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AN INNOVATIVE LEE, MASSACHUSETTS USA DISSOLVED AIR FLOTATION POTABLE WATER FILTRATION PLANT

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14. ABSTRACT The authors present the overall structural design, design criteria, and performance data of the two Krofta Sandfloat flotation-filtration clarifiers (DAFF; SAF-BP24) installed at the 2.0 MGD (7570 m^3/day) Lee Plant in treatment of surface water for potable purposes. Lenox Institute of Water Technology (LIWT) invented and patented the innovative DAFF system, while Krofta Engineering Corporation (KEC) manufactured and installed the Lee Plant. The author also discuss (a) current corrosion control program in order to comply with the US Federal Copper and Lead Rule, and (b) the current DAF-filtration plant's performance for removal of perchlorate, barium, sodium, disinfection by-products (DBP), total trihalomethane (THM), total haloacetic acid (HAA), microbial contaminants, turbidity, iron and manganese. The 19 years old innovative Lee DAF-filtration plant met all US Environmental Protection Agency, and the Commonwealth of Massachusetts primary and secondary drinking water standards in accordance with the 2018 Water Quality Report. The Town of Lee successfully uses zinc orthophosphate and pH adjustment to stabilize the water throughout of Lee distribution system for lead, copper and pipe corrosion control. This article has been written in memory of Dr. Milos Krofta, Dr. Donald B. Aulenbach and Dr. William A. Selke.

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ABSTRACT

The Town of Lee, Massachusetts USA potable flotation-filtration plant with a design capacity of 2.0 MGD (7570 m^3/day) was commissioned in December, 1998 to serve a population of approximately 6400 residents. The Lee plant utilizes the following treatment processes: chemical addition, oxidation, coagulation, dissolved air flotation, automatic backwash dual media filtration, and disinfection / corrosion control.

To comply with the required filtering of their three (3) surface water sources the Town chose to install an innovative Dissolved Air Flotation (DAF) system as the best and most economical answer to their needs. In clarification of the design 2.0 MGD (7570 m^3/day) flow two (2) Krofta Sandfloat SAF BP-24 dissolved air flotation-filtration clarifiers (DAFF) were utilized as the main treatment system in the plant.

This book chapter presents the overall structural design, design criteria, and performance data of the Krofta Sandfloat flotation-filtration clarifiers (DAFF) installed at the Lee plant in treatment of surface water for potable purposes. This chapter has been written in memory of: (a) late Dr. Milos Krofta, who was the President of both the Lenox Institute of Water Technology (LIWT), and Krofta Engineering Corporaton (KEC); and late Professor Dr. Donald B. Aulenbach of LIWT. . LIWT invented and patented the innovative DAFF system, while KEC manufactured and installed the Lee Plant. Also discussed are: (a) current corrosion control program in order to comply with the US Federal Copper and Lead Rule, and (b) the current DAF-filtration plant's performance for removal of perchlorate, barium, sodium, disinfection by-products (DBP), total trihalomethane (THM), total haloacetic acid (HAA), microbial contaminants, turbidity, iron and manganese. The 19 years old innovative Lee DAF-filtration plant met all US Environmental Protection Agency, and the Commonwealth of Massachusetts primary and secondary drinking water standards in accordance with the 2018 Water Quality Report. The Town successfully uses zinc orthophosphate and pH adjustment to stabilize the water throughout of Lee distribution system for lead, copper and pipe corrosion control.

KEYWORDS

Milos Krofta, Donald B. Aulenbach, Lenox Institute of Water Technology, Krofta Engineering Corporation, Dissolved Air Flotation, DAF, DAF-Filtration, DAFF, Potable Water, Backwash, Lead, Copper, Corrosion control, Zinc orthophosphate, Recommended future research, Sandfloat BP, Lee, Massachusetts, USA.

ACRONYM AND NOMENCLATURE

ABF	Automatic backwash filtration
ADT	Air dissolving tube
AL	Action level
$Al_2(SO_4)_3$	Aluminum sulfate
Cl_2	Chlorine
DAF	Dissolved air flotation
DAFF	Dissolved air flotation-filtration clarifier
DBP	Disinfection by-products
DEP	Massachusetts Department of Environmental Protection
DGF	Dissolved gas flotation
FDA	US Food and Drug Administration
GAC	Granular activated carbon
GPM	Gallons per minute
HAA	Haloacetic acid
KEC	Krofta Engineering Corporation, USA
$KMnO_4$	Potassium permanganate.
Krofta Sandfloat	DAFF clarifier
LIWT	Lenox Institute of Water Technology, USA
MCL	Maximum contaminant level
MCGL	Maximum contaminant level goal

MGD	Million gallons per day
$Na_2Al_2O_4$	Sodium aluminate
NaOH	Sodium hydroxide
ND	Non-detect
PLC	Programmable logic controller
PPB	Parts per billion
PPM	Parts per million
TT	Treatment technique
USEPA	US Environmental Protection Agency
VOC	Volatile organic carbon

1. BACKGROUND

The history of this type of dissolved air flotation technology in treatment of potable water began in 1982 with the installation of an innovative 1.2 MGD (4542 m^3/day) design capacity dissolved air flotation (DAF) system for the Town of Lenox, Massachusetts USA. This clarifier (Krofta Sandfloat type SAF) was designed to treat only about 2.5 GPM/FT^2 (0.102 $m^3/min./m^2$); today this rate has increased to a hydraulic loading of 5.0 GPM/FT^2 (0.204 $m^3/min./m^2$) due to improved design. These design improvements include incorporation of incline plates, an additional layer of anthracite coal for dual media filtration, air assisted backwashing, and several other proprietary changes.

