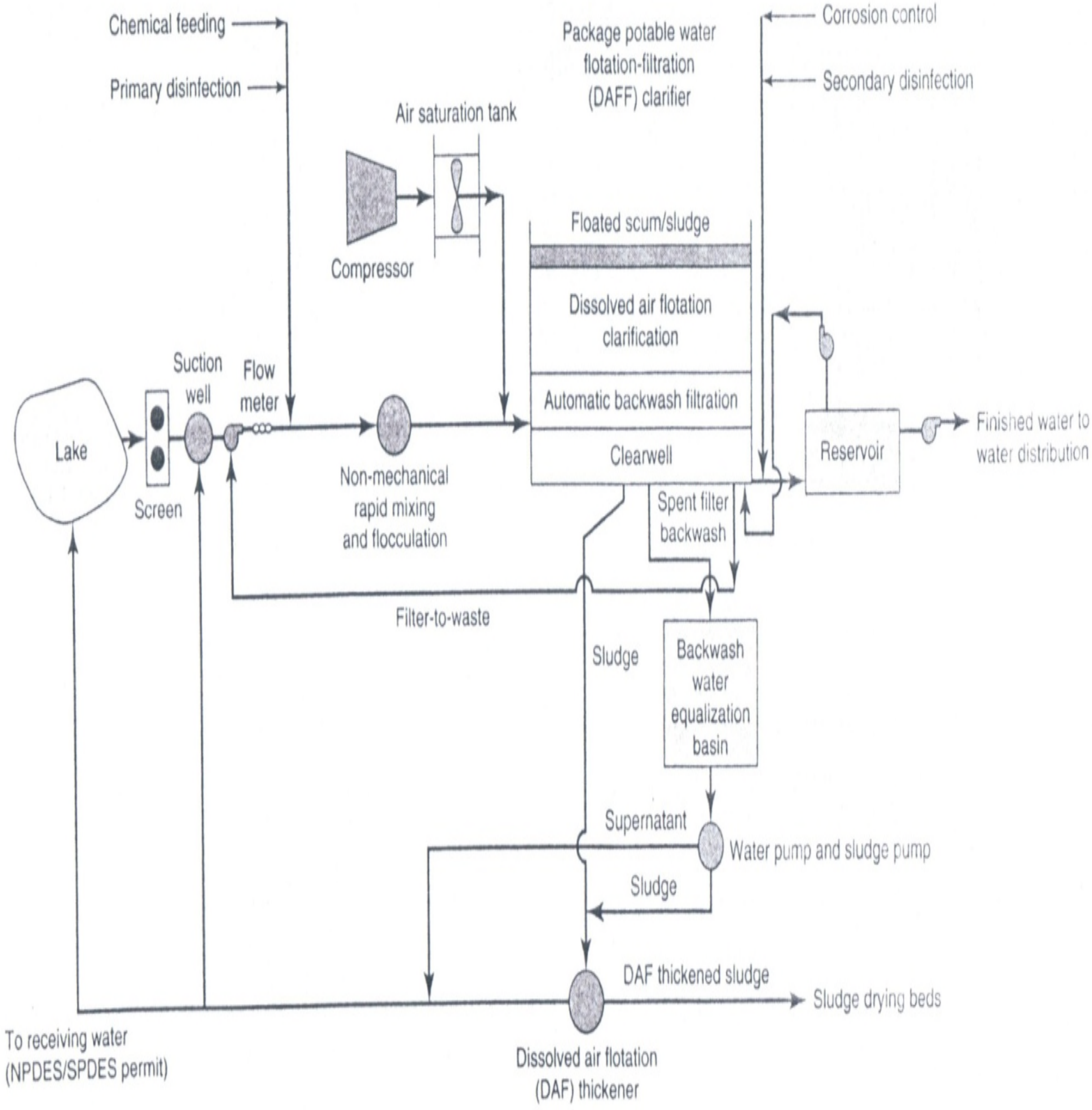
For municipal potable water plants, the compact size allows flotation clarifiers to be located close to the source, permitting the use of low cost land, and eliminating the use of additional pumping stations.

9.3 Description of a DAF-Filtration (DAFF or Sandfloat) Package Plant

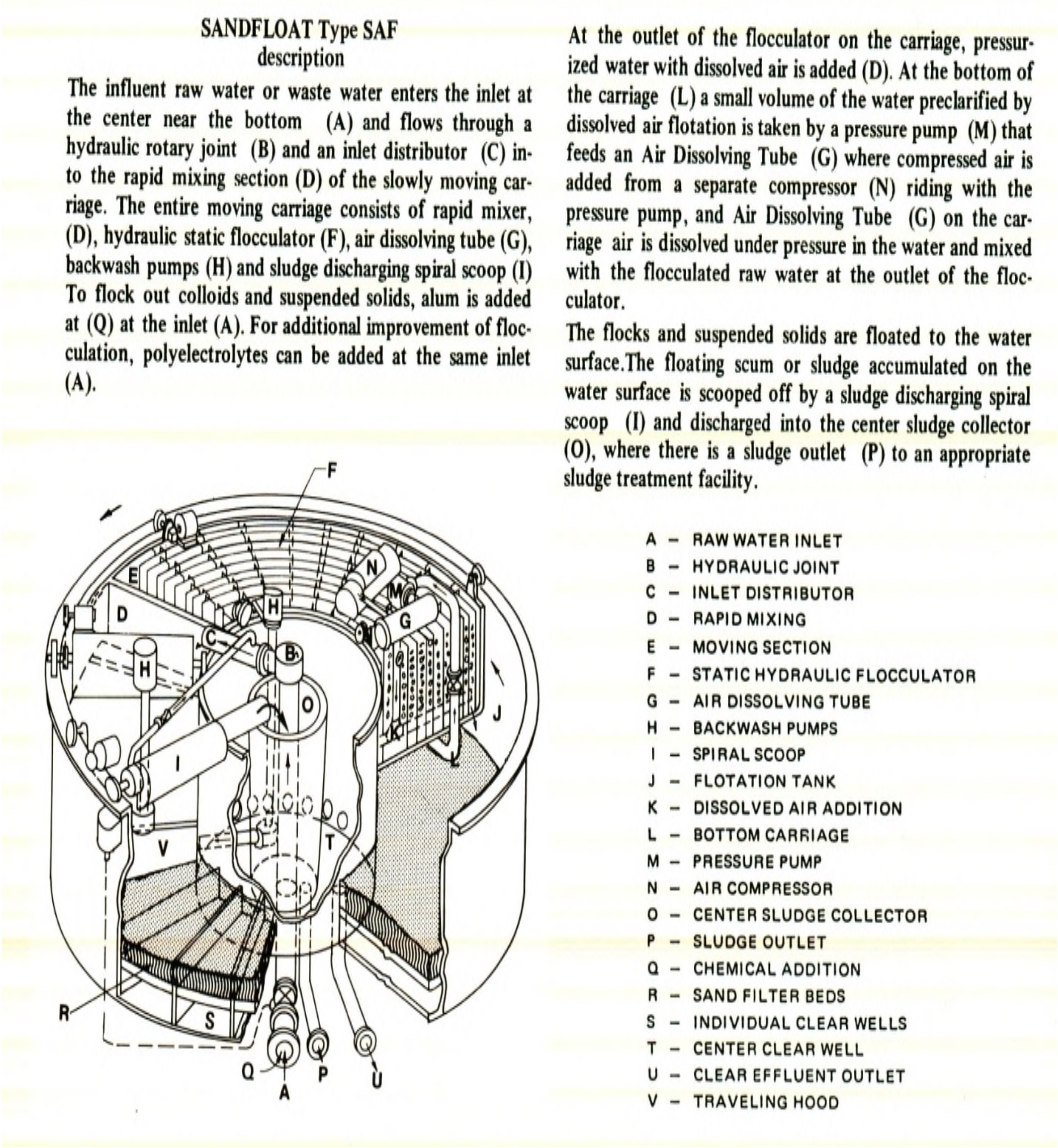
Components of the DAFF system include: moving carriage and flocculation module (including rapid mixing), flotation clarification chamber, ABF filtration module containing filter media, clear well for disinfection and corrosion control, clear well for disinfection and corrosion control, instrumentation and control system, and air dissolving system, which can be found from Figures 30-32, and are described in the following subsections.

9.3.1 Moving carriage and Flotation Module (including Rapid Mixing).

A moving carriage includes inlet structure, rapid mixing chamber, flocculator, air dissolving tube, backwash pump, spiral sludge scoop, and traveling hood (Figure 30, B, C, D, E, F, G, H, I, and V, respectively) is fabricated of 1/16 in. minimum thickness stainless steel plate, stiffened and reinforced as required to withstand normal handling and operational stresses. Stiffening of partition walls is provided to allow for draining of adjacent modules in the water treatment flotation tank Figure 30, J). Marine aluminum is used instead of stainless steel for the flocculation chamber (Figure 30, F). Each flocculation module is divided into a specified number of compartments of identical capacity by means of baffles with an adjustable opening, extending to the entire depth of the module. Each section of baffle is manually adjustable to provide for adequate slow mixing.



[Insert Figure 29. General flow diagram of a typical dissolved air flotation-filtration (DAFF or Sandfloat) water treatment plant (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016) (231)]



SANDFLOAT Type SAF
description

The influent raw water or waste water enters the inlet at the center near the bottom (A) and flows through a hydraulic rotary joint (B) and an inlet distributor (C) into the rapid mixing section (D) of the slowly moving carriage. The entire moving carriage consists of rapid mixer, (D), hydraulic static flocculator (F), air dissolving tube (G), backwash pumps (H) and sludge discharging spiral scoop (I) To flock out colloids and suspended solids, alum is added at (Q) at the inlet (A). For additional improvement of flocculation, polyelectrolytes can be added at the same inlet (A).

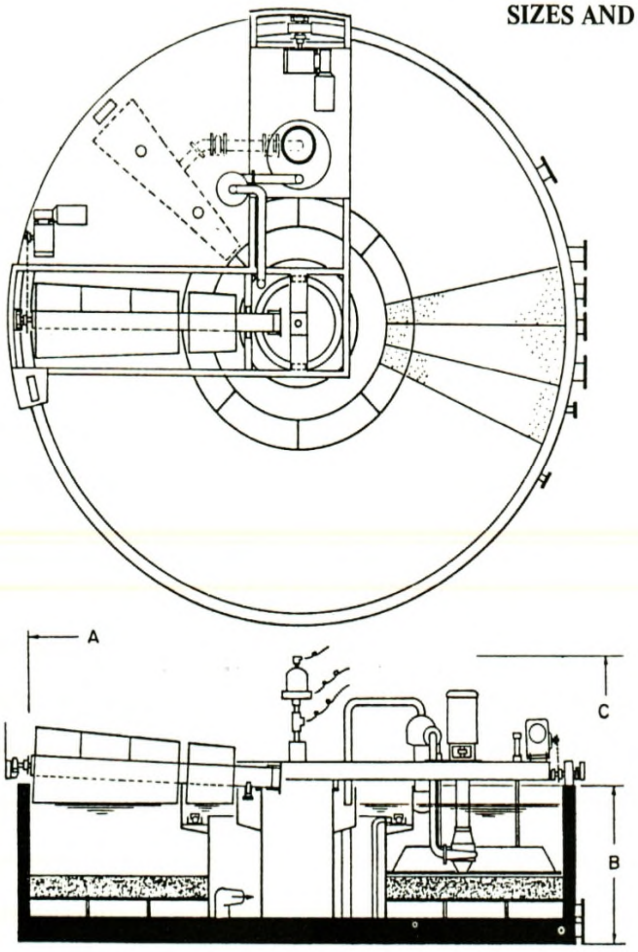
At the outlet of the flocculator on the carriage, pressurized water with dissolved air is added (D). At the bottom of the carriage (L) a small volume of the water preclarified by dissolved air flotation is taken by a pressure pump (M) that feeds an Air Dissolving Tube (G) where compressed air is added from a separate compressor (N) riding with the pressure pump, and Air Dissolving Tube (G) on the carriage air is dissolved under pressure in the water and mixed with the flocculated raw water at the outlet of the flocculator.

The flocks and suspended solids are floated to the water surface.The floating scum or sludge accumulated on the water surface is scooped off by a sludge discharging spiral scoop (I) and discharged into the center sludge collector (O), where there is a sludge outlet (P) to an appropriate sludge treatment facility.

A – RAW WATER INLET
B – HYDRAULIC JOINT
C – INLET DISTRIBUTOR
D – RAPID MIXING
E – MOVING SECTION
F – STATIC HYDRAULIC FLOCCULATOR
G – AIR DISSOLVING TUBE
H – BACKWASH PUMPS
I – SPIRAL SCOOP
J – FLOTATION TANK
K – DISSOLVED AIR ADDITION
L – BOTTOM CARRIAGE
M – PRESSURE PUMP
N – AIR COMPRESSOR
O – CENTER SLUDGE COLLECTOR
P – SLUDGE OUTLET
Q – CHEMICAL ADDITION
R – SAND FILTER BEDS
S – INDIVIDUAL CLEAR WELLS
T – CENTER CLEAR WELL
U – CLEAR EFFLUENT OUTLET
V – TRAVELING HOOD

[Insert Figure 30. Bird’s view and description of a DAF-Filtration (Sandfloat, or DAFF) clarifier. (161)]

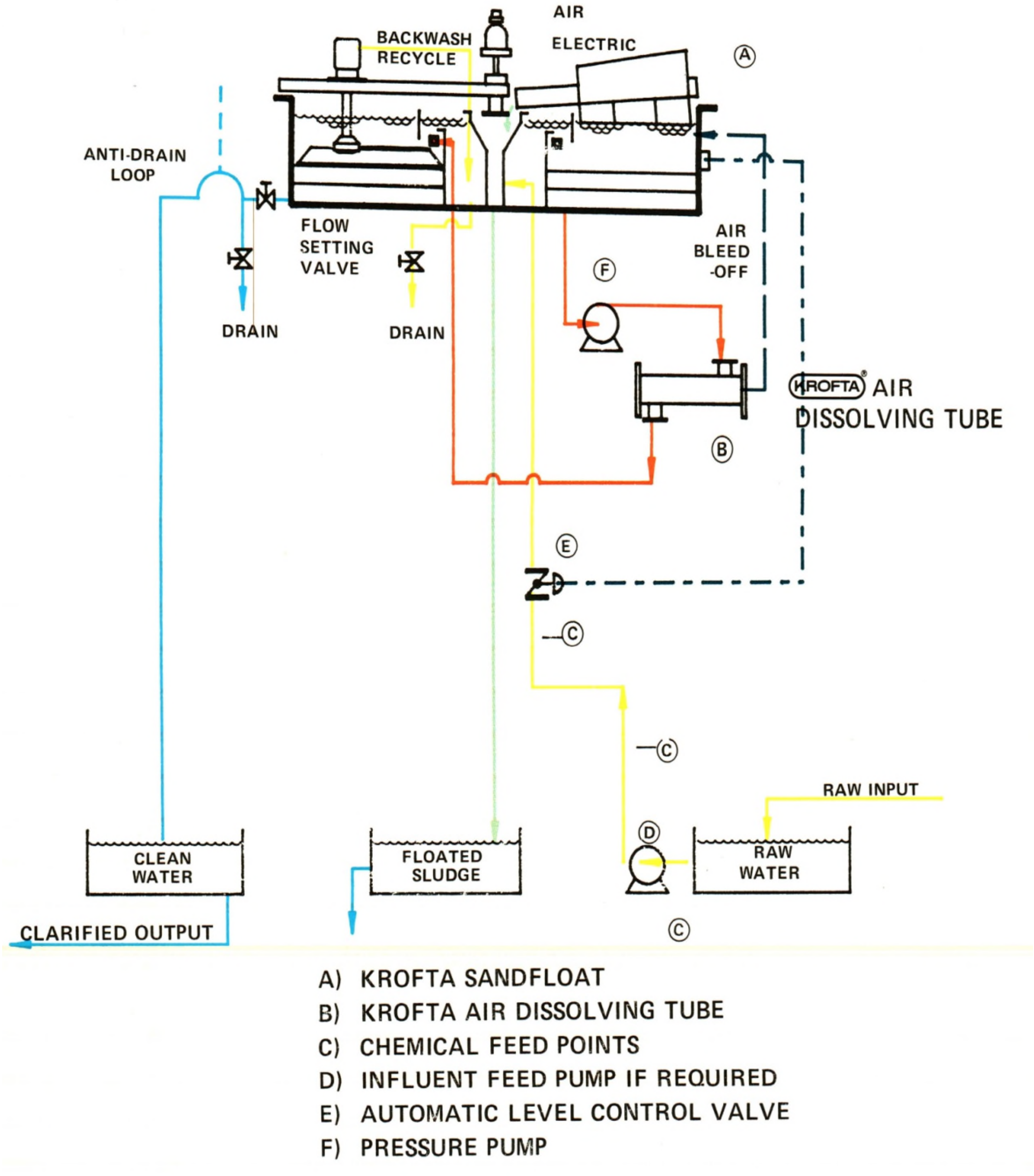
SIZES AND CAPACITIES



TYPE		FLOW			
A ft	AØ mm	US MGD	US GPM	m^3/min.	m^3/h
8	2400	0.16	110	0.42	25.2
10	3200	0.25	174	0.66	39.6
12	3900	0.36	250	0.95	57.0
15	4500	0.56	390	1.48	88.8
18	5500	0.81	562	2.14	128.4
20	6100	1.00	694	2.64	158.4
22	6700	1.21	840	3.19	191.4
24	7200	1.44	1000	3.80	228.0
27	8100	1.82	1270	4.81	288.6
30	9000	2.25	1560	5.93	355.8
33	10000	2.72	1890	7.18	430.8
36	11000	3.24	2250	8.55	513.0
40	12200	4.00	2780	10.55	633.0
44	13400	4.84	3360	12.77	766.2
49	14800	6.00	4170	15.83	949.8
55	16800	7.56	5250	19.95	1197.0
62	18800	9.61	6670	25.35	1521.0

A - Inside tank diameter (varies with TYPE)
B - Height of tank 6′ 0″ - 1830 mm
C - total max. height 13′ 4″ - 4060 mm

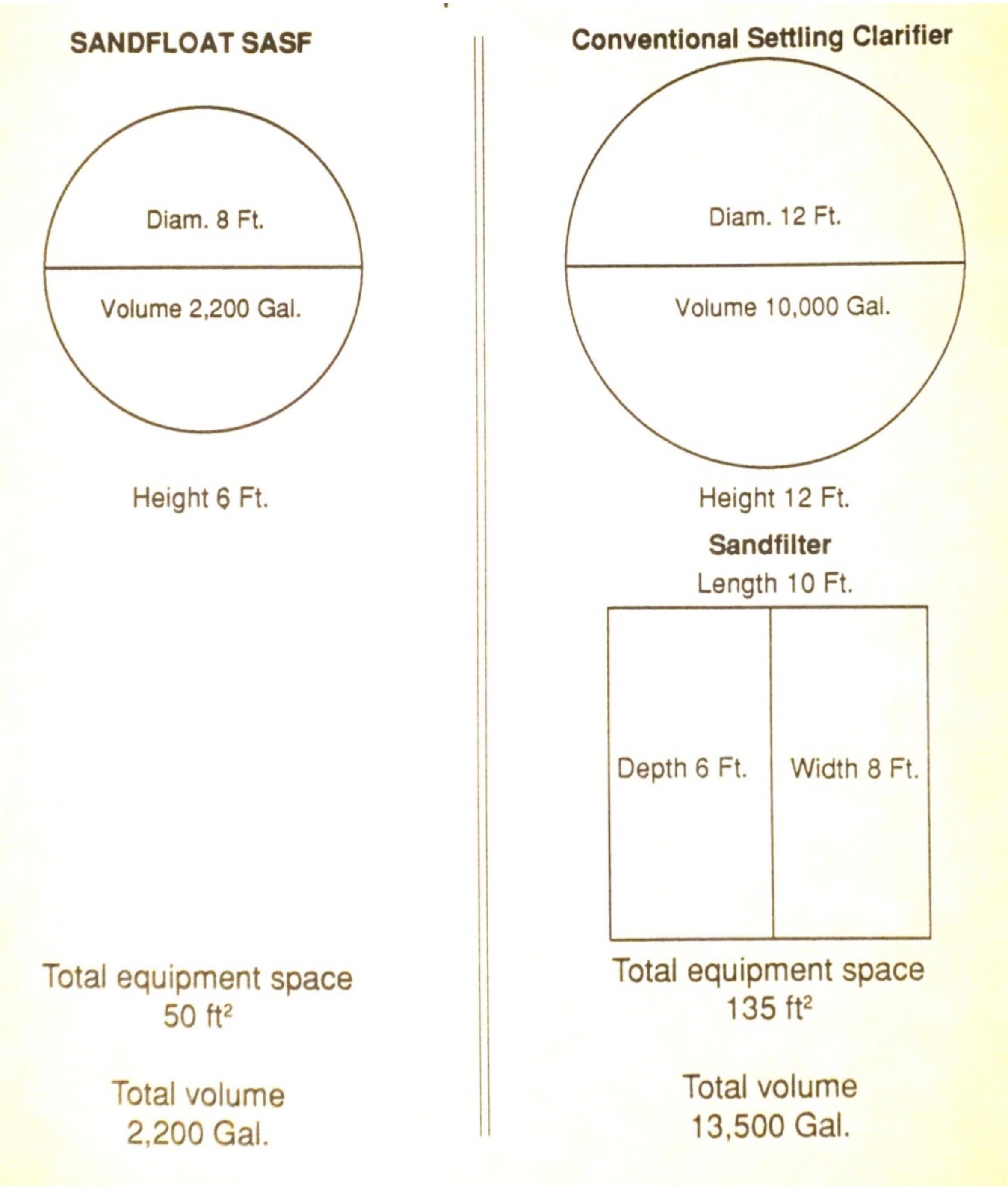
[Insert Figure 31. Top view, side view and sizes of DAF-Filtration clarifiers (Sandfloat, or DAFF)]



[Insert Figure 32. Flow diagram of a DAF-filtration clarifier (Sandfloat, DAFF)]

[Insert Figure 33. A comparison between a DAF clarifier and a sedimentation clarifier]

[Insert Figure 34. Construction of a 30-ft diameter DAF-filtration (DAFF; Sandfloat) unit on the top of an existing sedimentation clarifier in Berlin, Germany]



[Insert Figure 35. A foot-print and volume comparison between a DAF-filtration (DAFF, Sandfloat) clarifier and a conventional sedimentation-filtration combination]

9.3.2 Flotation Clarification Tank:

At the end of the flocculator (Figure 30 F) within the flotation tank (Figure 30 J), the flocculated water is saturated at several times atmospheric pressure (45–85 psig) by a pressurizing pump (Figure 30 N). The pressurized feed stream is held at this high pressure for at least 10 seconds in an air dissolving tube (ADT; Figure 30 G;) to provide efficient dissolution of air into the water stream. The pressurized stream enters the ADT tangentially at one end and is discharged at the opposite end. During the short passage, the water cycles inside the tube and passes repeatedly by an insert, fed by compressed air. Very thorough mixing under pressure then dissolves the air in the water. Figures 36-37 explain the ADT system for dissolving air into water.

A radial distribution pipe with small holes covered by a deflector feeds the pressurized water at the bottom of the flocculator outlet. The sudden reduction of pressure in the flotation chamber results in the release of microscopic air bubbles (diameter of 80 mm or smaller) that attach to suspended or colloidal particles in the process water in the flotation chamber. This results in agglomeration, which, due to the entrained air, gives a net combined specific gravity less than that of water and causes flotation. The floated materials rise to the surface of the flotation tank (Figure 30 J) to form a floated layer that is carried away by a spiral scoop (Figure 30 I). Clarified water (flotation effluent) is near the bottom of the flotation tank and is further polished by automatic backwash filters (Figure 30 R).

The design of the dissolved air flotation tank (main tank) is of circular shape and made possible by use of the principle of “zero velocity.” The flotation influent (flocculator effluent) distribution duct moves backward with the same velocity as the forward incoming flotation influent. A nearly “zero velocity” quiescent state in the flotation tank is created for flotation.

9.3.3 Automatic Backwash Filtration (ABF) Module Containing Filter Media:

Each filtration module (Figure 30 R) is fabricated of 1/4 in. minimum thickness fiberglass plate of 1/16 in. minimum thickness marine aluminum plate. The filter module is placed between the flotation chamber and the clears well. The filter underdrains are fabricated of stainless steel grid and a heavy-duty screen, and placed to ensure uniform wash water distribution and filtrate collection. Alternatively, the filter media can be supported by three inches of coarse garnet and graded gravel.

The filter media can be either a single medium system comprised of 12 in. of fine silica sand (ES = 0.36 mm; UC = 1.6) or a dual media system comprised of three inches of fine garnet in the bottom portion of the bed and nine inches of fine silica sand in the upper portion to provide the necessary polishing action. Dual media are provided, in size-identified bags, in sufficient volume by type and grade to enable a total depth of 12 inches after skimming of fines.

9.3.4 Clear Well for Disinfection and Corrosion Control

The filter effluent from ABF (Figure 30 R) are treated with disinfectant (such as chlorine or equivalent) and corrosion control chemicals in a clear well (Figure 30 S) before the treated water is pumped to a water storage tank to be used for domestic or industrial consumptions.

9.3.5 Air Dissolving System Including Air Compressors:

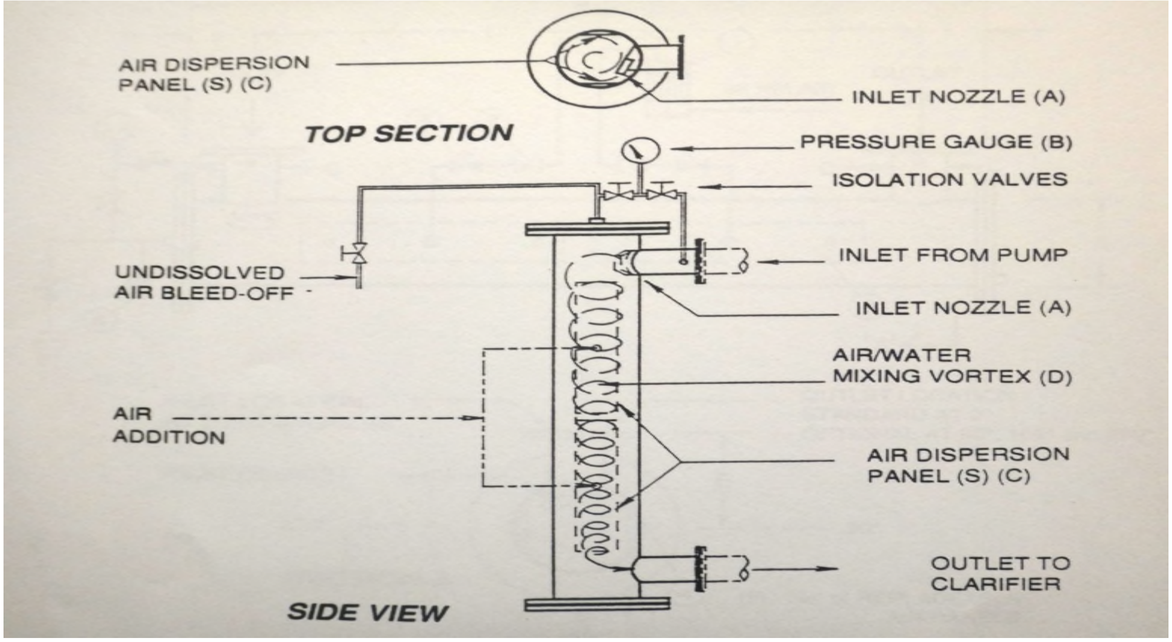
An air dissolving system, shown in Figures 36 and 37, includes (a) an air dissolving tube (ADT; or a pressure chamber) with a pneumatic sensor; (b) a water pump pumping recycled clean water to the ADT; (c) air compressors of a sufficient size providing compressed air to the recycled clean water line through an injector. Both the recycled clean water and the compressed air are mixed together and discharged to the ADT where air is completely dissolved in the pressured water. The ADT effluent containing supersaturated air is released to the DAF clarification chamber where a swarm of extremely fine air bubbles are formed for the flotation actions.

9.3.6 Instrument Control Panel and Control System:

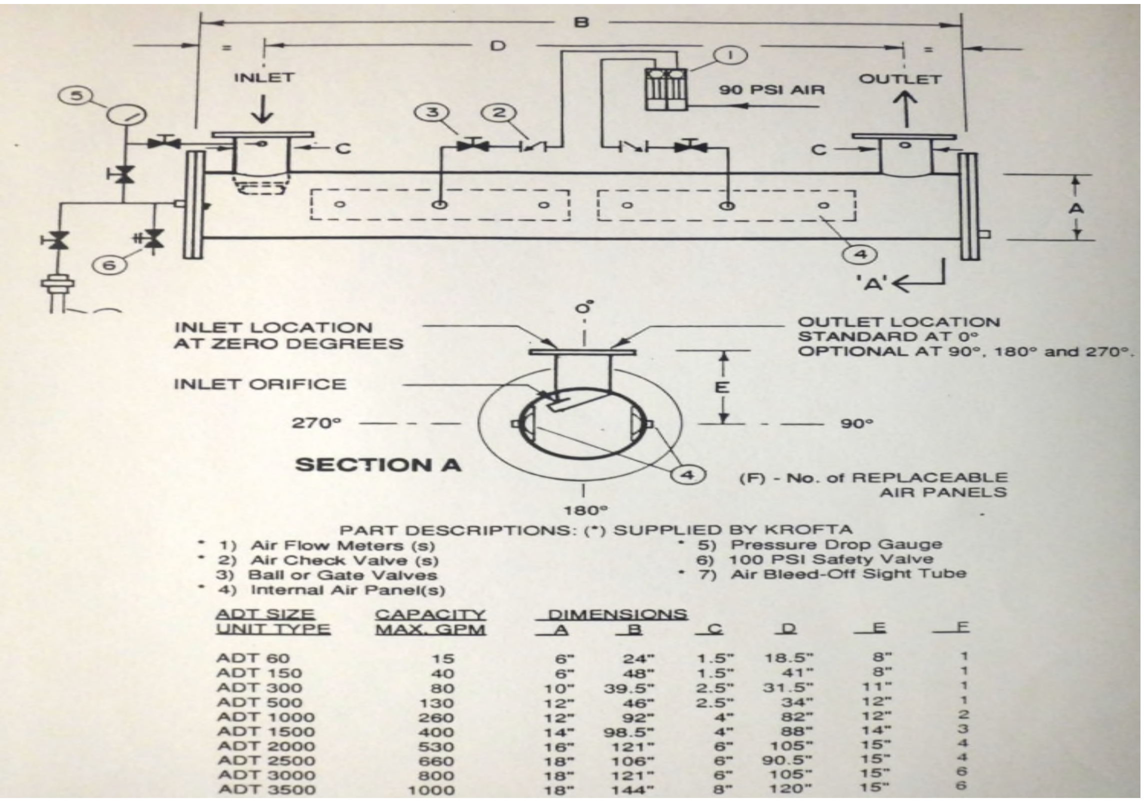
Each DAF–filtration clarifier (DAFF, or Sandfloat) has one floor mounted (in the base) electrical control panel for total automatic plant operation and process monitoring.

Each DAF-filtration water treatment unit is furnished with a float type level sensing system that transmits a 3–15 psig signal to control the 18-inch influent valve (modulate) and maintains a level over approximately 6 inches.

The level controller is arranged to decrease the inlet flow on the rising water level and decrease the inlet valve opening. Conversely, inlet flow increases on a lowering filter level and increases the valve opening.



[Insert Figure 36. Top view and side view of an air dissolving tube]



PART DESCRIPTIONS: (*) SUPPLIED BY KROFTA

- * 1) Air Flow Meters (s)
- * 2) Air Check Valve (s)
- 3) Ball or Gate Valves
- * 4) Internal Air Panel(s)
- * 5) Pressure Drop Gauge
- 6) 100 PSI Safety Valve
- * 7) Air Bleed-Off Sight Tube

ADT SIZE UNIT TYPE	CAPACITY MAX. GPM	DIMENSIONS A	B	C	D	E	F
ADT 60	15	6"	24"	1.5"	18.5"	8"	1
ADT 150	40	6"	48"	1.5"	41"	8"	1
ADT 300	80	10"	39.5"	2.5"	31.5"	11"	1
ADT 500	130	12"	46"	2.5"	34"	12"	1
ADT 1000	260	12"	92"	4"	82"	12"	2
ADT 1500	400	14"	98.5"	4"	88"	14"	3
ADT 2000	530	16"	121"	6"	105"	15"	4
ADT 2500	660	18"	106"	6"	90.5"	15"	4
ADT 3000	800	18"	121"	6"	105"	15"	6
ADT 3500	1000	18"	144"	8"	120"	15"	6

[Insert Figure 37. An air dissolving tube design diagram]

10. LENOX WATER TREATMENT PLANT, THE FIRST POTABLE WATER FLOTATION-FILTRATION PLANT IN AMERICA CONTINENTS

The new Lenox Water Treatment Plant (LWTP) in Lenox, Massachusetts, USA, is the first potable water flotation filtration plant built in Americas. LIWT grew from the Town of Lenox's need to lessen risks from trihalomethane (THM) reducing the level of turbidity, color and other THM precursors in its water. LIWT and KEC jointly showed the town and the Massachusetts Department of Environmental Quality Engineering (DEQE) – now called the Department of Environmental Protection (DEP) – that a DAF-filtration plant would efficiently and less expensively serve all residents and tourists in the scenic town in the Berkshire Mountains. (105-106, 112-114, 121, 144, 170, 197, 218-219, 224)

A full-scale potable water flotation system was constructed for improving the quality of Lenox water. The heart of the 1.2-million-gallon-per-day (MGD) Lenox Water Treatment Plant is an award-winning process consisting of chemical feeding, flocculation, dissolved air flotation, automatic backwash filtration, disinfection and corrosion control, shown in Figures 29-32. The uniqueness of the Lenox DAF drinking water treatment plant doesn't end with its status as the first in the United States. The team, led by LIWT and KEC, incorporated innovative technologies that exceeded those being used at the time in drinking water treatments plants in other parts of the globe.