In the years since this first installation there have been many other communities which have chosen to install this type of dissolved air flotation clarifier in treatment of their municipal potable water supplies. Municipalities in the states of New York, Massachusetts, New Jersey, Pennsylvania, and Indiana have all benefited from choosing DAF technology over conventional treatment consisting of chemical feeding, mixing coagulation/flocculation, sedimentation followed by filtration. DAF is one of dissolved gas flotation (DGF) processes. The readers are referred to the Glossary section for the details of DGF, DAF, etc., and the References section for the literature of potable water treatment plants (1-54)

2. INTRODUCTION

The Town of Lee is located in the Berkshire Hills of Western Massachusetts, USA. The Towns' population is approximately 6400 persons. Two (2) main surface water sources for potable purposes are utilized, Leahey and Schoolhouse Reservoirs which supply the approximately 1.2 MGD (4542 m^3/day) to the Town. A third small source (Vanetti Reservoir) is utilized only as an emergency water supply as needed. Before 1998 the Town utilized chlorination alone in treatment of Leahey and Vanetti reservoirs, which are characterized by low to moderate turbidity, color and trihalomethane (THM) precursors. Schoolhouse Reservoir was unable to be utilized without clarification due to high levels of turbidity, color, iron and manganese present.

The center of the Lee flotation-filtration facility is a package plant consisting of chemical pretreatment, coagulation, dissolved air flotation, and automatic backwash filtration (ABF) (trade name Krofta Sandfloat BP). On site pilot plant testing was conducted from 1994-1996 (using a 5-ft diameter pilot plant system shown in Figure 1) , with plant construction and start up in 1997-98 (installing a 24-ft diameter full-scale plant shown in Figure 2) . In this book chapter, Lee water quality, treatment plant design, construction, water clarification performance, and chemical pretreatment are discussed. Performance and operational data from six months of operation on Leahey Reservoir are summarized.

Figure 1. Krofta Engineering Corporation's DAF-filtration pilot trailer (Sandfloat Type SAF-BP-5; 5-inches diameter)

Figure 2. A full-scale DAF-filtration water treatment plant (Krofta Sandfloat Type SAF-BP-24; 24-inches diameter)

3. GENERAL DESCRIPTION OF THE LEE FLOTATION-FILTRATION PLANT

The Lee plant employs the following stages of treatment for water purification: (a) chemical addition and mixing, (b) oxidation, (c) coagulation, (d) clarification by dissolved air flotation (DAF), (e) dual media filtration and (f) disinfection / corrosion control.

The following is a brief description of the process flow scheme utilized at the Lee plant: gravity flow from either Schoolhouse or Leahey reservoirs is directed to a turbine to generate electricity for the treatment plant. Water then flows to a small mixing tank where it is injected with chlorine (Cl_2), sodium hydroxide (NaOH), and, when treating Schoolhouse reservoir water, potassium permanganate ($KMnO_4$). Chemically treated water then flows through two (2) baffled pre-oxidation tanks with approximately 77,500 gallon (293 m^3) total capacity to allow a minimum of almost 1 hour retention time at design flow to oxidize the manganese and iron present in Schoolhouse Reservoir. After leaving the pre-oxidation tanks water is injected with sodium aluminate ($Na_2Al_2O_4$) and aluminum sulfate ($Al_2 (SO_4)_3$) for coagulation and passed through a static mixer. The flow then enters the inlet chamber of the flotation-filtration unit for clarification by dissolved air flotation and dual media filtration. Filtered water leaving the clarifier is dosed with chlorine for disinfection and zinc orthophosphate for corrosion control and is pumped to two (2) 56' dia. x 42' high (17.1 m dia. x 12.8 m high) 775,000 gallon (2933.4 m^3) effluent storage tanks which in turn supply the Town distribution system via gravity flow.

The treatment building housing the clarifiers, chemical storage and dosing equipment, laboratory, turbine, and mixing tank has a total footprint of 72' x 94' = 6768 ft^2 (22 m x 28.7 m = 631 m^2); the pre-oxidation tanks and effluent storage tanks are located outside, adjacent to the treatment building.

4. DESIGN CRITERIA FOR THE LEE FLOTATION-FILTRATION CLARIFIERS

Specific design criteria for each Krofta flotation-filtration clarifier (DAFF) at the Lee plant are listed below:

Design flow:	2.0 MGD (7570 m^3/day)
Clarifier diameter:	24 feet (7.3 meter)
Clarifier retention time:	16 min.
Total filter area:	400 FT^2 (37.2 m^2)
DAF hydraulic loading:	3.5 GPM/FT^2 (0.141 m^3/min./m^2)
No. filter cells:	17
Filter cell area:	23.5 FT^2 (2.19 m^2)
Filtration rate:	3.5 GPM/FT^2 (0.141 m^3/min./m^2)
Anthracite coal media:	12" (30.5 cm) layer of 1.1 mm dia.
Quartz sand media:	12" (30.5 cm) layer of 0.35 mm dia.
Filter backwash (full):	20 GPM/FT^2 (0.812 m^3/min./m^2)
Filter backwash (partial):	16 GPM/FT^2 (0.650 m^3/min./m^2)

5. MECHANICAL DESCRIPTION OF LEE FLOTATION-FILTRATION CLARIFIERS

The following is a detailed description of how the package Krofta Sandfloat BP flotation-filtration clarifiers function. Figure 3 shows a bird's view of a Krofta Sandfloat Type SAF-BP system, while Figure 4 shows the features and advantages of this innovative DAF-filtration (DAFF) system.

5.1 Chemical Treatment .

The chemically pre-treated water enters the bottom of the central flocculator, an internal mixing chamber separate from the rest of the unit, and flows tangentially in a slow mix to allow chemical reactions to occur and flocs to form. Detention time in this inner chamber at 2.0 MGD (7570 m^3/day) is approximately 1.2 minutes.