Begun in 1981 and completed in about a year, the Lenox plant features a treatment chamber only about 22 feet in diameter and 6 feet in height. Yet it can process up to 1.2 MGD for the tourist destinations 6,000 year-round residents as well as the additional 4,000 seasonal visitors.

The Lenox plant's treatment tank is circular, rather than the traditional rectangular shape. A primary benefit is that it allows for a continuous flow for backwashing filters. This circular "automatic backwash filtration (ABF)" process was inspired by a similar rectangular ABF process in use at a conventional plant in nearby Lowell Water Treatment Plant in Massachusetts. The LIWT/KEC team incorporated the circular ABF process into to the DAF tank design to form a combined DAF-Filtration process unit, known as DAFF, or Sandfloat. Milos Krofta and Lawrence K. Wang formally introduced this Americas' first DAF-filtration plant at American Water Works Association (AWWA) conference in San Diego, California, USA. AWWA Research Foundation our engineering data in 1984 (170), and New England Water Works Association published our results in 1985 (218-219), when both Krofta and Wang received a 5-Star Engineering Award from Pollution Engineering for the LIWT/KEC accomplishment in Lenox. (100) It was a century's innovation because the entire LWTP detention time (not counting post-disinfection) was only about 15-30 minutes. A comparable conventional water treatment plant (not counting post-disinfection) treating the same influent flow of 1.2 MGD will need a detention time of 4 to 9 hours. The water treatment facility's volume is almost directly proportional to the detention time. This is why the 1.2-MGD Lenox plant (Sandfloat 22-ft diameter) serving 10,000 people can be as small as a car garage. Building DAF directly on the top of sand filters also significantly reduces the plant's foot-print, and the winter's heating energy. Since a DAF-filtration is so small, it may be built next to the reservoir level, without losing hydraulic head. The plant effluent, or product water, may be delivered to all customers by gravity.

On behalf of LIWT , KEC, and of course, also our beloved late Dr. Milos Krofta, the author would like to thank LIWT Professor Mu-Hao Sung Wang, Professor

Donald B. Aulenbach, Professor William A. Selke, and Supervisor Betty C. Wu, KEC Vice President Daniel Guss, KEC Marketing Manager Craig C. Gaetani, Massachusetts Regional Environmental Engineer Angelo Iantosca, and Tri-Town Sanitarian Peter J. Kolodziej for their technical assistance, collaboration and encouragement for successful completion of this 21-century's revolutionary Lenox project.

11. PITTSFIELD WATER TREATMENT PLANT, ONCE THE LARGEST POTABLE WATER FLOTATION-FILTRATION PLANT IN THE WORLD

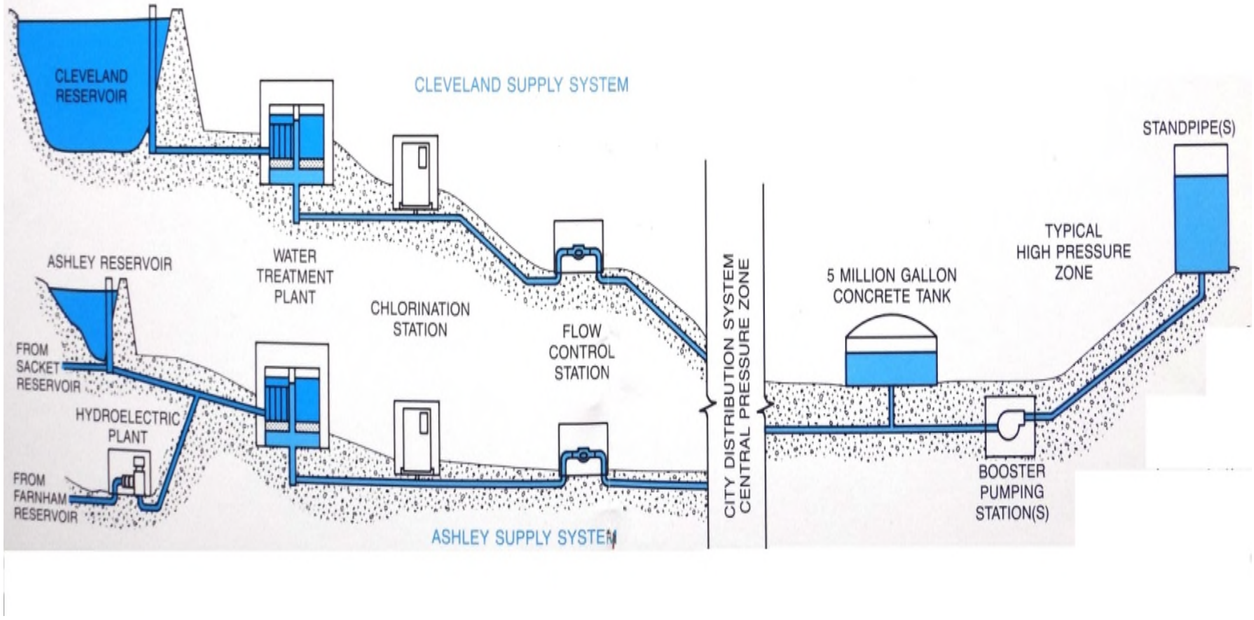
With the success of the Lenox plant assured, the Commonwealth of Massachusetts, USA, approved a much larger DAF water filtration plant in the nearby city of Pittsfield. When the 37.5-MGD (142 million liters per day) Pittsfield water treatment plant was installed in 1986, it was then the world's largest water treatment plant using dissolved air flotation (DAF). This status has since been eclipsed by other plants in the U.S. and abroad. (122-124, 163-165, 214, 220, 226)

The decision to build such a large Pittsfield plant was driven by concern that the DAF process may not work as advertised, despite the example of the small Lenox full-scale DAF water filtration plant. As a result, the Commonwealth of Massachusetts wanted a new Pittsfield flotation-filtration plant to be planned to handle double the amount needed by the City of Pittsfield.

Since the Lenox DAF-filtration (DAFF) plant came fully on line in July of 1982 and operated successfully, the Commonwealth of Massachusetts gave final approval of the much larger plant in the 50,000-resident City of Pittsfield, Massachusetts. A waiver from the state was necessary because DAF was not a standard process; DAF was not included as a form of treatment for drinking water in the "10 State Standards" guideline publication.

The heart of the Pittsfield Water Treatment Plant System is two potable DAF–filtration plants: (a) the Ashley Plant has two DAF-filtration clarifiers, and (b) the Cleveland Plant has four DAF-filtration clarifiers. Each DAF-filtration clarifier has a capacity of 6.25 MGD, for a total capacity of 37.5 MGD. Each DAF-filtration clarifier is 49 ft in diameter and 6 ft in depth, and is a Krofta Sandfloat Model

SAF49 package clarifier consisting of mainly dissolved air flotation and automatic backwash sand filtration, shown in Figures 29-32 and 38.



[Insert Figure 38. Pittsfield Water Treatment Plant System: (a) Cleveland Plant: four DAFF (Sandfloat SAF49) units; and (b) Ashley Plant: two DAFF (Sandfloat SAF49) units.]

12. MORE LIWT/KEC NEW FLOTATION SYSTEMS AND INSTALLATIONS POINTING TO NEW RESEARCH DIRECTIONS AND ENGINEERING APPLICATIONS

12.1 Adsorption Flotation Process

Adsorption flotation is either a dissolved gas flotation (DGF), or induced gas flotation (IGF, or dispersed air flotation), in which powdered activated carbon is added for taste, odor, THM, VOC, and/or color reductions in a drinking water treatment plant. (138, 185, 223). Again, the author is hoping that more research and practicing applications can be carried out by researchers and plant managers, respectively.

12.2 Sequencing Batch Flotation Systems and Sequencing Sedimentation Systems

The author, L Kurylko and MHS Wang have developed the Sequencing Batch Flotation (SBF) systems and Sequencing Batch Sedimentation (SBS) systems for potable water treatment applications. The readers are referred to the literature for the details (210, 228, 229). SBF can be divided into Sequencing Batch Dissolved Gas Flotation (SBDGF), or Sequencing Batch Induced Gas Flotation (SBIGF). SBIGF is Sequencing Batch Foam Separation (SBFS). The clarifiers can be in any shapes, circular or rectangular. The authors invented these sequencing batch processes (229), hoping that there will be more further improvements and more construction of full scale plants to be done by the young generations in the future.

12.3 Float-Press: Flotation Thickening of Sludge Produced in Drinking Water Plants

Under the joint research of LIWT and KEC, a special process equipment, known as Float-Press, was successfully developed and installed in Lenox Water Treatment Plant (LWTP) in 1982. Float-Press is combination of Dissolved Air Flotation and Sludge Press. The full Scale unit is shown in Figure 39. The process description and performance are recorded elsewhere by Krofta and Wang (219).

12.4 Advanced DGF-DGF Water Treatment System Installation

Due to Dr. Milos Krofta's passing, both LIWT and KEC do not exist at present. KEC business portion has changed its names and management hands many times. LIWT students are serving as flotation engineers, scientists, researchers, professors and managers around the world. LIWT professors are compiling previous lecture materials for publication as the university textbooks and reference books, and continuously developing new potable water flotation systems for the benefit of humanity .

Section 7 introduces a double DGF-DGF system for a water treatment situation (Figures 21-22, two-stage lime soda ash softening process system) that two clarifiers are needed. DGF-DGF two-stage system can be used for both two-stage water treatment or wastewater. Figure 40 shows the full-scale installation of a two-stage DAF-DAF system because air is used for generation of gas bubbles.

12.5 Advanced DGF-DGFF Water Treatment System Installation

In the final days of LIWT/KEC, a double DGF-DGFF (or DAF-DAFF if air is used) was developed for potable water treatment or wastewater treatment. Figures 41 and 42 illustrate the innovative DGF-DGFF process system, and its full-scale installation, respectively, which are self-explanatory. The readers are encouraged to read Section 7 and the related literature regarding its theories and principles (234).

12.6 Water Treatment by Dissolved Air Flotation Using Magnesium Carbonate as a Recyclable Coagulant

A raw water having 10 units of color, 13 NTU of turbidity, and 417 mg/L of calcium hardness in terms of $CaCO_3$, was successfully treated by a continuous pilot plant consisting of a static hydraulic flocculation, a dissolved air flotation clarifier (Krofta Supracell Model SPC3, diameter = 3 ft.), a recarbonation facility and three sand filters. When the raw water was dosed with 42.3 mg/L of magnesium carbonate as coagulant. Figures 43 and 44 present the chemical reactions and it flow diagram, respectively. The readers are referred to a US government report (96) for the experimental results, and are urged for continuous research, using any manufacturer's flotation equipment, and using either dissolved air flotation (DAF) or dissolved carbon dioxide flotation (DCDF). Reaction (h) in Figure 43 is for carbonation of the magnesium hydroxide sludge, and the reproduced magnesium carbonate is a recyclable coagulant.

12.7 Using Popular Flotation Processes as a Pretreatment to Equally Popular Membrane Processes

It will be very logic if the best available flotation process is used as a pretreatment step to the best available membrane process for (a) potable water treatment especially in the areas where the sources of fresh water is limited in quantity or poor in quality, or (b) for industrial process water recycle . (206, 216, 231, 235, 237). The readers are referred to the literature for more detailed technical information.

12.8 Using Popular DAF-DAFF Clarifier (Sandfloat) for Granular Activated Carbon Filtration or Dual-Media Filtration.

Attached are Figures 45 and 46 showing the rectangular automatic backwash filters (RABF) are used as granular activated carbon filtration and dual-media filtration, respectively. The bottom of the DAF-DAFF clarifier is a circular automatic backwash filtration (CABF) unit. Currently all circular DAF-DAFF clarifiers (Sandfloat clarifiers) in operation worldwide are applied to sand filtration only. Equipment manufacturers may be interested in this new applications because a CABF has certain advantages over a RABF, due to the fact that each filter section can be backwashed in proper order in circular direction without losing any operational times.

12.9 Using Circular Automatic Backwash Filter (CABF) as an Independent Process Unit.

Again a process equipment manufacturer may be interested in this new invention and applications. The bottom portion of a DAF-DAFF clarifier (Sandfloat) may be cut out and patented as a new process equipment – circular automatic backwash filter (CABF), which can be used as a sand filter, and dual-media filter, or a GAC filter.

Will professors, students, researchers, consulting engineers and equipment manufacturers, please continue all or some of the authors' proposed new research directions in Section 12, for exploring further process improvement or new applications to the existing process equipment. Will new researchers please continue all proposed new research directions in Section 12.

12. 10. Further Research for Cream Flotation

Cream flotation process was invented by the author and reported as a Federal Government report as follows (151):

> Wang, L. K., "Theory and Application of Flotation Processes," U.S. Dept. of Commerce, National Technical Information Service, PB86-194198/AS, 15 p., Nov. 1985.

Although Cream flotation was invented by the author at the Lenox Institute of Water Technology long time ago, it is still in developmental stage. The new process involves pressurization of air or other gases at 25-60 psig for dissolving air or other gas into water containing surfactant, and subsequent release of pressure (to 1 atm) under laminar hydraulic flow conditions for generation of thick cream or foam bubbles, which become attached to the suspended matter (impurities or the recoverable substances) to rise together to the water surface. The attachment of foam bubbles to the suspended matter can be a combined result of physical entrapment, electrochemical attraction and surface adsorption. The specific gravity of foam-suspended agglomerate is less than one, resulting in rapid buoyancy or flotation. Cream flotation can also be operated in different modes: (a) full flow pressurization; (b) partial flow pressurization, and (c) recycle flow pressurization.

It is economically feasible for separation of insoluble matter from a water stream which already contains surfactant (151).

The author invites flotation researchers and equipment manufacturers to investigate this conceptually developed cream flotation process further, and make it useful for wastewater treatment or resources recovery.

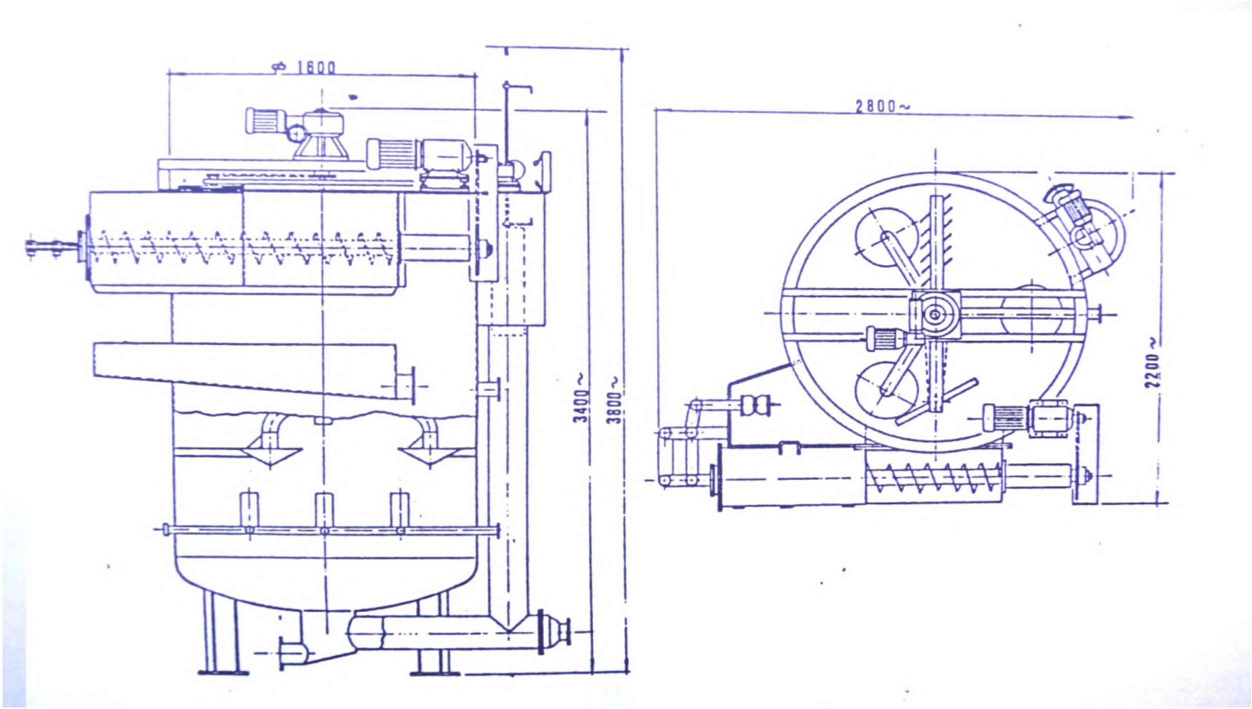
13. LENOX INSTITUTE OF WATER TECHNOLOGY: A COLLEGE OF HUMANITARIAN ENGINEERING

The practice of humanitarian engineering is discussed by Daley and Anderson (238).

It appears that establishment of the Lenox Institute of Water Technology (LIWT) was , indeed, a practice of humanitarian engineering because LIWT was for (a) providing totally free water engineering (flotation) education to cross-cultural, international students with any engineering and science disciplines; (b) voluntarily offering continuous education and training courses to the international communities at large, and (c) continuously distributing environmental and ecological knowledge to general public through worldwide public speeches, and publication of US government reports, UN reports, books and journal articles, again all free of charge.

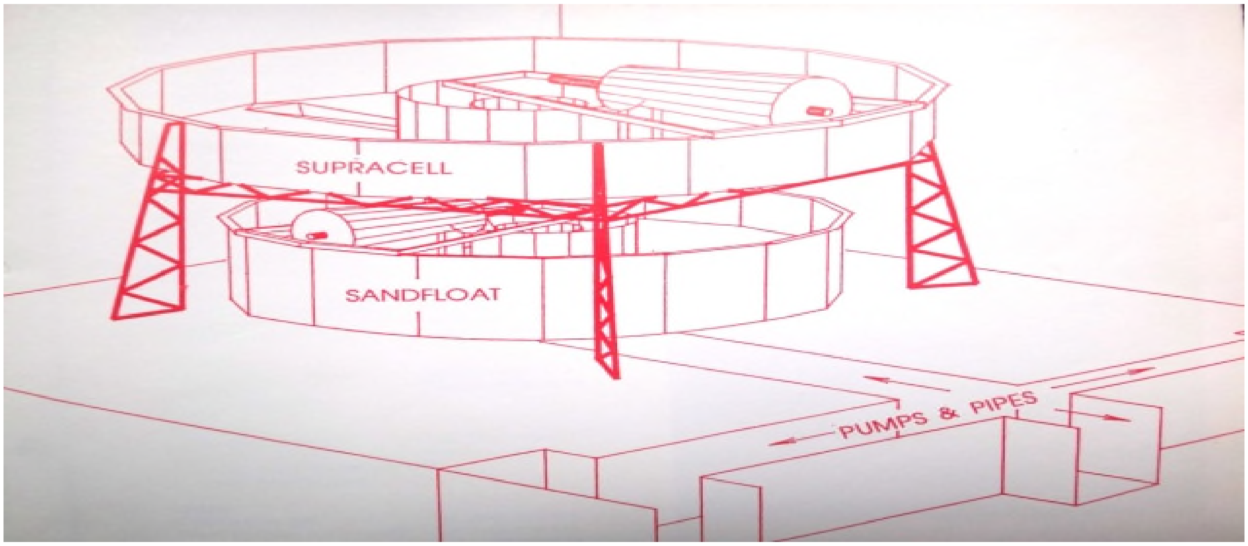
Due to the passing of the LIWT founder, Dr. Milos Krofta, at his old age of 90, the function of (a) or free flotation engineering education, only lasted for 20+ years, the only flotation college in the world closed its campus. Although the faculty and graduates of LIWT still carry on the functions of (b) and (c) listed above assuming LIWT is still a college without walls, these voluntary activities and services are not sustainable. The author along with other faculty and students are still documenting the R&D and engineering experiences of both LIWT and KEC to be our academic contributions to the society, such as: (a) Handbook of Environmental Engineering series (Springer, 18 books), (b) Advances in Industrial and Hazardous Wastes Treatment (CRC Press, 10 books), (c) Handbook of Environment and Waste Management series (World Scientific, 3 books); (d) Water and Wastewater Engineering series (John Wiley & Sons, 2 books); and (e) US government reports (many).

The society needs more donors, like late Dr. Milos Krofta, more humanitarian engineering colleges like LIWT, more academic researchers like Dr. James K. Edzwald and his coworkers (241-253), and more volunteers.



[Insert Figure 39. A full-scale FloatPress (a combination of dissolved air flotation and sludge press) installed at Lenox Water Treatment Plant, Lenox, MA, USA, in 1982.]

[Insert Figure 40. A full-scale installation of a two-stage DAF-DAF system]

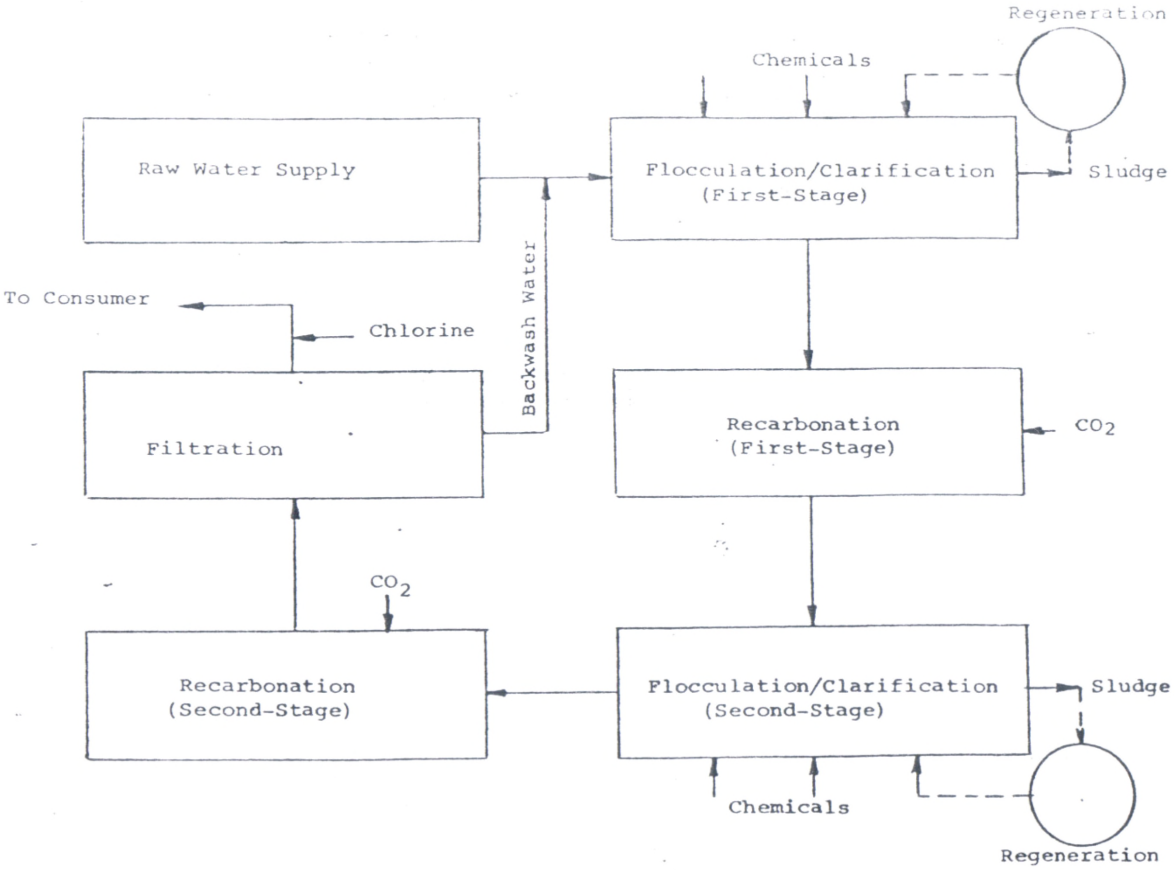


[Insert Figure 41. Graphical illustration of a double DGF-DGFF (or DAF-DAFF, or Supracell-Sandfloat) system for potable water treatment Plant.   ]

[Insert Figure 42. Full-scale double DGF-DGFF (or DAF-DAFF, or Supracell-Sandfloat) system]

(a) $Ca(HCO_3)_2 + Ca(OH)_2 = 2\ CaCO_3 + H_2O$
(b) $Mg(HCO_3)_2 + Ca(OH)_2 = 2\ CaCO_3 + H_2O$
(c) $MgCO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_3$
(d) $CaSO_4 + MgCO_3 = CaCO_3 + MgSO_4$
(e) $MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$
(f) $CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$
(g) $CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$
(h) $CO_2 + Mg(OH)_2 = MgCO_3 + H_2O$

[Insert Figure 43. Chemical reactions of a two-stage DAF-DAF lime-magnesium carbon softening process using magnesium carbon as a recyclable coagulant]



[Insert Figure 44. Flow diagram of a two-stage DAF-DAF lime-magnesium carbon softening process for hardness removal using magnesium carbon as a recyclable coagulant]

[Insert Figure 45. Rectangular Automatic Backwash Filter Installed at Lowell Regional Utility, Massachusetts, USA for Dual Media Filtration (Credit: Superintendent Steve Duchesnel, LRU, August 2019) (236)]

[Insert Figure 46. Rectangular Automatic Backwash Filter Installed at Lowell Regional Utility, Massachusetts, USA for Granular Activated Carbon Filtration (Credit: Superintendent Steve Duchesnel, LRU, August 2019) (236)]

GLOSSARY (151, 231, 239, 240)

Adsorption flotation: The powdered activated carbons (PAC) may be dosed into a dissolved air flotation system for taste and odor control and/or toxic substances removal. A flotation process involving the use of PAC is adsorption flotation.

Adsorptive bubble separation: Any water, wastewater, or sludge treatment system that involves the use of gas bubbles for water-solids separation.

Automatic backwash filtration (ABF): A filtration system that is divided into many identical-shape filtration sections for automatic filtration operation and backwash. There is a moving carriage having a backwash hood and a backwash pump and traveling back and forth on top of the filtration sections. When the backwash hood covers one filtration section for automatic backwash (controlled by a timer), the rest filtration sections are in filtration mode. One filtration section is backwashed at a time, until all filtration sections are backwashed and restored to filtration mode again.

Biological flotation: In a biological flotation system, fermentations take place in the presence of anaerobic bacteria, nitrates and substrates under anaerobic environment, anaerobic bacteria in waste sludge convert nitrate and the substrate with carbon source (such as methanol, or residual BOD) to nitrite, water and carbon dioxide fine bubbles. Nitrite further reacts with a substrate (such as methanol or residual BOD) in the same waste sludge, producing fine nitrogen bubbles, more fine carbon dioxide bubbles, water and hydroxide ions. The biological waste sludge, such as activated sludge can then be floated to the surface by the fine nitrogen and carbon dioxide bubbles and be thickened (i.e. concentrated). The thickened sludge which are the final products of the biological flotation thickening process are skimmed or scooped off from the liquid sludge surface; while the subnatant clarified water is discharged from the biological flotation thickener's bottom. The energy consumption of this process is low. Its detention time is long. More research is needed for this newly developed sludge thickening process (151).

Cream flotation: It is a new process invented by the Lenox Institute of Water Technology. The new process involves pressurization of air or other gases at 25-60 psig for dissolving air or other gas into water containing surfactant, and subsequent release of pressure (to 1 atm) under laminar hydraulic flow conditions for generation of thick cream or foam bubbles, which become attached to the suspended matter (impurities or the recoverable substances) to rise together to the water surface. The attachment of foam bubbles to the suspended matter can be a combined result of physical entrapment, electrochemical attraction and surface adsorption. The specific gravity of foam-suspended agglomerate is less than one, resulting in rapid buoyancy or flotation. Cream flotation can also be operated in different modes: (a) full flow pressurization; (b) partial flow pressurization, and (c) recycle flow pressurization. It is economically feasible for separation of insoluble matter from a water stream which already contains surfactant (151).

DAF-DAF: A two-stage water or wastewater treatment process system consisting of double dissolved air flotation clarifiers (2 DAF clarifiers) connected in series, usually one DAF is on the top of another DAF.

DAF-DAFF: A two-stage water or wastewater treatment process system consisting of a dissolved air flotation clarifier (DAF) and a dissolved air flotation-filtration clarifier (DAFF) connected in series, usually DAF is on the top of a DAFF.

Deep shaft flotation: Same as micro-flotation.

Dispersed air flotation: Same as induced air flotation (IGF). It is one of induced gas flotation (IGF) processes when air is used for generation gas bubbles.

Dispersed gas flotation: Same as induced gas flotation (IGF).

Dispersed gas flotation: Same as induced gas flotation (IGF).

Dispersed nitrogen flotation: Same as induced nitrogen flotation (IGF). It is one of induced gas flotation (IGF) processes when nitrogen is used for generation gas bubbles.

Dissolved air flotation (DAF): One of dissolved gas flotation (DGF) processes when air is used for generation of gas bubbles. A typical example is Krofta Engineering Corporation’s Supracell clarifier; See dissolved gas flotation (DGF).

Dissolved air flotation-filtration (DAFF): A package plant which consists of both dissolved air flotation and filtration. A typical example is Krofta Engineering Corporation’s Sandfloat clarifier.

Dissolved carbon dioxide flotation (DCDF): One of dissolved gas flotation (DGF) processes when carbon dioxide is used for generation of gas bubbles. See dissolved gas flotation (DGF).

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 non-selective flotation (i.e. Save-All).

Dissolved nitrogen flotation (DNF): One of dissolved gas flotation (DGF) processes when nitrogen is used for generation of gas bubbles. See dissolved gas flotation (DGF).

Dissolved ozone flotation (DOF): One of dissolved gas flotation (DGF) processes when ozone is used for generation of gas bubbles. See dissolved gas flotation (DGF).

Electroflotation: It is process involving the generation of hydrogen and oxygen bubbles in a dilute electrolytic aqueous solution by passing a direct current between two electrodes (a) anode and (b) cathode. Anode reaction generates oxygen bubbles and hydrogen ions; while cathode reaction generates hydrogen bubbles and hydroxide ions. Either aluminum or steel sacrificial electrodes can be employed for generating the gas bubbles as well as coagulants at the same time. Non-sacrificial electrodes are employed for generating the gas bubbles only, and can be mode of titanium (as the carrier material) and lead dioxide (as the coating material). Electrical power is supplied to the electrodes at a low voltage potential of 5 to 20 volts DC by means of a transformer rectifier. Small bubbles in the range of 20-50m microns are produced under laminar hydraulic flow conditions feasible for flotation separation of fragile flocs from water in a small system. The floats on the water surface are the impurities/pollutants removed from water. The clarified water is discharged from the flotation clarifier's bottom. There can be unexpected advantages and disadvantages when electroflotation is employed. For instance, chlorine bubbles may be generated as a water disinfectant if the water contains significant amount of chloride ions. Certain unexpected gas bubbles may be generated and may be undesirable. (151)

Electrolytic flotation: Same as Electroflotation.

Flotation-sludge press (FloatPress): A combined dissolved air flotation thickener and sludge press with the flotation thickener at the bottom and the sludge press on the top. A typical example is FloatPress manufactured by Krofta Engineering Corporation.

Foam separation: Same as induced gas flotation (IGF), normally air is used for generation of gas bubbles.

Granular activated carbon (GAC) filtration: A filtration bed consists of granular activated carbon.

Gravity flotation: : It is a water-solids separation process by flotation relying on natural specific gravity difference of a water and the light-weight solids (specific gravity is less than 1) within water. In natural gravity flotation, oil, grease, wax, fiber, or other substances lighter than water (specific gravity is less than 1) are allowed to rise naturally to the water surface of quiescent tank, where they are skimmed off or scooped off. The bottom clean water is discharged as the treated water. The floats skimmed off or scooped off from the water surface are either the impurities/pollutants to be removed, or the resources (such as fibers, or oils) recovered for reuse.

Induced gas flotation (IGF) : It is a process involving introduction of gas directly into the water through a revolving impeller, a diffuser system, or an ejector, or a combination of them, at low pressure (slightly higher than one atm) for generating big gas bubbles (80 microns to over one mm) in large volume under turbulent hydraulic flow conditions. The gas flow rate is about 400 percent of the influent water flow rate. Physical entrapment and electrochemical attraction play minor roles in an induced gas flotation system. The attachment of gas bubbles to the impurities is mainly a result of surface adsorption, gas stripping and oxidation. Surface active substances (inks, detergents, ores, soaps, etc.) together with impurities are selectively separated in a foam phase at the water surface. The foam containing the surfactant and the impurities are removed by suction device, Volatile substances are removed by gas stripping action. The clarified waster is discharged from the flotation clarifier’s bottom. Reducing agents, such as ferrous ions, can be oxidized to ferric ions for subsequent separation in ferric hydroxide form if air is used as a gas.

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.

Micro-flotation: In micro-flotation, the entire volume of water to be treated is subjected to the increased pressure by passing the water down and up a shaft approximately 10 meters deep. At the bottom of the shaft, on the down-comer side, air is injected by one air blower under low pressure (20 psig) . Un-dissolved air rises up the shaft against the flow thus increasing the saturation of the water. As the water rises in the up-flow section, the hydrostatic pressure decreases. Some of the soluble air is then released out of solution in the form of fine air bubbles due to a reduction in air solubility caused by pressure reduction. Floc agglomeration and bubble generation occur simultaneously and gently; providing good attachment of the air bubbles to the flocs. The amount of air which can be dissolved is limited by the depth of shaft (e.g. hydrostatic pressure provided). The saturation of the water with air at that depth is dependent on the way the air is introduced to the system. (e.g. size of air bubbles produced at point of injection.). Similarly the floats collected on water surface are the impurities/pollutants removed from the water. The floats are collected by a rotating sludge collection scoop or equivalent. The bottom flotation clarified water is discharged as the treated water (151).

Natural flotation: Same as gravity flotation, or natural gravity flotation.