5.2 Dissolved Air Flotation.

After the chemical pretreatment / slow mixing stage the water reaches the top of the flocculator where a stream of aerated, filtered water at approximately 277 GPM (1.05 m^3) or 20% of the raw flow containing microbubbles in the 80 micron range are added. This aerated water is created by injecting compressed air into an air dissolving tube (ADT) which dissolves the air into the water [see Figure 5]. The internal ADT pressure is approximately 65-75 psi (448-517 kPa); 20-30 SCFH (0.57-0.85 standard m^3/hr) of compressed air is added and dispersed into the tube through multiple porous plastic panels. Water spiraling past the panels picks up the air and carries it to the pressure release points at the top of the flocculator. Upon release to atmospheric pressure the air comes out of solution in the form of millions of tiny bubbles, giving the water a “milky white” appearance. Flow and pressure is controlled by several globe type throttling valves. Excess, undissolved air is purged from the center of the ADT in a side stream of air and water piped to drain to prevent coalescing and formation of larger bubbles which are not conducive to optimum flotation.

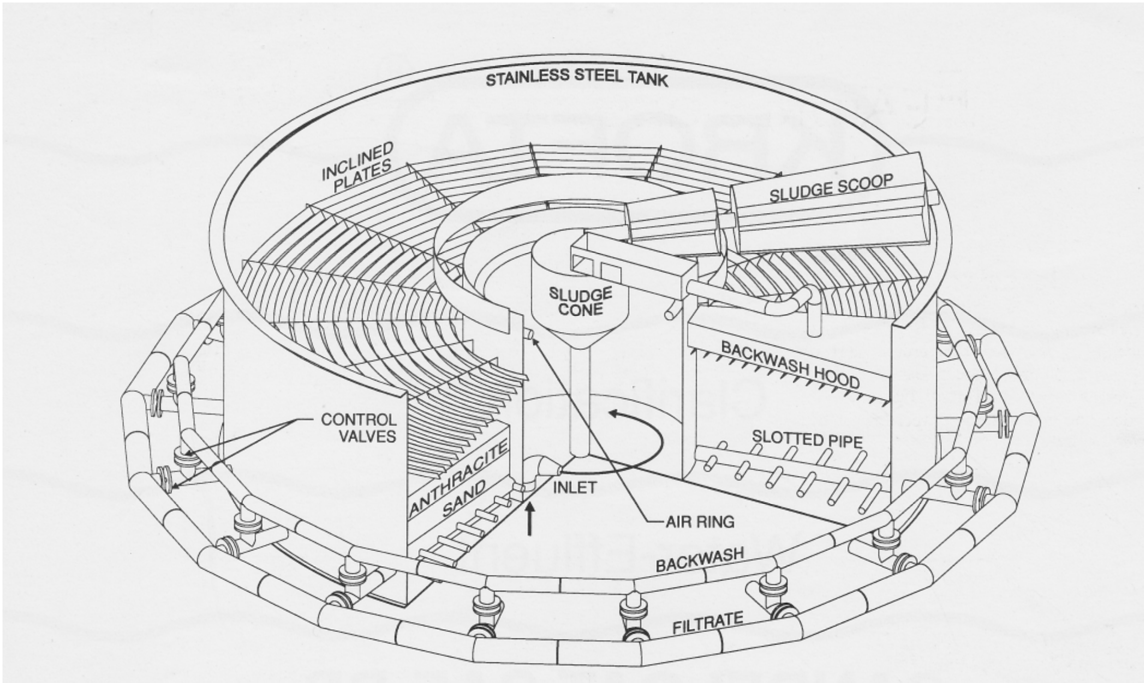
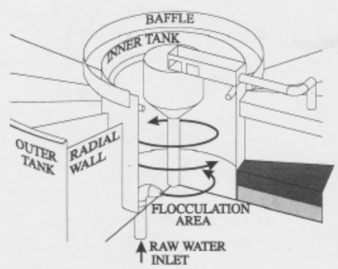


Figure 3. A bird/s view of a Krofta Engineering Corporation's DAF-filtration water treatment plant (Sandfloat Type SAF-BP)

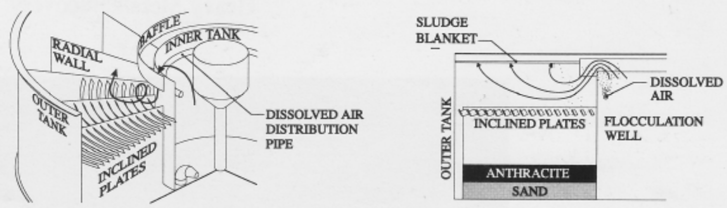
Flocculation

Raw water mixed with flocculating agents enters through a system of nozzles into the flocculating chamber of the unit. The resulting gentle mixing velocity causes solids to aggregate together forming flocs. The extended floc tank assures proper flocculation detention time.



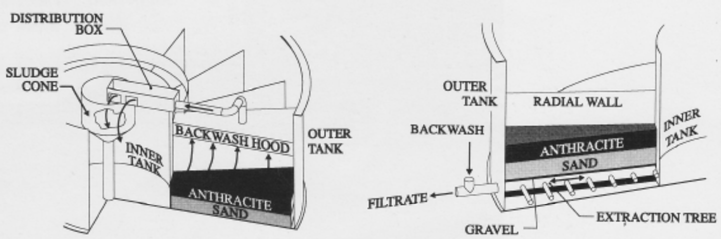
Flotation/Clarification

Water with flocculated solids flows out of the flocculation tank, passing over an area where air saturated water is released. An air dissolving tube system located outside the SANDFLOAT unit generates microscopic, entrained air bubbles which attach themselves to the floc particles, causing them to float to the surface. Laminar plates located under the main flotation zone allow hydraulic loading to 4-5 GPM/SF. (1 GPM/SF = 40 LPM/M²)



Filtration/ On-Line Backwashing

One dual media sandfilter section is individually backwashed while the other sections continue to filter water. Water from the first filtrate water reservoir is pumped from below, through the filter media, washing out impurities. Backwash water is recycled back to the flocculation chamber. The first filtrate (after backwash) isolation system allows for meeting potable water design standards.