Sedimentation-flotation (SediFloat): A combined sedimentation and dissolved air flotation clarifier, with sedimentation at the bottom and dissolved air flotation on the top. A typical example is SediFloat manufactured by Krofta Engineering Corporation.

Vacuum flotation: In vacuum flotation, the influent process water to be treated is usually almost saturated with air at atmospheric pressure. There is an air-tight enclosure on the top of the flotation chamber in which partial vacuum is maintained. The fine air bubbles (20-80 microns) are generated under laminar hydraulic flow conditions by applying a vacuum (negative pressure) to the flotation chamber. The theory is that the lower the pressure, the lower the air solubility in water. The soluble air originally in water is partially released out of solution as extremely fine bubbles due to a reduction in air solubility caused by negative vacuum pressure. The bubbles and the attached solid particles rise to the water surface to form a scum blanket, which can be removed by a continuous scooping or skimming mechanism. Grit and other heavy solids that settle to the bottom are raked to a central sludge sump for removal. Auxiliary equipment includes an aeration tank for saturating the water or wastewater with air, vacuum pumps, and sludge pumps. (151)

Vertical shaft flotation: Same as deep shaft flotation.

REFERENCES

1. Boyd, J.L. and Shell, G.L., "Dissolved Air Flotation Application to Industrial Wastewater Treatment", Proceedings of the 27th Industrial Waste Conference, (1972)

2. Stander, G.J. and Van Vuuren, L.R.J., "Flotation of Sewage and Waste Solids", Water Quality Improvement by Physical and Chemical Processes, 190-199, (Edited by E.F. Gloyna and W. W. Eckenfelder, Jr.) Univ. of Texas Press, Texas (1970)

3. Metcalf & Eddy, Inc., "Wastewater Engineering, Collection, Treatment, Disposal", McGraw—Hill Book Co., New York, 296-301 (1972)

4. Anon, "Electrolysis—bred Bubbles Clarify Water", Chemical Engineering, 82-84 (July 29, 1968)

5. Lemlich, R., "Adsorptive Bubble Separation Techniques", Academic Press, New York (1972).

6. Wang, L.K., "Environmental Engineering Glossary", Calspan Corporation, Buffalo, New York, 439 pages (1974)

7. Greives, R.B., "Foam Separations for Industrial Wastes: Process Selection", Proceedings of the 25th Industrial Waste Conference, Purdue University, Indiana, 398-405, 1970.

8. London, M. et al, "Fractionation of An Enzyme by Foaming", Notes, Vol. 75, p. 1746 (April 5, 1953)

9. Charm S. E. et al, "The Separation and Purification of Enzymes Through Foaming", Analytical Biochemistry, 15, 498-508 (1966)

10. Schnepf, R.W., and Gaden, E.L., Jr., "Foam Fractionation of Proteins: Concentration of Aqueous Solutions of Bovine Serum Albumin", Journal Biochemical and Microbiological Technology and Engineering, 1 (1) , 1-8 (1959)

11. Wallace, G.T. and Wilson, D.F., "Foam Separation as a Tool in Chemical Oceanography", Naval Research Laboratory Report 6958, 20 pages (Nov. 1969)

12. Kevorkian, V., and Gaden, E. L., Jr., "Froth—frothate Concentration Relations in Foam Fractionation", Journal of the American Institute of Chemical Engineers, 3, 180 (June, 1957)

13. Hargis L.G., and Rogers, L.B., "Enrichment and Fractionation by

Foaming", Separation Science, 4 (2), 119-127 (1969)

14. Wood, R. K. and Tran, T., "Surface Adsorption and the Effect of Column Diameter in the Continuous Foam Separation Process", The Canadian Journal of Chemical Engineering, (1966)

15. Sheiham, I. and Pinfold, T.A., "Some Parameters Affecting the Flotation of Cationic Surfactants", Separation Science, 25-41 (1972)

16. Harding, C.I., "Foam Fractionation in Kraft Black Liquor Oxidation", Ph.D. Thesis, University of Florida, Gainesville, Florida (1963)

17. Georgia Kraft Company, "Foam Separation of Kraft Pulping Wastes", Water Pollution Control Research Series, DAST-3, U.S. Department of the Interior, Federal Water Pollution Control Administration (1969)

18. Michelsen, D. L., "Treatment of Dyeing Bath Waste Streams by Foaming and Flotation Techniques", Project Report of Water Resources Research Center, Virginia Polytechnic Institute and State University, Virginia (Dec. 1970)

19. Karger, B. L., Grieves, R. B., Lemlich, R., Rubin, A. J., and Sebba, F., "Nomenclature Recommendations for Adsorptive Bubble Separation Methods", Separation Science, 2, 401, 1967.

20. Wang, M. H. S., "Separation of Lignin from Aqueous Solution by Adsorptive Bubble Separation Processes", Ph.D. Thesis, Rutgers University, New Brunswick, N.J. (1972); Selected Water Resources Abstracts, 6 (4), (Feb. 1973)

21. Wang, M. H.S., Granstrom, M. L., Wilson, T. E. and Wang, L. K., "Removal of Lignin from Water by Precipitate Flotation", Proceedings of American Society of Civil Engineers, Journal of Environmental Engineering Division, 100 (EE3) , 629-640, (June 1974).

22. King, L.J. et al, "Pilot Plant Studies of the Decontamination of Low Level Process Waste by a Scavenging Precipitation Foam Separation Process", U.S. Atomic Energy Commission, ORNL-3808, 57 pages (1968)

23. Davis, B.M., and Sebba, F., "The Removal of Radioactive Caesium Contaminants from Simple Aqueous Solutions", Journal Applied Chemistry, 17, 40-43 (1967)

24. Mahne, E. J., and Pinfold, T. A., "Precipitate Flotation: Flotation of

Silver, Uranium and Gold", Journal Applied Chemistry, 19, 57-5 9 (1969)

25. Lusher, J. A. and Sebba, F., "Separation of Aluminum from Beryllium in Aqueous Solutions by Precipitate Flotation", Journal Applied Chemistry, Vol. 16, 129-132 (April 1966)

26. Rubin, A. J., and Johnson, J. D., "Effect of pH on Ion and Precipitate Flotation Systems", Analytical Chemistry, 39, 2 98-302 (1967)

27. Mahne, E. J. and Pinfold, T. A., "Precipitate Flotation, Separation of Palladium from Platinum, Gold, Silver, Iron, Cobalt and Nickel", Journal Applied Chemistry, Vol. 18, (May 1968)

28. Grieves, R B. and Bhattacharyya, "Foam Separation of Cyanide Complexed by Iron", Separation Science, 3 (2), 185-202 (1968)

29. Bhattacharyya, D., "Foam Separation Processes", Ph.D. Thesis, Illinois Institute of Technology, Illinois (1966)

30. Wilson, T. E. and Wang, M. H. S., "Removal of Lignin by Foam Separation Processes", Proceedings of the 25th industrial Waste Conference, Purdue University, Indiana, 731- 738, 1970.

31. Wang, M.H.S., Granstrom, M.L., Wilson, T.E. and Wang, L.K., "Lignin Separation by Continuous Ion Flotation: Investigation of Physical Operational Parameters", Water Resources Bulletin, 10 (2) , 283-294 (April 1974)

32. Karger, B.L. and Rogers, L.B., " Foam Fractionation of Organic Compounds", Separation, 33 (9) , 1165-1169 (1961)

33. Karger, B.L. et al, "Foam Fractionation Under Total Reflux", Separation, 38 (6), 764-767 (May 1966).

34. Grieves, R.B. et al, "Optimization of the Ion Flotation of Dichromate", Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, 515 (June 1969)

35. Grieves, R.B. et al, "Continuous Dissolved—Air Ion Flotation of Hexavalent Chromium", Journal of American Institute of Chemical Engineers, 13 (6) , 1167-1170 (1967)

36. Karger, B.L. and DeVivo, D.G., "General Survey of Adsorptive Bubble Separation Processes", Separation Science, 3 , 393—424, (1968)

37. Rubin, A.J. and Cassell, E.A., “Microflotation of Bacteria”, Proceedings Southern Water Resources and Pollution Control Conference, 14, 222 (1965)

38. Rubin, A.J. et al, “Microflotation: New Low Gas Flow Rate Foam Separation Technique for Bacteria and Algae”, Biotechnol. Bioeng., 8, 135 (1966)

39. Rubin, A.J., “Microflotation: Coagulation and Foam Separation of Aerobactic Aerogenes”, Biotechnol. Bioeng., 10, 89 (1968)

40. Henderson, 0., “ The Effect of pH on Algae Flotation”, Ph.D. Thesis, University of North Carolina, Chapel Hill (1967)

41. Dobias, B. and Vinter, V., “Flotation of Microorganisms”, Folia Microbiology, 11, 314 (1966)

42. Cassell, E., Rubin, A.J. A. et al., “Removal of Organic Colloids by Microflotation”, Proceedings of the 23rd Industrial Waste Conference, Purdue University, Indiana, (1968)

43. Kozhukhovskaya, A.N. et al (USSR), “Selective Flotation of Microlite and Rutile”, Nauch. Tr., Irkutsk. Gos. Nauch. Issled. Inst.

Redk. Tsvet. Metal., No. 19, 105-111 (Russ) (1968)

44. Katashin, L.V. et al (USSR), “Flotation of Pyrochlore from Slimes Left After Gravitational Concentration of Rare Metal Carbonatite Ores”, Nauch. Tr., Irkutsk. Gos. Nauch. Issled. Inst. Redk. Isvet. Metal., No. 19 (1968).

45. Onoprienko, N.N. et al (USSR), “Flotation of Iron Oxides”, Izr. Vyssh. Ucheb. Zaved., Gorn. Zh., 12 (1), 157—161 (Russ) (1969)

46. Wang. L.K. et al., “Treatment of Tannery Effluents by Physical-Chemical Processes”, Proceedings of the 45th Annual Conference of the Water Pollution Control Federation, Atlanta, Georgia, 36 pages (Oct. 1972); Selected Water Resources Abstract, 7 (5) W74—02175, 56—57 (March 1974)

47. Wang, L.K. et al., “Surface Adsorption: A Promising Approach for the Treatment of Tannery Effluents”, Report No. VT-3045-M-2, Cornell Aeronautical Laboratory, Inc., Cornell University, Buffalo, N.Y., 60 pages (Oct. 1971); Selected Water Resources Abstracts, 6 (21), W73—13648, (Nov. 1973)

48. Wang, L.K. et al, “Evaluation and Development of Physical-Chemical Techniques for the Separation of Emulsified Oil from Water”, Report No. 189, Calspan Corporation, Buffalo, N.Y., 31

pages, (May 1973); Selected Water Resources Abstract, 6 (21) , w73—13642, p.90 (Nov. 1973)

49. Kim, Y.S. and Zeitlin, H., "The Separation of Zinc and Copper from Seawater by Adsorption Colloid Flotation", Separation Science, 7 (1) , 1—12 (1972).

50. Pinfold, T.A., "Adsorptive Bubble Separation Methods", Separation Science, 5 (4) , 379—384 (1970)

51. KondrataviciUs, V., "Removal of Synthetic Surface-Active Agents from Waste Waters of Tanneries", Kozk Obur. Prom. (USSR) , 11 (1) , 18-18 (1969)

52. Wang, L.K. et al, "Treatment of Glue Factory Wastes by Physicochemical Processes", Report No. VT-3045-M-3, Cornell Aeronautical Laboratory, Inc., Cornell University, Buffalo, N.Y., 79 pages (Jan. (1972); Pollution Abstracts, p. 113 (Nov. 1973)

53. Dorman, D.C. and Lemlich, R., "Separation of Liquid Mixtures by Non-foaming Bubble Fractionation", Nature, 4993, 145-146 (July 1965)

54. Harper, D.O., "Bubble and Foam Fractionation", Ph.D. Thesis,

University of Cincinnati, Cincinnati, Ohio, (1967)

55. Lemlich, R., "Theoretical Approach to Non-foaming Adsorptive Bubble Fractionation", A.I. Ch.E. Journal, 12 (4) , 802—804 (July 1966)

56. Lemlich, R., "Adsubble Processes: Foam Fractionation and Bubble Fractionation", Journal of Geophysical Research, 77 (27) , 5204-5210 (Sept. 1972)

57. Wang, L. K., "Continuous Bubble Fractionation Process", Ph.D. Thesis, Rutgers University, New Brunswick, N. J. (1972)

58. Cannon, K.D. and Lemlich, R., "A Theoretical Study of Bubble Fractionation", A.I. Ch.E. Symposium Series, 68 (124) , (1972)

59. Kown, B.T. and Wang, L. K., "Solute Separation by Continuous Bubble Fractionation", Separation Science, 6 (4), 537—552, (Aug 1971); Selected Water Resources Abstracts, 6 (21) W73—l3638, p. 89 (Nov 1973)

60. Maas, K., "A New Type of Adsubble Methods: Booster Bubble Fractionation -- Hastened and Improved Bubble Fractionation of Low Foaming Solutions", Separation Science, 4 (6), 457— 465

(Dec. 1969)

61. Wang, L.K. et al, “Continuous Bubble Fractionation: Part I, Theoretical Considerations”, Environmental Letters, 3 (4), 2 51—265 (1972)

62. Wang, L.K., et al, “Continuous Bubble Fractionation: Part II, Effects of Bubble Size and Gas Rate”, Environmental Letters, 4 (3) , 233—252 (1973)

63. Wang, L.K., et al, “Continuous Bubble Fractionation: Part III, Experimental Evaluation of Flow Parameters”, Environmental Letters, 5 (2) , 71-89 (1973)

64. Shah, G.N. and Lemlich, R., “Separation of Dyes in Non—foaming Adsorptive Bubble Columns”, Ind. Eng. Chem. Fundam., 9 (3), 350-355 (1970).

65. Bruin, S. et al “Continuous Nonfoaming Adsorptive Bubble Fractionation”, Ind. Eng. Chem. Fundam., 11 (2) 175-181 (1972)

66. Karger, B.L., Caragay, A.B., and Lee, S.B., “Studies in Solvent Sublation: Extraction of Methyl Orange and Rhoda-mine B”, Separation Science, 2 (1) , 39-64 (1967)

67. Sheiham, I. and Pinfold, T.A., “The Solvent Sublation of Hexadecyltrimethylaininonium Chloride”, Separation Science, (1) 43—50 (1972)

68. Quigley, R.E., and Hoffman, E.L., “Flotation of Oily Wastes”, Proceedings of the 21st Industrial Waste Conference, Purdue University, Indiana, 527-533 (1966)

69. Hart, J.A., “Air Flotation Treatment and Reuse of Refinery Wastewater”, Proceedings of the 25th Industrial Waste Conference, Purdue University, Indiana, 406-413 *(1970)*

70. Lundgren, H., “Air Flotation Purifies Wastewater From Latex Polymer Manufacturer”, Chemical Engineering Progress Symposium Series—Water, 191-195 (1969)

71. Wang, L. K., et al, “Water Treatment with Multiphase Flow Reactor and Cationic Surfactants”, Journal of American Water Works Association, 70 (9), 522-528, (Sept. 1978)

72. Krofta, M., Wang, L.K., Barris, D. and Janas, J., “Treatment of Pittsfield Raw Water for Drinking Water Production by Innovative Process Systems”, US Department of Commerce, National

Technical Information Service, Technical Report No. PB82-118795, 87p, 1981.

73. Hyde, R.A., et al, “Water Clarification by Flotation”, Journal of American Water Works Association, 69 (7), 369- 374 (July 1.977)

74. Krofta, M. and L. K. Wang, “Development of an Innovative Process System for Water Purification and Recycle”, Proceedings of American Water Works Association. Water Reuse Symposium II, Volume 2, p. 1292-1315, Aug. 1981.

75. Wang, L. K., M. H. S.Wang and G.Y. Hu, “Determination of Lignin and Tannin in Aqueous Solution by a Modified Method”, U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA., Report No. PB82-133042 (NSF/RA-81052), 14 p., Sept. 1981.

76. Krofta, M. and L. K. Wang, “Potable Water Pretreatment for Turbidity and Color Removal by Dissolved Air Flotation and Filtration for the Town of Lenox, Massachusetts”, U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA., Report No. PB82-182064, 48 p., Oct. 1981.

77. Krofta, M. and L. K. Wang, “Report on Projected Water Treatment Plant for the City of Pittsfield, Massachusetts with the Application

of Flotation Technology", U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA., Report No. PB82-118779, January 1982.

78. Krofta, M. and L. K. Wang, "Innovation in the Water Treatment Field and Systems Appropriate and Affordable for Smaller Communities", U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA., Report No. PB82-2O1476, 30 p. March 1982.

79. Krofta, M. and L.K. Wang, "Potable Water Treatment by Dissolved Air Flotation and Filtration", Journal American Water Works Association, Vol. 74, No. 6, June 1982.

80. Vrablik, E.R. "Fundamental Principles of Dissolved Air Flotation of Industrial Wastes". Proc. 14th Industrial Waste Conference, May 5-7, Purdue University, Lafayette, Indiana, USA. (1959).

81. Barton, C.A., Byrd, J.F., Peterson, R.C., Walter, J.H., Woodruff, P.H., "A Total Systems Approach to Pollution Control at a Pulp and Paper Mill". J. Water Pollut. Control Fed., 40, 1471. (1968).