Sludge Removal

The rotating KROFTA *Spiral Scoop* mounted on the carriage, circulates around the unit, gently lifting the floated impurities from the water surface. The sludge, at 1-3% consistency, is emptied into the central collector for removal from the SANDFLOAT unit.

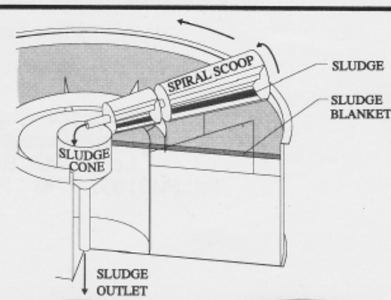


Figure 4. Special features and advantages of a DAF-filtration package plant (Krofta Sandfloat Type SAF-BP)

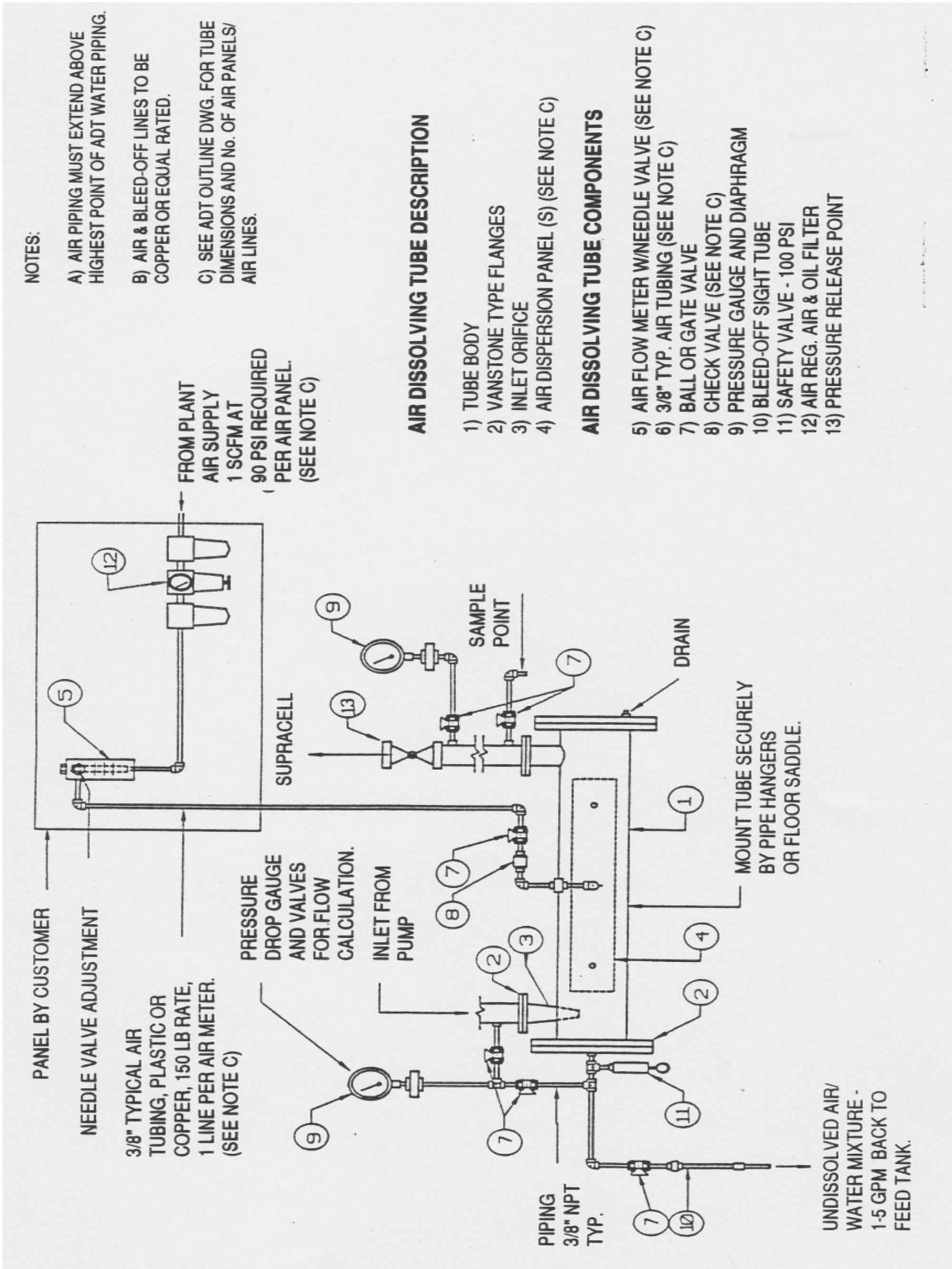


Figure 5. Innovative air dissolving tube (ADT) system

When in contact with the raw water stream the microbubbles in the aerated water stream attach to the flocs formed by chemical addition, reducing their density to less than that of water resulting in flotation of the agglomerates to the surface of the unit where they collect in a scum layer of up to several inches deep. The scum layer is then removed by a rotating spiral scoop mounted on a traveling carriage and discharged into a central sludge well and ultimately to the POTW. The floated sludge TS consistency ranges from 1-2% solids depending upon operator adjustment of the spiral scoop speed and clarifier water depth.

The clarified water then flows downward through a series of incline plates which act as a "water break", reducing the velocity of the water which allows any remaining flocs to float to the surface for removal.

5.4 Dual Media Filtration.

Below the incline plates the water passes through a 12" (30.5 cm) layer of 1.1mm crushed anthracite coal followed by a 12" (30.5 cm) layer of 0.35mm diameter quartz sand. Filtered water is collected in a slotted pipe arrangement below the media beds which retains the media while allowing filtered water to pass into an external annular ring where it is discharged to a chlorination station. The rotating carriage stops periodically to individually and automatically backwash each of the sectors of the filter bed in sequence. Compressed air is used in conjunction with a flow of filtered water to cleanse the media during backwashing. A two stage backwash flow is employed, first at a rate of 20 GPM/FT^2 (0.812 $m^3/min./m^2$) for 60-90 seconds followed by a partial flow of approximately 16 GPM/FT^2 (0.650 $m^3/min./m^2$) for 25-35 seconds to redistribute the media. The backwash water (containing any small particles which were captured by the filter beds) is collected in a hood equipped with a fabric reinforced EPDM flexible seal which inflates to isolate each cell during backwashing. The hood is attached to the rotating carriage and directs backwash water back to the inlet flocculator for optional re-treatment or to POTW. The previously described flotation enhancing incline plates also serve to retain the media during the backwashing process.

After the backwash sequence is completed the hood seal deflates and flow passing through the freshly backwashed media (first filtrate water) is directed to the air dissolving system supply pump for a predetermined period of time to allow turbidity levels to stabilize prior to being sent to the final clarified effluent storage tanks.

All processes described are controlled by a dedicated PLC (programmable logic controller) tied to the treatment plant main computer system.

6. COMPARISON OF THE INNOVATIVE LEE FLOTATION-FILTRATION PLANT WITH CONVENTIONAL WATER TREATMENT PLANT

In terms of water treatment plant’s flow diagram, there is very little difference between a conventional water treatment plant and an innovative DAF-filtration water treatment plant. Generally a conventional water treatment plant (conventional water filtration plant) includes at least the unit operations and unit processes of screening, pumping, rapid mixing for chemical feeding, flocculation, sedimentation, filtration, post-disinfection, corrosion control, storage and water distribution, and, of course, also waste disposal..

On the other hand, an innovative dissolved air flotation water treatment plant (innovative dissolved air flotation water filtration plant) includes at least the unit operations and unit processes of screening, pumping, rapid mixing for chemical feeding, flocculation, dissolved air flotation, filtration, post-disinfection, corrosion control, storage and water distribution and waste disposal. It appears that the only difference is that DAF clarification in the innovative water plant replaces the sedimentation clarification in the conventional water plant.

There are several key differences between a conventional water treatment system which utilizes sedimentation followed by filtration in two separate steps and the Lee flotation-filtration plant (DAFF plant). The Krofta Sandfloat BP unit is an innovative two (2) stage clarifier that incorporates dissolved air flotation with dual media filtration in one footprint, which minimizes space requirements. Use of dissolved air flotation also allows higher possible hydraulic loading rates (up to 5 GPM/FT^2 (0.204 $m^3/min./m^2$) as opposed to up to 2 GPM/FT^2 (0.081$m^3/min./m^2$) for typical sedimentation) and reduced overall clarifier diameter.

The total treatment detention time of the Lee flotation-filtration plant including chemical pretreatment, oxidation, coagulation, flotation, and dual media filtration is approximately 71 minutes. Of this time approximately 55 minutes at design flow is utilized for oxidation of dissolved metals prior to removal by dissolved air flotation. Because of the DAF clarifiers' compact design and short 16 minute retention time (two units for complete redundancy, each having a diameter of 24 feet (7.3 meter) and a depth of 7 feet (2.1 meter)) capital equipment installation costs and building size requirements were all reduced when compared to a conventional treatment system. Smaller size also allows fast start up of the clarifiers, with full flow reached within five (5) minutes of activation.

The Lee unit employs semi-continuous backwashing of the segmented filter bed, with optional recycling of the backwash water to the central inlet chamber for re-treatment to minimize waste. Due to the low volume used in backwashing the innovative Lee clarifiers the supply water can be provided from the clarified effluent piping, effectively eliminating the need for large capacity backwash water storage tanks such as required by standard filtration units.

7. START-UP OPERATION OF THE LEE FLOTATION-FILTRATION PLANT

Since start up plant operation has been very successful in treatment of the Leahey and Schoolhouse reservoirs for potable purposes. All pilot-scale and full-scale operational data can be found from Edward M. Fahey's Master of

Engineering thesis, entitled, "*Pilot –Scale Demonstrations and Full-Scale Operation of Potable Water Flotation-Filtration Plants*" (Lenox Institute of Water Technology, Massachusetts, USA; January 7, 2001; 91 pages; Major Research Advisor Dr. Lawrence K. Wang). Based on a summary of the last six (6) months of Leahey Reservoir treatment performance data, the authors have reviewed and summarized in below..

A review of these data indicate that the treated water flow increased in the summer months to an average high of 1,237,656 GPD (4684.5 m^3/day) in July 1999. The single highest recorded flow of the year was on June 28 with 1,491,512 GPD (5645.4 m^3/day).

Leahey reservoir raw water temperature ranged from 57°F (14°C) to 75°F (24°C) over the six month data range. Influent pH averaged 5.6 and effluent 6.3 units. Influent turbidity averaged 0.8 NTU and effluent averaged 0.07 NTU for a removal efficiency of over 91%. Effluent aluminum and iron levels were both well below required discharge limits, averaging 0.007 mg/L and 0.023 mg/L respectively.