82. Wang, L. K., "Removal of Organic Pollutants by Adsorptive Bubble Separation Processes," 1974 Earth Environment and Resources Conference Digest of Technical Papers, 1(74), p. 56-57,

Sept. 1974.

83. Mennell, M., Merrill, D.T., Jorden, R.M. “Treatment of Primary Effluent by Lime Precipitation and Dissolved Air Flotation”. J. Water Pollut. Control Fed., 46, 2471. (1974).

84. Wang, L. K. et al., "Treatment of Tannery Effluents by Surface Adsorption," Journal of Applied Chemistry and Biotechnology, Vol. 25, p. 475-490, 1975. (ENGLAND)

85. Wang, L. K., et al., "Treatment of a Wastewater from Military Explosive and Propellants Production Industry by Physicochemical Processes," U.S. Defense Technical Information Center, Alex., VA, AD-A027329, 121 p., June 1976.

86. Wang, L. K., "Mathematical Modeling and Experimental Evaluation of Surfactant Transfer in A Two-Phase Bubble Flow Reactor," The 7th Northeast Regional Meeting of American Chemical Society, Aug. 1976.

87. Woodard, F.E., Hall, M.W., Sproul, O.J., and Ghosh, M.M. “New Concepts in Treatment of Poultry Processing Wastes”. Water Research, 11, 873-877. (1977).

88. Coertze, J.A., “Dissolved Air Flotation Treatment of Paper Mill Effluent”. Prog. Wat. Tech., 10, (1/2), 449-457. (1978).

89. Cooper, R.N., Denmead, C.F., “Chemical Treatment of Slaughterhouse Wastes with Protein Recovery”. J. Water Pollut. Control Fed., 51, 1017. (1979).

90. Szabo, A.J. “ Dissolved Air Flotation for Treatment of Seafood Wastewater”. Proc. Seafood Waste Management , September 23-25, Orlando, Florida, USA. (1980).

91. Henry, J.G., and Gehr, R., “ Dissolved Air Flotation for Primary and Secondary Clarification”. Canada Mortgage and Housing Corporation. Report SCAT – 9. Ottawa, Ontario, Canada. (1981).

92. Jedele, K., Hoch, W., and Rölle, R. “Einsatz der Entstpnnungsflotation in Belebtschlammanlagen anstelle herkömmlicher Nachklärbecken”. Korrespondenz Abwasser, Heft 27, 611-618. (1980).

93. Krofta, M, Wang, LK, Potable Water Treatment by Dissolved Air Flotation, Journal of American Water Works Association, June 1982..

94. Wang, L. K., "Monitoring and Control of Lenox Water Treatment Plant, Lenox, Massachusetts," U.S. Department of Commerce, National Technical Information Service, PB84-192079, 17 p., March 1982.

95. Krofta, M., and Wang, L. K., "First Full-Scale Flotation Plant in

U.S.A. for Potable Water Treatment," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB82-220690, 67 p. March 1982.

96. Krofta, M., and Wang, L. K., "Alternative Water Treatment Systems Using Flotation Technology," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB82-211400, 34 p., April 1982.

97. Wang, L. K. and Wood, G. W., "Water Treatment by Disinfection, Flotation and Ion Exchange Process System," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB82-213349, 115 p., May 1982.

98. Krofta, M., and Wang, L. K., "Startup and Continuous Operation of Lenox Water Treatment Plant, Lenox, Massachusetts," U.S. Dept. of Commerce, National Technical Information Service, PB85-182616/AS, 28 p., 1982.

99. Krofta, M., and Wang, L. K., "Operational Data of Lenox Water Treatment Plant, Lenox, Massachusetts," U.S. Dept. of Commerce, National Technical Information Service, PB84-192061, 46 p., July 1982.

100. Krofta, M., and Wang, L. K., "Development of Innovative

Sandfloat Systems for Water Purification and Pollution Control," ASPE Journal of Engineering Plumbing, 0(1), p. 1-16, 1984 (Recipient of 1982 Pollution Engineering Five-Star Award). U.S. Department of Commerce, National Technical Information Service, PB83-107961, 1983..

101. Wang, L. K., "Compact Nitrogen Removal Options for Lake Como, Italy", Effluent and Water Treatment Journal, 22 (11), p. 435-437, 1982 (ENGLAND).

102. Krofta, M, Wang, LK, and Wang, MHS. Septic Tank Effluent Treatment Options: Electroflotation and Filtration, New England Water Pollution Control Association (NEWPCA), Boston, NY, USA, January 22-25, 1989.

103. Wang, L. K., "Principles and Kinetics of Oxygenation - Ozonation Waste Treatment System, U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB83-127704, 139 p., 1982.

104. Krofta, M., and Wang, L. K., "Tertiary Treatment of Secondary Effluent by Dissolved Air Flotation and Filtration," Civil Engineering for Practicing and Design Engineers, Volume 3, p. 253-272, 1984. (NTIS-PB83-171165).

105. Krofta, M., and Wang, L. K., "Design, Construction and Operation

of Lenox Water Treatment Plant, Project Summary," U.S. Dept. of Commerce, <u>National Technical Information Service</u>, PB83-171264, 40 p., 1983.

106. Krofta, M., and Wang, L. K., "Design, Construction and Operation of Lenox Water Treatment Plant, Project Documentation," U.S. Dept. of Commerce, <u>National Technical Information Service,</u> PB83-164731, 330 p., 1983.

107. Krofta, M., and Wang, L. K., "Potable Water Treatment by Foam Separation and Dissolved Air Flotation," <u>American Institute of Chemical Engineers, National Conference</u>, Houston, TX, March 1983. (NTIS-PB83-232843).

108. Krofta, M., and Wang, L. K., "Design of Dissolved Air Flotation Systems for Industrial Pretreatment and Municipal Wastewater Treatment -- Design and Energy Considerations," <u>American Institute of Chemical Engineers National Conference,</u> Houston, TX, March 1983, 30 p. (NTIS-PB83-232868).

109. Krofta, M., and Wang, L. K., "Design of Dissolved Air Flotation Systems for Industrial Pretreatment and Municipal Wastewater Treatment -- Case History of Practical Applications," <u>American Institute of Chemical Engineers National Conference</u>, Houston, TX, March 1983, 25 p., (NTIS-PB83-232850)

110. Krofta, M., Wang, L. K., Spencer, R. L., and Weber, J., "Separation of Algae from Lake Water by Dissolved Air Flotation and Sand Filtration," Proceedings of the Water Quality and Public Health Conference, WPI, MA. PB93-219550, p. 103-110, 1983.

111. Krofta, M., Wang, L. K., Wu, B. C. and Bien, C. C. J., "Recent Advances in Titanium Dioxide Recover, Filler Retention and White Water Treatment," U.S. Dept. of Commerce, National Technical Information Service, PB83-219543, 39 p., June 1983.

112. Krofta, M., and Wang, L. K., "Over One-Year Operation of Lenox After Treatment Plant--Part 1", U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB83-247270, 1-264 p., July 1983.

113. Krofta, M., and Wang, L. K., "Over One-Year Operation of Lenox Water Treatment Plant-Part 2", U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB83-247288, 265-425 p., July 1983.

114. Wang, L. K. and Kolodziej, "Removal of Trihalomethane Precursors and Coliform Bacteria by Lenox Flotation-Filtration Plant," Proceedings of the Water Quality and Public Health Conference, PB83-244053, p. 17-29, 1983. PB83-244053).

115. Krofta, M., Wang, L. K., Kurylko, L. and Thayer, A. E., "Pretreatment and Ozonation of Cooling Tower Water, Part I," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA. PB84-192053, 34 p., April 1983.

116. Krofta, M., Wang, L. K., Kurylko, L. and Thayer, A. E., "Pretreatment and Ozonation of Cooling Tower Water, Part II," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA. PB84-192046, 29 p., Aug. 1983.

117. Wang, L. K., Barris, C., Milne, P., Wu, B. C., and Hollen, J., "Removal of Extremely High Color from Water Containing Trihalomethane Precursor by Flotation and Filtration," U.S. Dept. of Commerce, National Technical Information Service, PB83-240374, 11p., 1982.

118. Wang, L. K., "Design of Innovative Flotation -Filtration Wastewater Treatment Systems for A Nickel-Chromium Plating Plant," U.S. Dept. of Commerce, National Technical Information Service, PB88-200522/AS, 50 p., Jan. 1984.

119. Krofta, M, Wang, L. K., and Wang, MHS. "Laboratory Simulation and Optimization of Physical-Chemical Treatment Processes," U.S. Dept. of Commerce, National Technical Information Service,

PB86-188794/AS, 42 p., Nov. 1983.

120. Wang, L. K., and Wu, B. C., "Development of Two-Stage Physical-Chemical Process System for Treatment of Pulp Mill Wastewater," Lenox Institute of Water Technology Technical Report #LIR/05-84/2, 65 p., May 1984.

121. Krofta, M., and Wang, L. K., "Symposium on Environmental Technology and Management 1984," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB84-209337, 149 p., April 1984.

122. Krofta, M. and Wang, L. K., "Treatment of Farnham and Ashley Reservoir Water by Krofta Sandfloat Process System – Project Summary", U.S. Department of Commerce, National Technical Information Service, Technical Report No. PB88-200647/AS, 40p, January 1984.

123. Krofta, M. and Wang, L. K., "Treatment of Farnham and Ashley Reservoir Water by Krofta Sandfloat Process System – Project Documentation", U.S. Department of Commerce, National Technical Information Service, Technical Report No. PB88-200654/AS, 188p, January 1984.

124. Krofta, M. and Wang, L. K., "Treatment of Farnham and Ashley

Reservoir Water by Krofta Sandfloat Process System – Final Project Report", U.S. Department of Commerce, National Technical Information Service, Technical Report No. PB88-200639/AS, 194p, February 1984.

125. Krofta, M. and Wang, L. K., "Treatment of Rome Raw Water by Krofta Sandfloat Process System – Project Summary", U.S. Department of Commerce, National Technical Information Service, Technical Report No. PB88-200662/AS, 35p, December 1983.

126. Krofta, M. and Wang, L. K., "Treatment of Rome Raw Water by Krofta Sandfloat Process System – Project Documentation Part A", U.S. Department of Commerce, National Technical Information Service, Technical Report No. PB88-200670/AS, 238p, February 1984.

127. Krofta, M. and Wang, L. K., "Treatment of Rome Raw Water by Krofta Sandfloat Process System – Project Documentation Part B", U.S. Department of Commerce, National Technical Information Service, Technical Report No. PB88-200688/AS, p. 239-276, February 1984.

128. Krofta, M. and Wang, L. K., "Treatment of Rome Raw Water by Krofta Sandfloat Process System – Project Documentation Part C", U.S. Department of Commerce, National Technical Information

Service, Technical Report No. PB88-200696/AS, 145p, March 1984.

129. Shuster, W. W. and Wang, L. K., “Role of Polyelectrolytes in the Filtration of Colloidal Particles from Water and Wastewater”, U.S. Department of Commerce, National Technical Information Service, Technical Report No. AD-A131-109, 49 p., June 1983.

130. Reid, H. J. and L. K. Wang, “The Effects of Cationic Surfactant Concentration on Bubble Dynamics in a Bubble Franctionation Column”, U.S. Department of Commerce, Technical Report No. PB86-197845/AS, 47p, July 1984. National Technical Information Service,

131. Krofta, M., and Wang, L. K., "Waste Treatment by Innovative Flotation-Filtration and Oxygenation-Ozonation Process," U.S. Dept. of Commerce, National Technical Information Service, PB85-174738-AS, 171 p., 1984.

132. Ross, R. G., and Wang, L. K., "Process Control Using Zeta Potential and Colloid Titration Techniques," U.S. Dept. of Commerce, National Technical Information Service, PB87-179099/AS, 126 p., Oct. 1984.

133. Krofta, M., and Wang, L. K., "Treatment of Cooling Tower Water

by Dissolved Air-Ozone Flotation," Proceedings of the Seventh Mid-Atlantic Industrial Waste Conference, p. 207-216, June 1985.

134. Krofta, M., and Wang, L. K., "Development of Innovative Electroflotation Water Purification System for Single Families and Small Communities," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB85-207595/AS, 57 p., Aug. 1984.

135. Krofta, M., and Wang, L. K., "Development of a Total Closed Water System for a Deinking Plant," Proceedings of the American Water Works Association, Water Reuse Symposium III, Vol. 2, 881-898 p., Aug. 1984.

136. Krofta, M., and Wang, L. K., "Total Waste Recycle System for a Wastewater Treatment System Using Primary Coagulants Containing Aluminum," Lenox Institute of Water Technology Technical Report # LIR/01-84/6, 21 p., Jan. 1984.

137. Wang, L. K., Wu, B. C., Meier, A., Marshall, J., Zepka, J., Foote, R., Janas, J., and Mulloy, M., "Removal of Arsenic from Water and Wastewater," U.S. Dept. of Commerce, National Technical Information Service, PB86-169299, 45 p., Oct. 1984.

138. Krofta, M., Wang, L. K., and Boutroy, M., "Development of a

New Treatment System Consisting of Adsorption Flotation and Filtration," U.S. Dept. of Commerce, National Technical Information Service, PB85-209401/AS, 28 p., Oct. 1984.

139. Layer, W., and Wang, L. K., "Water Purification and Wastewater Treatment with Sodium Aluminate," U.S. Dept. of Commerce, National Technical Information Service, Springfield, VA, PB85-214-492/AS, 17 p., 1984.

140. Krofta, M., and Wang, L. K., "Removal of Arsenic and Other Contaminants from Storm Run-off Water by Flotation, Filtration, Adsorption and Ion Exchange," U.S. Dept. of Commerce, National Technical Information Service, PB88-200613/AS, 54 p., Nov. 1984.

141. Krofta, M., Wang, L. K., Wu, B. C., and Janas, J., "Analysis of Sludges Generated from Flotation Treatment of Storm Run-off Water," U.S. Dept. of Commerce, National Technical Information Service, PB88-20062I/AS, 20 p., Nov. 1984.

142. Wang, L. K. and Wu, B. C., "Treatment of Groundwater by Dissolved Air Flotation Systems Using Sodium Aluminate and Lime as Flotation Aids," OCEESA Journal, Vol. 1, No. 3, p. 15-18, Oct. 1984. (NTIS-PB85-167229/AS).

143. Zabel, T. “Flotation in Water Treatment”. NATO ASI Series. Martinus, Nijhoff Publishers, Boston, MA, USA. (1884).

144. Krofta, M., and Wang, L. K., "Development of an Innovative and Cost-Effective Municipal-Industrial Waste Treatment System," U.S. Dept. of Commerce, National Technical Information Service PB88-168109/AS, 27 p., Jan. 1985.

145. Krofta, M., and Wang, L. K., "Treatment of Potable Water from Seoul, Korea by Flotation, Filtration and Adsorption," U.S. Dept. of Commerce, National Technical Information Service, PB88-200530/AS, 21 p., March 1985.

146. Krofta, M., and Wang, L. K., “Pollution Abatement Using Dissolved Air Flotation Technology in the Paper and Pulp Industry," Proceedings of the 1985 Powder and Bulk Solids Conference., Chicago, IL, 28 p., May 1985.

147. Wang, L. K., Wu, B. C., Fat, R., Rogalla, F., "Treatment of Scallop Processing Wastewater by Flotation, Adsorption and Ion Exchange," U.S. Dept. of Commerce, National Technical Information Service, PB89-143556/AS, 17 p., May 1985.

148. Huntley, G. M., Wang, L. K., and Layer, L. W., "Evaluation of Sodium Aluminate as a Coagulant for Cost Savings at Water

Treatment Plants," U.S. Dept. of Commerce, National Technical Information Service, PB88-168075/AS, 23 p., May 1985.

149. Krofta, M., and Wang, L. K., "Wastewater Treatment by Biological-Physicochemical Two-Stage Process System," Proceedings of the 41st Industrial Waste Conference, p. 67-72, Lewis Publishers, Inc., Chelsea, MI, May 1987.

150. Krofta, M., Wang, L. K., and Foote, R., "Separation of High Grade Sulfur from an Ore by Flotation," Lenox Institute of Water Technology Report #LIR/09-85/155, 15 p., 1985.

151. Wang, L. K., "Theory and Application of Flotation Processes," U.S. Dept. of Commerce, National Technical Information Service, PB86-194198/AS, 15 p., Nov. 1985.

152. Wang, L. K., "Secondary Treatment of Bangor Primary Effluent by Supracell Clarifier," Lenox Institute of Water Technology Technical Report #LIR/11-85/160, 10 p., Nov. 1985.

153. Krofta, M., and Wang, L. K., "Investigation of Municipal Wastewater Treatment by A Compact Innovative System," Lenox Institute of Water Technology Technical Report #LIR/01-86/165, 59 p., Jan. 1986.

154. Wang, L. K., "Removal of Algae from Lagoon Effluent," Lenox Institute of Water Technology Technical Report #LIR/01-88/167, Jan. 1988.

155. Krofta, M., and Wang, L. K., "Tertiary Wastewater Treatment," U.S. Dept. of Commerce, National Technical Information Service, PB88-168133/AS, 23 p., Jan. 1986.