The Town of Lee currently employs two (2) full time operators for the treatment plant. Complete automation includes continuous monitoring of pH, turbidity, chlorine residual, and flow with alarms to alert the operator of any malfunction.

Typical chemical dosage for coagulation of Leahey Reservoir consists of a low dose of sodium hydroxide (to raise the pH to 6.5- 7) followed by 0.5

mg/L of sodium aluminate, and 12-15 mg/L of aluminum sulfate (as $AL_2(SO_4)_3$). Estimated cost for this level of chemical pretreatment is approximately $0.01 / 1000 gallons ($0.01 / 3.785 m^3) treated. These were the year 2001 costs.

8. CURRENT OPERATION OF THE LEE FLOTATION-FILTRATION PLANT

8.1 Corrosion Control for Compliance with the Federal Lead and Copper Rule

Soluble copper is an essential nutrient to human health, but some people who drink water containing copper in excess of the action level of 1.3 ppm over a relatively short period of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the copper's action level over many years could suffer liver and/or kidney damage. People with Wilson's disease should consult their personal doctor.

Lead exposure remains a concern for pregnant and lactating women. There is increasing awareness that exposures to lead adversely affect maternal and infant health, including the ability to become pregnant, maintain a healthy pregnancy, and have a healthy baby. Lead is also an established risk factor for hypertension in adults. The action level of lead in drinking water is 15 ppb. It is known that lead in drinking water is primarily from materials and components associated with water distribution service lines and home plumbing system. A water treatment plant is responsible for providing high quality drinking water throughout the water distribution system, therefore, corrosion control as the last step of water treatment is required. However, a water treatment plant can not control the variety of materials used in home plumbing components. When a water consumer’s water is sitting for several hours, he/she can minimize the potential for lead exposure by flushing the tap water for 30 seconds to 2 minutes before using water for drinking or cooking.

Following the passage of the Dederal Lead and Copper Rule and initial copper and lead sampling in 1991, the Lee Water Department failed to meet the regulated action levels (AL) of copper and lead. The Commonwealth of Massachusetts Department of Environmental Protection (DEP) distributed the notification, bill stuffers, etc. to the Town of Lee forcing the Town to comply with regulations until a water treatment facility could be constructed. (54) In 1998, the Town of Lee completed construction of the innovative dissolved air flotation potable water filtration plant. A combined pH adjustment and zinc orthophosphate addition stabilizes the water throughout the Lee water distribution system, reducing the aggressive and corrosive action of the water and therefore reducing copper and lead concentrations . The Town of Lee’s water is now under the AL for lead (15 ppb), and the AL for copper (1.3 ppm) based on the water samples taken in September 2018. (54)

8.2. Removal of Perchlorate, Barium, Sodium, DBPs, THMs, HAAs, Microbial Contaminants, Turbidity, Iron and Manganese.

Quantitatively the Town of Lee's DAF-filtration plant is well positioned to treat up to 2 million gallons a day (2 MGD) and it is water supply is abundant. (54)

Qualitatively any water treatment plant (including Lee Plant) is responsible for removal or contaminants in drinking water supply, such as (a) Microbial contaminants: They include viruses, bacteria, etc., which may come from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife. Determination of total coliforms (as an indicator) is for controlling microbial contaminants. (b) Organic chemical contaminants: They include synthetic and volatile organic chemicals (VOCs), which are the by-products of industrial processes and petroleum production, and can also come from gas stations, urban storm water runoff, and septic systems. (c) Pesticides and herbicides contaminants: They may come from a variety of sources such as agricultural, urban storm water runoff, etc., (d) Inorganic contaminants: They include salts and soluble metals, which can be naturally occurring or result from urban storm water runoff, industrial, or domestic wastewater discharge, oil and gas production, mining or farming, etc. and (e) Radioactive contaminants: They can be naturally occurring or be the result of oil and gas production and mining activities.

Each year the Town of Lee conducts water quality testing according to the requirements set by the DEP and the US Environmental Protection Agency (USEPA). In order to ensure that the Lee Plant's tap water is safe to drink, the USEPA prescribes the Primary Drinking Water Standards and the Secondary Drinking Water Standards that limit and recommend, respectively, the amount of the above contaminants in water provided by the public water systems, such as the Lee Plant. It should be noted that the US Food and Drug Administration (FDA) only limits for contaminants in bottled water.

Table 1 summarizes the drinking water quality of the Town of Lees DAF-filtration plant in 2018.   It appears that the innovative DAF-filtration plant has successfully removed perchlorate, barium, sodium, disinfectant b-product (DBPs), total trihalomethanes (THMs), total haloacetic acids (HAAs), microbial contaminants, turbidity, iron and manganese from raw reservoir water. The readers are referred to the Glossary section for the definitions of action levels (AL), maximum contaminant level (MCL), maximum contaminant level goal (MCGL), treatment technique (TT), 90^{th} percentile level, etc. .

Table 1.   2018 Water quality report of the Lee, Massachusetts, USA, dissolved air flotation potable water filtration plant

Contaminant (Units)	Sites Sampled	AL	90th Percentile	Sample Date	Exceeding AL	Violation	Possible Source of Contamination
Lead and Copper							
Lead	20	15 PPB	3.8 PPB	Sept. 2018	0	No	Corrosion of household plumbing system
Copper	20	1.3 PPM	0.055 PPM	Sept. 2018	0	No	Corrosion of household plumbing system

Contaminant (Units)	Level Detected	MCL	MCLG	Sample Date	Violation	Possible Source of Contamination
Inorganic Contaminants						
Perchlorate*	ND PPM	0.0020 PPM	0 PPM	2018	No	Fireworks, flares, rocket propellants and blasting agents
Barium	0.0064 PPM	2.0 PPM	2.0 PPM	2014	No	Erosion of natural deposits
Unregulated contaminants						
Sodium	9.9 PPM	None	None	2018	No	By-product of corrosion control, naturally occurring.
Disinfection By-Products						
Total Trihalomethane	56 Avg. Range 25.0-110.0 PPB	80 PPB	None	2018	No	By-product of drinking water chlorination
Total Haloacetic Acid	30.0Avg. Range 21.0-46.0 PPB	60 PPB	None	2018	Yes	By-product of drinking water chlorination. See front page.
Microbial Contaminants						
Turbidity	0.091 NTU	TT=0.3 NTU	None	2018	No	Soil runoff
Secondary Contaminants						
Iron	ND	0.3	None	2018	No	Naturally occurring
Manganese	0.0077	0.05	None	2018	No	Naturally occurring

9. CONCLUSION

This book chapter introduces mainly the structural design, design criteria, and water purification performance data for the Lee flotation-filtration plant.

Improved design has allowed the hydraulic limit of the Krofta Sandfloat clarifier to be increased from 2.5 GPM/FT^2 (0.102 m^3/min./m^2) in 1982 to up to a design 5.0 GPM/FT^2 (0.204 m^3/min./m^2) in 1999.

Based on the operation and performance data generated during the Lee plant's start-up period in 1999 and now in 2018, the innovative Lee plant consisting of chemical pretreatment, oxidation, coagulation-flocculation, dissolved air flotation, automatic backwash dual media filtration and disinfection, corrosion control has proven to be a feasible system for water purification for over 19 years.

It is concluded that the innovative Lee flotation-filtration plant represents a cost effective, feasible treatment solution that warrants consideration by all municipalities.

Although Lee flotation-filtration plant is a DAF-ABF package plant shown in Figures 2-4, any potable water plants with separate, individual DAF, filtration unit processes will perform equally well (55). DAF is now a main stream potable water treatment process.

It has also been demonstrated that a combination of pH adjustment and zinc orthophosphate addition is an excellent method for corrosion control and, in turn, for complying with the Federal Copper and Lead Rule.

10. RECOMMENDATIONS

10.1 Further Study of Dissolved Air-Ozone Flotation For Potable Water Treatment

Pilot plant testing for the Town of Lee, MA included some operation of the DAF-ABF pilot unit with ozone (O_3) in a pretreatment stage. The main purpose was to evaluate the possibility of utilizing ozone for precipitation of the iron and manganese present in the raw water into an insoluble form prior to removal by the dissolved air stage. The evaluation had to be abandoned before completion due to time constraints but did show some promise as an alternative to the chemical pretreatment program of potassium permanganate. It was visually noted the addition of O_3 to the raw water produced a flotable floc and yielded significant reductions in iron and manganese levels similar to the permanganate. Dosages were not able to be optimized, however. Additional evaluation of ozone as an oxidizing agent or coagulant in the treatment of potable water with DAF-ABF units is recommended.

10.2 Further Study of Arsenic Removal by DAF-ABF

Treatment of groundwater contaminated with arsenic by DAF-ABF technology is a potential application which has not been thoroughly explored.

10.3 Detailed Study of Filter Backwash Water Recycle in DAF Systems

The recycling of backwash water for re-treatment in potable applications introduces several questions with regards to the actual impact recycling has on final effluent qualities and chemical pretreatment dosages. Further testing is recommended.

12.4 Further Study of Sequential Batch DAF Developed By Dr. Lawrence K. Wang

Wang, Kurylko and Wang (1994) and Wang and Clesceri (1995) invented and described, respectively, a sequential batch DAF process which was developed for groundwater decontamination. This should be further investigated as an alternative to the DAF-ABF unit in treatment of contaminated groundwater. (31, 35-36)

10.5 More Theoretical and Kinetics Studies

Theoretical and kinetics studies of DAF systems will lead to a more complete understanding of system dynamics and perhaps will provide models for a more energy efficient unit. (41-53)

10.6 Further Development and Improvement to DAF-ABF Systems

The DAF-ABF water clarifier (Krofta type SAF BP) utilized for the testing of potable water sources presented in this paper was a third generation DAF clarifier which has been developed over the past 20 years. Continued advances and modifications to the unit as tested will facilitate increased acceptance of this device by municipalities and consulting engineers for treatment of surface waters for potable purposes. Recommended specific improvements which should be investigated in the future:

. • utilization of ozone instead of oxygen for production of dissolved air

. • improved headloss measuring devices to minimize backwashing and save energy consumption

. • inclusion of lamella plates in the flocculation section for higher possible hydraulic loading rates (>5.0 gpm/ft^2)

. • evaluation of replacing the anthracite media with a layer of GAC in the filter bed sectors for VOC removal of contaminated groundwater.

11. GLOSSARY (37-40, 54)

90^{th} percentile level: It means that out of 10 sites sampled, 9 out of 10 were at or below this level.

Action level (AL): The concentration of a contaminant which, if exceeded, triggers water treatment or other requirements which a water system must follow.

Conventional water treatment plant (conventional water filtration plant): It includes at least the unit operations and unit processes of screening, pumping, rapid mixing for chemical feeding, coagulation-flocculation, sedimentation, filtration, post-disinfection, corrosion control, storage and water distribution, and waste disposal..

Copper: Soluble copper is an essential nutrient to human health, but some people who drink water containing copper in excess of the action level of 1.3 ppm over a relatively short period of time could experience gastrointestinal distress. Some people who drink water containing copper in excess of the copper's action level over many years could suffer liver and/or kidney damage. People with Wilson's disease should consult their personal doctor.