156. Wang, L. K., "Recent Advances in Water and Wastewater Treatment", Symposium on Environmental Technology and Management, PB88-2005589/AS, 137 p., July 1986.

157. Wang, L. K., "A Promising and Affordable Solution to Sludge Treatment," U.S. Dept. of Commerce, National Technical Information Service, PB88-168398/AS, 12 p., May 1986.

158. Krofta, M., and Wang, L. K., "Flotation Technology and Secondary Clarification," Technical Association of the Pulp and Paper Industry Journal, (TAPPI Journal), 70 (4), p. 92-96, April 1987.

159. Krofta, M., and Wang, L. K., "Municipal Waste Treatment by Supracell Flotation, Chemical Oxidation and Star System," U.S. Dept. of Commerce, National Technical Information Service, PB88-200548/AS, 22 p., Oct. 1986.

160. Pappanchen, A., Kurylko, L., and Wang, L. K., "Development of a New Water Treatment Process for Decreasing the Potential for THM Formation," U.S. Dept. of Commerce, National Technical Information Service, PB81-202541, 80 p., 1987.

161. Krofta, M., and Wang, L. K., "Dissolved Air Flotation Processes," U.S. Dept. of Commerce, National Technical Information Service, PB88-168448/AS, 35 p., Nov. 1986.

162. Wang, L. K., Wang, M. H.S, and Wang, J. C., "Design, Operation and Maintenance of the Nation's Largest Physicochemical Waste Treatment Plant, Volume 1," Lenox Institute of Water Technology Report #LIR/03-87-248, 183 p., March 1987.

163. Wang, L. K., Wang, M. H.S., and Wang, J. C., "Design Operation and Maintenance of the Nation's Largest Physicochemical Waste Treatment Plant, Volume 2," Lenox Institute of Water Technology Report #LIR/03-87/249, 161 p., March 1987.

164. Wang, L. K., Wang, M. H.S., and Wang, J. C., "Design Operation and Maintenance of the Nation's Largest Physicochemical Waste Treatment Plant, Volume 3," Lenox Institute of Water Technology Report #LIR/03-87/250, 227 p., March 1987.

165. Krofta, M., and Wang, L. K., "Winter Operation of Nation's Largest Potable Flotation Plants," Joint Conference of American Water Works Association and Water Pollution Control Federation, Cheyenne, Wyoming, USA. Sept. 1987. (NTIS-PB88-200563/AS).

166. Krofta, M., Guss, D., and Wang, L. K., "Development of Low-Cost Flotation Technology and Systems for Wastewater Treatment," Proceedings of the 42nd Industrial Waste Conference, p. 185, 1988.

167. Wang, L. K., and Daly, P. G., "Preliminary Design Report of a 10-MGD Deep Shaft-Flotation Plant for the City of Bangor", U.S. Dept. of Commerce, National Technical Information Service, PB88-200597/AS, 42 p., 1987.

168. Wang, L. K., and Daly, P. G., "Preliminary Design Report of a 10-MGD Deep Shaft-Flotation Plant for the City of Bangor", Appendix," U.S. Dept. of Commerce, National Technical Information Service, PB88-200605/AS, 171 p., 1987.

169. Odegaard, H., “Particle Separation in Wastewater Treatment”. Documentation at the 6th EWPC Association Symposium, München, p. 351-400. (1987).

170. Krofta, M and Wang, LK. Development of Innovative Flotation-Filtration System for Water Treatment, Part A: First Full-Scale Sandfloat Plant in US. American Water Works Association Water Reuse Symposium III, San Diego, CA, USA. August 26-31, 1984. Published by AWWA Research Foundation, Denver, CO, USA.

171. Jokela, P., Jormalainen, S., Keskitalo, P., and Rantala, P., “Efficient Pretreatment of Foodstuff Industry Wastewater”. Water Pollution Control in Asia, Panswald, T., Polprasert, C., Yamamoto, K. (Eds.). Pergamon Press, Oxford, p. 535-540. (1988).

172. Krofta, M., Guss, D., Wang, L.K. “ Developement of Low-Cost Flotation Technology and Systems for Wastewater Treatment”. Proc. 42nd Industrial Waste Conference, May 12-14, 1987, Purdue Univ., Lewis Publishers, Chelsea, Michigan, USA, p. 185-195. (1988).

173. Krofta, M., Wang, L. K., Pollman, C.D. “Treatment of Seafood Processing Wastewater by Dissolved Air Flotation, Carbon Adsorption and Free Chlorination”. Proc. 43rd Ind. Waste Conf., Lewis Publishers, Chelsea, Michigan, 535. (1989).

174. Krofta, M., and Wang, L. K., "Total Closing of Paper Mills with Reclamation and Deinking Installations," Proceedings of the 43rd Industrial Waste Conference, p. 673, 1989.

175. Wang, L. K., "Recent Development in Cooling Water Treatment

with Ozone," Lenox Institute of Water Technology LIR/03-88/285, 237 p., 1988.

176. Wang, L. K., "Treatment of Cooling Tower Water with Ozone," Lenox Institute of Water Technology Report #LIR/05-88/303, 55 p., May 1988.

177. Krofta, M., Guss, D., and Wang, L. K., "Pretreatment of Food Industry Wastewater Using a High Rate Flotation Clarifier," Proceedings of the 1988 Food Processing Waste Conference, GIT, Atlanta, GA, Oct. 1988.

178. Krofta, M., and Wang, L. K., "Development of Innovative Flotation Processes for Water Treatment and Wastewater Reclamation," National Water Supply Improvement Assoc. Conf., San Diego, 42 p., Aug. 1988.

179. Bennoit, H., “Anwendung der Entspannungsflotation bei der Abwasserreinigung in der Chemischen Industrie”. GVC-Kongress in Baden-Baden, Preprints, Band 1, 53-65. (1988).

180. Wang, L. K., and Wang, M. H.S, "Bubble Dynamics and Air Dispersion Mechanisms of Air Flotation Process Systems, Part A: Material Balances," Proceedings of the 44th Industrial Waste Conference, p. 493-504, 1990.

181. Krofta, M., and Wang, L. K., "Bubble Dynamics and Air Dispersion Mechanisms of Air Flotation Process Systems, Part B: Air Dispersion," Proceedings of the 44th Industrial Waste Conference, p. 505-515, 1990.

182. Wang, L. K., and Mahoney, W. J., "Treatment of Storm Run-off by Oil-Water Separation, Flotation, Filtration and Adsorption, Part A: Wastewater Treatment," Proceedings of the 44th Industrial Waste Conference, 655-666, 1990. Water Treatment, 9 (1994), p. 223-233, 1994.

183. Wang, L. K., Wang, M. H.S, and Mahoney, W. J., “Treatment of Storm Run-off by Oil-Water Separation, Flotation, Filtration and Adsorption, Part B: Waste Sludge Management," Proceedings of the 44th Industrial Waste Conference, 667-673, 1990.

184. Wang, L. K., "Using Air Flotation and Filtration in Removal of Color, Trihalomethane Precursors and Giardia Cysts," NYSDOH Workshop on Water Treatment Chemicals and Filtration, Ramada Inn, Saratoga Springs, NY, May 1989. American Slow Sand Association Annual Meeting, NY, 30 p., 1989.

185. Wang, L. K., Wang, M. H.S., and Hoagland, F. M., "Reduction of Color, Odor, Humic Acid and Toxic Substances by Adsorption,

Flotation and filtration," Annual Meeting of American Institute of Chemical Engineers, Symposium on Design of Adsorption Systems for Pollution Control, Philadelphia, PA, Aug. 1989. (P926-08-89-20; 18 p.). Water Treatment, 7 (1992), p. 1-16, 1992.

186. Wang, L. K., and Van Dyke, J. P., "Treatment of Rotating Biological Contactor Effluent by Dissolved Air Flotation," Annual Meeting of Engineering Foundation, Palm Coast, FL, 23 p., Dec. 1989.

187. Wang, L. K., "Decontamination of Groundwater and Hazardous Industrial Effluents by High-Rate Air Flotation Processes," Great Lakes `90 Conference Proceedings, Hazardous Materials Control Research Institute, Silver Spring, Maryland, Sept. 1990.

188. Wang, L. K., "Modern Technologies for Prevention and Control of Groundwater Contamination," Proceedings of New York - New Jersey Environmental Exposition, NYNJEE, Belmont, MA, Oct. 1990.

189. Wang, L. K., "New Dawn in Flotation Treatment of Industrial Water and Wastes," Proceeding of the 1990 Modern Engineering Technology Seminar, Taipei, Taiwan, R.O.C., 25 p., Dec. 1990.

190. Pieterse, T., Kfir, R. “Plant Quartet Proves Potable Water Reuse”. Water Quality Int., 4, 31. (1991).

191. Rusten, B., Eikebrokk, B., Thorvaldsen, G. " Coagulation as Preatreatment of Food Industry Wastewater". Wat. Sci. Tech., 22, (9), 108. (1990).

192. Keskitalo, P., Sundholm, I., "Poultry and Vegetable Processing Wastewater Treatment with Two Stage Dissolved Air Flotation and Biological Purification". Proc. 6th Int. Symp. On Agricultural and Food Processing Wastes, December 17-18, Chicago, Illinois, USA. (1990).

193. Kiuru, H.J., "Tertiary Wastewater Treatment with Flotation Filters". Wat. Sci. Tech., 22, 139. (1990).

194. Kollajtis, J.A., "Dissolved Air Flotation Applied in Drinking Water Clarification". Proceedings of the Annual AWWA Conference – Water Quality for the New Decade, Philadelphia, PA, USA, 433-448. (1991).

195. Wang, L. K., "Water and Waste Treatment Using Advanced Dissolving Air Flotation," Proceedings of the 1991 Annual Conference of the Korea Society of Water Pollution Research and Control, Seoul, Korea, 33 p., Feb. 1991.

196. Malley, J.P., Edzwald, J.K., "Concepts of Dissolved Air Flotation of Drinking Water". Journal Water SRT-Aqua, 40(1), 7-17. (1991).

197. Wang, L. K., Wang, M. H. S. And Kolodzicj, "Ïnnovative and Cost-effective Lenox Water Purification Plant", Water Treatment, 7 (1992), p. 387-406, 1992.

198. Graham, K.A., Venkatesh, M., ”Improve the Performance and Increase the Capacity of an Activated Sludge Plant with a Dissolved Air Flotation Clarifier”. Proc. 47th Ind. Waste Conf., Lewis Publishers, Chelsea, Michigan, USA. (1992).

199. Peter, A., Libra, J., von Wagenheim, U., Wiesmann, U. “Abwasserreinigung in Hochreaktoren und Abtrennung von Belebtem Schlamm durch Flotation – Messungen zur Flotation und Ergebnisse einer Wirtschaftlichkeitsrechnung”. 2. GVC-Kongress in Würzburg, Preprints, Band 2, 63-80. (1992).

200. Wang, L. K., and Hwang, C. S., "Removal of Trihalomethane Precursor (Humic Acid) by Innovative Dissolved Air Flotation and Conventional Sedimentation," Proceedings of the 1991 Annual Conference of the Korea Society of Water Pollution Research and Control, Seoul, Korea, 10 p., Feb. 1991. Water Treatment, Vol. 8, No. 1, pages 7-16, March 1993.

201. Chandra, S., “The Effluent-Free Paper Mill. Myth or Reality ?”. Papermaker, (November), 40-42. (1993).

202. Cizinska, S., Matejo, V., Wase, C., Klasson, Y., Krejci, J., Dalhammar, G., “Thickening of Waste Activated Sludge by Biological Flotation”. Wat. Res., 26, 139. (1992).

203. Dewitt, N., and Shammas, N.K., “Flotation: A Viable Alternative to Sedimentation in Wastewater Treatment”. Wat. Environ. Fed.,

65th Annual Conf. & Expo., Sept. 20-24, New Orleans, Louisiana, USA. (1992).

204. Viitasaari, M. “Finnish Experience of Water Pollution Control: Case Study – Pulp and Paper Industry”. Environ. & Safty Tech., (Summer), 49, 51, 53, 55. (1993).

205. Pascual, B., Tansel, B., Shalewitz, R. “Economic Sensitivity of the Dissolved Air Flotation Process with Respect to the Operational Variables”. Proc. 49th Ind. Waste Conf., Lewis Publishers, Chelsea, Michigan, USA . (1994).

206. Wang, L. K., and Cheryan, M., "Application of Membrane Technology in Food Industry for Cleaner Production", United Nations Industrial Development Organization (UNIDO) Technical Paper No. 8-6-95, 44 pages, June 1995.

207. Wang, L. K., "The State-of-the-art Technologies for Water Treatment and Management", United Nations Industrial Development Organization (UNIDO) Training Manual No. 8-8-95, 145 pages, August 1995.

208. Wang, L. K., and Wang, M.H.S. “Bubble Dynamics and Material Balances of Dissolved Gas Flotation Process”, Water Treatment,

10(1995), p. 41-54, 1995.

209. Viitasaari, M., Jokela, P., Heinänen, J. “Dissolved Air Flotation in the Treatment of Industrial wastewater with a Special Emphasis on Forest and Foodstuff Industries”. Wat. Sci. Tech., Vol. 31, No. 3-4, pp. 299-313, (1995).

210. Wang, L. K., Wang, P, and Clesceri, N. L., “Groundwater Decontamination Using Sequencing Batch Processes”, Water Treatment, 10(1995) 121-134, 1995.

211. Wang, L. K., and Wang, M. H.S., “Laboratory Simulation of Water and Wastewater Treatment Processes”, Water Treatment, 10(1995) 261-282, 1995.

212. Carawan, R.E., Valentine, E.G., “Dissolved Air Flotation Systems (DAF`s) for Bakeries”. North Carolina Cooperative Extension Service, CD-43, (March 1996).

213. Gnirss, R., Peter-Fröhlich, A., “Biological Treatment of Municipal Wastewater with Deep Tanks and Flotation for Secondary Clarification”. Wat. Sci. Tech., Vol. 34, No. 3-4, p. 257-265. (1996).

214. Wang, L. K., “Potable Water Treatment Using Dissolved Air Flotation”, OCEESA Journal, Vol. 13, No. 1, P.12-16, January 1996.

215. Guss D., and Klaer, R.L., “Improvement of Biological Wastewater Systems Using Dissolved Air Flotation”. Wat. Environ. Fed. Conf., October 19-22, Chicago, Illinois, USA. (1997).

216. Wang, L. K., ”City of Cape Coral Reverse Osmosis Water Treatment Facility”, US Department of Commerce, National Technical Information Service, Springfield, Virginia 22161, USA. 15 pages, January 1997.

217. Mels, A.R., Van Nieuwenhuijzen, A.F., Van der Graaf, J.H.J.M., Klapwijk, A., De Koning, J., Rulkens, W.H. , “Sustainability Criteria as a Tool in the Development of New Sewage Treatment Methods”. Options for Closed Water Systems, Wageningen. (1998).

218. Krofta, M., and Wang, LK (1985). Application of dissolved air flotation to the Lenox, Massachusetts water supply: water purification by flotation, Journal of New England Water Works Association, 99(3), pp. 249-264.

219. Krofta, M., and Wang, LK (1985). Application of dissolved air flotation to the Lenox, Massachusetts water supply: sludge thickening by flotation and lagoon, Journal of New England Water Works Association, 99(3), pp. 265-284.

220. Forestell, W, and Wang, LK (1991). Air flotation and sand filtration : a success for innovation in Pittsfield, MA, Journal of New England Water Works Association, 105(3), pp. 223-243.

221. Wang, LK, Fahey, EM, and Wu, Z. (2005). Dissolved air flotation. In: Physicochemical Treatment Processes, (Wang, LK, Hung, YT, and Shammas, NK, editors), Humana Press, Totowa, NJ., USA, pp. 431-500.

222. Wang, LK, Shammas, NK, Aulenbach, DB, Selke, WA, and Guss, DB (2010). Pittsfield water treatment plant: once the world's largest flotation-filtration plant. In: Flotation Technology (Wang, LK, Shammas, NK, Selke, WA and Aulenbach, DB, editors), Humana Press, Totowa, NJ, USA, pp. 485-502.

223. Wang, LK. (2006). Adsorptive bubble separation and dispersed air flotation, In: Advanced Physicochemical Treatment Processes (Wang, LK, Hung, YT, and Shammas, NK, editors), Humana Press, Totowa, NJ, USA, pp.81-122.

224. Wang, LK (2018). Development and construction of the first two potable DAF-Filtration plant in Two America Continents. Journal of New England Water Works Association, pp.90-95, July 2018.

225. Wang, LK (2007). Emerging flotation technologies. In: Advanced Physicochemical Treatment Technologies (Wang, LK, Hung, YT, and Shammas, NK, editors), Humana Press, Totowa, NJ, USA, pp.449-484.

226. Wang, LK, Shammas, NK, Selke, WA, and Aulenbach, DB (2010). Flotation Technology. Humana Press, Totowa, NJ, USA. 680 pages.

227. Shammas, NK, Wang, LK, Guild, J, and Pollock, D (2009). Vertical shaft bioreactors. In: Advanced Biological Treatment Processes. (Wang, LK, Shammas, NK, and Hung, YT, editors), Humana Press, Totowa, NJ, USA. Pp.59-108

228. Wang, LK and Li, Y (2009). Sequencing batch reactors. In: Biological Treatment Processes, (Wang, LK, Pereira, NC, and Hung, YT, editors), Humana Press, Totowa, NJ, USA. Pp.459-512.

229. Wang, LK, Kurylko, L, and Wang, MHS (1994). Sequencing Batch Liquid Treatment. US Patent 5354458, October 11, 1994

230. Wang, LK, Shammas, NK, and Wu, BC (2010). Electroflotation. In: Flotation Technology. (Wang, LK, Shammas, NK, Selke, WA, and Aulenbach, DB, editors) Humana Press, Totowa, NJ, USA. Pp. 165-198.

231. Shammas, NK and Wang, LK (2016). Water Engineering: Hydraulics, Distribution and Treatment. John Wiley & Sons, Hoboken, NJ, USA. 806 pages.

232. Wang, LK, Hung, YT and Shammas, NK (2004) Physicochemical Treatment Processes. Humana Press, Totowa, NJ, USA. 723 pages.

233. Reh, CW (1979). Lime-soda softening processes. In: Water Treatment Plant Design, Sanks, RL, editor. Ann Arbor Science, MI, USA. Pp.567-596.

234. Wang, LK, , Wu, J, Shammas, NK, and Vaccari, DA (2004). Recarbonation and softening, In: Physicochemical Treatment Processes. Wang, LK, Hung, YT, and Shammas, NK, editors), Humana Press, Totowa, NJ, USA. Pp.199-228.

235. Wang, LK, Chen, JP, Hung, YT and Shammas, NK. (2011) Membrane and Desalination Technologies. Humana Press, Totowa, NJ, USA. 716 pages.

236. Wang, LK and Duchesnel S. (2019), Personal Communication, email, August 26, 2019. Steve Duchesnel , Superintendent of Operations, Lowell Regional Utility, City of Lowell, MA, USA (www.Lowell.org)

237. Joykutty, S and Ranganathan, K (2019). Reducing Poverty Through Economic Growth: MCC’s water investment in Mongolia. Clear Waters, 49(2), 57-59.

238. Daley, D and Anderson, G (2019). Humanitarian engineering:

education and application. Clear Waters, 49(2), 16-21.

239. Wang, MHS and Wang LK (2016). Glossary of land and energy resources engineering. In: Natural Resources and Control Processes. (Wang LK, Wang MHS, Hung YT, and Shammas NK , editors). Springer, New York, USA. 493-623.

240. Wang, MHS and Wang LK (2015). Environmental water engineering glossary. In: Advances in Water Resources Engineering. (Yang CT and Wang LK , editors). Springer, New York, USA. 471-556.

241. Edzwald, J.K.,(1995). Principles and applications of dissolved air flotation.Water Science and Technology 31(3–4),1–23.

242. Edzwald, J.K.,(2007). Fundamentals of dissolved air flotation. Journal of the New England Water Works Association 121(3),89–112.

243. Edzwald, J.K.,(2007). Developments of high rate dissolved air flotation for drinking water treatment. Journal of Water Supply: Research and Technology –Aqua 56(6–7),399–409.

244. Edzwald, J.K., MalleyJr.,J.P., Yu,C., (1990). Aconceptual model for dissolved air flotation in water treatment. Water Supply 8,141–150.\

245. Edzwald, J.K., Walsh,J.P., Kaminski,G.S. ,Dunn,H.J., (1992). Flocculation and air requirements for dissolved air flotation. Journal

of the American Water Works Association 84(3),92–100.

246. Edzwald,J.K., Olson,S.C., Tamulonis,C.W., (1994). Dissolved AirFlotation: Field Investigations. American Water Works Association Research Foundation, Denver. CO, USA.

247. Edzwald,J.K., Tobiason,J.E., Amato,T., Maggi,L.J., (1999). Integrating high rate dissolved air flotation technology into plant design. Journal of the American Water Works Association 91(12),41–53.

248. Edzwald,J.K., Tobiason,J.E., Parento,L.M., Kelley,M.B., Kaminski,G.S., Dunn,H.J., Galant,P.B., (2000). *Giardia*and*Cryptosporidium* removals by clarification and filtration under challenge conditions. Journal of the American Water Works Association 92(12),70–84.

249. Edzwald,J.K., Tobiason,J.E., Udden,C., Kaminski,G.S., Dunn,H.J., Galant,P.B., Kelley,M.B., (2003). Evaluation of the effect of recycle of waste filter backwash water on plant removals of *Cryptosporidium*. Journal of Water Supply: Research and Technology– Aqua 52(4),243–258.

250. Edzwald,J.K., Han,M., (2007). In: Edzwald,J.K., Han,M. (Eds.), The 5th International Conferenceon Flotationin Water and Wastewater Systems. Seoul National University, Seoul, South Korea, p.393.

251. Edzwald,J.K., Kaminski,G.S., (2009). A practical method for water plants to select coagulant dosing. Journal of the New England Water Works Association 123(1),15–31.

252. Edzwald,J.K., Kelley,M.B., (1998). Control of *Cryptosporidium*: from reservoirs to clarifiers to filters. Water Science and Technology 37(2),1–8.

253. Edzwald,J.K., Wingler,B.J., (1990). Chemical and physical aspects of dissolved air flotation for the removal of algae. Journal of Water Supply: Research and Technology– Aqua 39(2),24–35.

APPENDIX A. LIST OF TABLES

APPENDIX B. LIST OF FIGURES

Figure 13. A flow diagram of the LIWT/KEC developed potable water electroflotation-filtration plant

Figure 14. A small electroflotation-filtration water treatment plant developed by LIWT/KEC for serving individual home owners, apartments, or small lake communities..

Figure 15. Operation of a complete electroflotation-filtration package plant.

Figure 16. The flow diagram of a general water treatment system. (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016; pp. 326) (231)

Figure 17. The flow diagram of a simplified water treatment system (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016; pp. 667) (231)

Figure 18. An Innovative high rate dissolved gas flotation clarifier (Supracell)

Figure 19. A high rate dissolved gas flotation clarifier in UK (Supracell 62; tank depth = 750 mm; flow = 35.2 m^3/min; diameter = 62 ft = 19,900 mm)

Figure 20. A flow diagram of a complete water treatment plant in which (a) a dissolved air flotation clarifier (Supracell or equivalent) replaces a conventional sedimentation clarifier; and (b) a dissolved air flotation clarifier replaces a conventional gravity thickener for overall cost saving and foot-print reduction. (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016) (231)

Figure 21. Water treatment for hardness removal using two-stage lime/soda ash softening process (Credit: LK Wang, YT Hung and NK Shammas, Physicochemical Treatment Processes, Humana Press, NJ, USA, pp. 221, 2004) (232)

Figure 22. Flow diagram of lime-soda ash softening plant in Topeka, Kansas, USA (Credit: CW Reh, Lime-soda softening processes, Water Treatment Plant Design, RL Sanks, editor, Ann Arbor Science, MI, USA, 1979; pp. 583)

Figure 23. Top view and side view of a double DGF-DGF clarifier (Double Supracell)

Figure 24. A conventional water treatment plant involving the use of pre-sedimentation and upflow contact sedimentation clarifiers (231)

Figure 25 . Design and Operation of a Sedimentation-DAF Clarifier (SDF; or SediFloat)

Figure 26 . Construction of Sedimentation-Flotation Clarifier (SDF-36FT) in Acid-Resistant Tiles (Holland)

Figure 27 . Construction of Two Sedimentation-DAF Clarifiers (SDF-55FT) in Italy

Figure 28. Removal of Chlorophy II-a by sedimentation alone and combined sedimentation-DAF (Credit: Dongshin EnTech, South Korea) (145, 200)

Figure 29. General flow diagram of a typical dissolved air flotation-filtration (DAFF or Sandfloat) water treatment plant (credit: NK Shammas and LK Wang; Water Engineering, Wiley, 2016) (231)

Figure 30. Bird’s view and description of a DAF-Filtration (Sandfloat, or DAFF) clarifier. (161)

Figure 31. Top view, side view and sizes of DAF-Filtration clarifiers (Sandfloat, or DAFF)

Figure 32. Flow diagram of a DAF-filtration clarifier (Sandfloat, DAFF)

Figure 33. A comparison between a DAF clarifier and a sedimentation clarifier

Figure 34. Construction of a 30-ft diameter DAF-filtration (DAFF; Sandfloat) unit on the top of an existing sedimentation clarifier in Berlin, Germany

Figure 35. A foot-print and volume comparison between a DAF-filtration (DAFF, Sandfloat) clarifier and a conventional sedimentation-filtration combination

Figure 36. Top view and side view of an air dissolving tube

Figure 37. An air dissolving tube design diagram

Figure 38. Pittsfield Water Treatment Plant System: (a) Cleveland Plant: 4 DAFF (Sandfloat SAF49); and (b) Ashley Plant: 2 DAFF (Sandfloat SAF49).

Figure 39. A full-scale FloatPress (a combination of dissolved air flotation and sludge press) installed at Lenox Water Treatment Plant, Lenox, MA, USA, in 1982.

Figure 40. A full-scale installation of a two-stage DAF-DAF system

Figure 41. Graphical illustration of a double DGF-DGFF (or DAF-DAFF, or Supracell-Sandfloat) system for potable water treatment Plant.

Figure 42. Full-scale double DGF-DGFF (or DAF-DAFF, or Supracell-Sandfloat) system

Figure 43. Chemical reactions of a two-stage DAF-DAF lime-magnesium carbon softening process using magnesium carbon as a recyclable coagulant

Figure 44. Flow diagram of a two-stage DAF-DAF lime-magnesium carbon softening process for hardness removal using magnesium carbon as a recyclable coagulant

Figure 45. Rectangular Automatic Backwash Filter Installed at Lowell Regional Utility, Massachusetts, USA for Dual Media Filtration (Credit: Superintendent Steve Duchesnel, LRU, August 2019) (236)

Figure 46. Rectangular Automatic Backwash Filter Installed at Lowell Regional Utility, Massachusetts, USA for Granular Activated Carbon Filtration (Credit: Superintendent Steve Duchesnel, LRU, August 2019) (236)

EDITORS PAGE

Editors of *"EVOLUTIONARY PROGRESS IN SCIENCE, TECHNOLOGY, ENGINEERING, ARTS AND MATHEMATICS (STEAM)"*

1. Dr. Lawrence K. Wang (王抗曝)

Lawrence K. Wang has over 30+ years of professional experience in facility design, environmental sustainability, natural resources, STEAM education, global pollution control, construction, plant operation, and management. He has expertise in water supply, air pollution control, solid waste disposal, drinking water treatment, waste treatment, and hazardous waste management. He was the Director/Acting President of the Lenox Institute of Water Technology, Engineering Director of Krofta Engineering Corporation and Zorex Corporation, and a Professor of RPI/SIT/UIUC, in the USA. He was also a Senior Advisor of the United Nations Industrial and Development Organization (UNIDO) in Austria. Dr. Wang is the author of over 700 technical papers and 45+ books, and is credited with 24 US patents and 5 foreign patents. He earned his two HS diplomas from the High School of National Taiwan Normal University, and the State University of New York. He also earned his BS degree from National Cheng-Kung University, Taiwan, ROC, his two MS degrees from the University of Missouri and the University of Rhode Island, USA, and his PhD degree from Rutgers University, USA. Currently he is the Chief Series Editor of the Handbook of Environmental Engineering series (Springer); Chief Series Editor of the Advances in Industrial and Hazardous Wastes Treatment series, (CRC Press, Taylor & Francis); co-author of the Water and Wastewater Engineering series (John Wiley & Sons); and Co-Series Editor of the Handbook of Environment and Waste Management series (World Scientific). Dr. Wang is active in professional activities of AWWA, WEF, NEWWA, NEWEA, AIChE, ACS, OCEESA, etc.

2. Dr. Hung-ping Tsao (曹恆平)

Hung-ping Tsao has been a mathematician, a university professor, and an assistant actuary, serving private firms and universities in the United States and Taiwan for 30+ years. He used to be an Associate Member of the Society of Actuaries and a

Member of the American Mathematical Society. His research have been in the areas of college mathematics, actuarial mathematics, management mathematics, classic number theory and Sudoku puzzle solving. In particular, bikini and open top problems are presented to share some intuitive insights and some type of optimization problems can be solved more efficiently and categorically by using the idea of the boundary being the marginal change of a well-rounded region with respect to its inradius; theory of interest, life contingency functions and pension funding are presented in more simplified and generalized fashions; the new way of the simplex method using cross-multiplication substantially simplified the process of finding the solutions of optimization problems; the generalization of triangular arrays of numbers from the natural sequence based to arithmetically progressive sequences based opens up the dimension of explorations; the introduction of step-by-step attempts to solve Sudoku puzzles makes everybody's life so much easier and other STEAM project development. Dr. Tsao is the author of 3 books and over 30 academic publications. He earned his high school diploma from the High School of National Taiwan Normal University, his BS and MS degrees from National Taiwan Normal University, Taipei, Taiwan, his second MS degree from the UWM in USA, and a PhD degree from the University of Illinois , USA.

Editors of the eBOOK Series of the *"EVOLUTIONARY PROGRESS IN SCIENCE, TECHNOLOGY, ENGINEERING, ARTS AND MATHEMATICS (STEAM)"*

Dr. Lawrence K. Wang (王抗曝) -- left

Dr. Hung-ping Tsao (曹恆平) -- right

E-BOOK SERIES AND CHAPTER INTRODUCTON

Introduction to the eBOOK Series of the *"EVOLUTIONARY PROGRESS IN SCIENCE, TECHNOLOGY, ENGINEERING, ARTS AND MATHEMATICS (STEAM)"* and This Chapter *"HUMANITARIAN ENGINEERING EDUCATION OF THE LENOX INSTITUTE OF WATER TECHNOLOGY AND ITS NEW NEW POTABLE WATER FLOTATION PROCESSES"*

The acronym STEM stands for "science, technology, engineering and mathematics" . In accordance with the National Science Teachers Association (NSTA), "A common definition of STEM education is an interdisciplinary approach to learning where rigorous academic concepts are coupled with real-world lessons as students apply science, technology, engineering, and mathematics in contexts that make connections between school, community, work, and the global enterprise enabling the development of STEM literacy and with it the ability to compete in the new economy".

The problem of this country has been pointed out by the US Department of Education that "All young people should be prepared to think deeply and to think well so that they have the chance to become the innovators, educators, researchers, and leaders who can solve the most pressing challenges facing our nation and our world, both today and tomorrow. But, right now, not enough of our youth have access to quality STEM learning opportunities and too few students see these disciplines as springboards for their careers." STEM learning and applications are very popular topics at present, and STEM related careers are in great demand. According to the US Department of Education reports that the number of STEM jobs in the United States will grow by 14% from 2010 to 2020, which is much faster than the national average of 5-8 % across all job sectors. Computer programming and IT jobs top the list of the hardest to fill jobs. Despite this, the most popular college majors are business, law, etc., not STEM related. For this reason, the US government has just extended a provision allowing foreign students that are earning degrees in STEM fields a seven month visa extension, now allowing them to stay for up to three years of “on the job training”. So, at present STEM is a legal term.

The expanded acronym STEAM now stands for “science, technology, engineering, arts and mathematics”. As one can see, STEAM (adds “arts”) is simply a variation of STEM. The word of “arts” means application, creation, ingenuity, and integration, for enhancing STEM inside, or exploring of STEM outside. It may also mean that the word of “arts” connects all of the humanities through an idea that a person is looking for a solution to a very specific problem which comes out of the original inquiry process. STEAM is an academic term in the field of education. The University of San Diego and Concordia University offer a college degree with a STEAM focus. Basically STEAM is a framework for teaching or R&D, which is customizable and functional, thence the “fun” in functional. As a typical example, if STEM represents a normal cell phone communication tower looking like a steel truss or concrete column, STEAM will be an artificial green tree with all devices hided, but still with all cell phone communication functions. This ebook series presents the recent evolutionary progress in STEAM with many innovative chapters contributed by academic and professional experts.

This ebook chapter, *“Humanitarian Engineering Education of the Lenox Institute of Water Technology and Its New New Potable Water Flotation Processes”* is Dr.

Lawrence K. Wang's unofficial, partial memoir, summarizing his lifetime experience in working with Dr. Milos Krofta for (a) creating the Lenox Institute of Water Technology (LIWT) as an humanitarian engineering college, (b) inventing numerous new water treatment processes and systems, (c) constructing the first ever DAF-filtration plant, Lenox Water Treatment Plant (LWTP) in the Continents of North and South Americas, and eventually (d) constructing the once world's largest DAF-filtration plant, Pittsfield Water Treatment (PWTP). The accomplishments of LIWT and its partner, Krofta Engineering Corporation (KEC) are documented in this chapter as a step-stone for future generations to follow. The definition and importance of the new engineering field, humanitarian engineering, are described by Douglas Daley and Grace Anderson (*Humanitarian Engineering: Education and Application*, Clear Waters, Volume 49, No. 2, 16-21, 2019). This planet of Earth needs more humanitarian engineering colleges or programs for protection of not only the environment, but also the resources and our humanity.