Disinfectant by-products contaminants: Disinfectant by-products (DBPs) are organic compounds produced when chlorine and/or bromine are used as the disinfectant(s) to kill microbial contaminants, such as bacteria, in the water supply. These disinfectants react with naturally occurring organic matters forming DBPs.

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 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).

Innovative dissolved air flotation water treatment plant (innovative dissolved air flotation water filtration plant): It includes at least the unit operations and unit processes of screening, pumping, rapid mixing for chemical feeding, coagulation-flocculation, dissolved air flotation, filtration, post-disinfection, corrosion control, storage and water distribution and waste disposal.

Inorganic contaminants: They include salts and soluble metals, which can be naturally occurring or result from urban storm water runoff, industrial, or domestic wastewater discharge, oil and gas production, mining or farming.

Lead: Lead exposure remains a concern for pregnant and lactating women. There is increasing awareness that exposures to lead adversely affect maternal and infant health, including the ability to become pregnant, maintain a healthy pregnancy, and have a healthy baby. Lead is also an established risk factor for hypertension in adults. The action level of lead in drinking water is 15 ppb. It is known that lead in drinking water is primarily from materials and components associated with water distribution service lines and home plumbing system. A water treatment plant is responsible for providing high quality drinking water throughout the water distribution system, therefore, corrosion control as the last step of water treatment is required. However, a water treatment plant can not control the variety of materials used in home plumbing components. When a water consumer's water is sitting for several hours, he/she can minimize the potential for lead exposure by flushing the tap water for 30 seconds to 2 minutes before using water for drinking or cooking.

Microbial contaminants: They include viruses, bacteria, etc., which may come from sewage treatment plants, septic systems, agricultural livestock operations, and wildlife. Determination of total coliforms (as an indicator) is for controlling microbial contaminants.

Maximum contaminant level (MCL): The highest level of a contaminant that is allowed in drinking water. MCLs are set as close to the MCLGs as feasible using the best available treatment technology.

Maximum contaminant level goal (MCGL): The level of a contaminant in drinking water below which there is not known or expected risk to health. MCGLs allow for a margin of safety.

Organic chemical contaminants: They include synthetic and volatile organic chemicals (VOCs), which are the by-products of industrial processes and petroleum production, and can also come from gas stations, urban storm water runoff, and septic systems.

Pesticides and herbicides contaminants: They may come from a variety of sources such as agricultural, urban storm water runoff, etc.

Radioactive contaminants: They can be naturally occurring or be the result of oil and gas production and mining activities.

Treatment technique (TT): It is a required process intended to reduce the level of a contaminant in drinking water. 0.5 NTU must be met 95% of the time. The TT was met 100% of the time.

12. ACKNOWLEDGMENT

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This book chapter has been written in memory of both late Dr. Milos Krofta, (former President of Lenox Institute of Water Technology and former President of Krofta Engineering Corporation), and late Dr. and Professor Donald B. Aulenbach .

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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); Co-Series Editor of the Handbook of Environment and Waste Management series (World Scientific) and Co-Series Editor of the Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics

(Lenox Press). 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. Currently Dr. Tsao is the Co-Series Editor of the "Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics" eBook series (Lenox Press).

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Dr. Lawrence K. Wang (王抗曝) - - left

Dr. Hung-ping Tsao (曹恆平) -- right

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Introduction to the eBOOK Series of :

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

and This Chapter

"AN INNOVATIVE LEE, MASSACHUSETTS USA DISSOLVED AIR FLOTATION POTABLE WATER FILTRATION PLANT"

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 acronym STEAM 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. The acronym STEAM stands for “science, technology, engineering arts and mathematics”. STEAM is an academic new 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, “*“AN INNOVATIVE LEE, MASSACHUSETTS USA DISSOLVED AIR FLOTATION POTABLE WATER FILTRATION PLANT"* is the authors’ collection of thoughts, water treatment pilot plant testing, Lee Water Treatment Plant's full scale operation and literature articles about historical development of innovative DAFF potable water treatment systems in Lee, Massachusetts, USA. The authors present the overall structural design, design criteria, and performance data of the two Krofta Sandfloat flotation-filtration clarifiers (DAFF; SAF-BP24) installed at the 2.0 MGD

(7570 m^3/day) Lee Plant in treatment of surface water for potable purposes. Lenox Institute of Water Technology (LIWT) invented and patented the innovative DAFF system, while Krofta Engineering Corporation (KEC) manufactured and installed the Lee Plant. The author also discuss (a) current corrosion control program in order to comply with the US Federal Copper and Lead Rule, and (b) the current DAF-filtration plant's performance for removal of perchlorate, barium, sodium, disinfection by-products (DBP), total trihalomethane (THM), total haloacetic acid (HAA), microbial contaminants, turbidity, iron and manganese. The 19 years old innovative Lee DAF-filtration plant met all US Environmental Protection Agency, and the Commonwealth of Massachusetts primary and secondary drinking water standards in accordance with the 2018 Water Quality Report. The Town of Lee successfully uses zinc orthophosphate and pH adjustment to stabilize the water throughout of Lee distribution system for lead, copper and pipe corrosion control. This article has been written in memory of Dr. Milos Krofta, Dr. Donald B. Aulenbach and Dr. William A. Selke. Drs. Krofta, Aulenbach and Selke were formerly Lenox Institute Professors. Dr. Krofta who passed away at 90 years old was also the President of both LIWT and KEC. This book chapter partially documents their contributions in STEAM education and technology development.

LIST OF TABLE

Contaminant (Units)	Sites Sampled	AL	90th Percentile	Sample Date	Exceeding AL	Violation	Possible Source of Contamination
Lead and Copper							
Lead	20	15 PPB	3.8 PPB	Sept. 2018	0	No	Corrosion of household plumbing system
Copper	20	1.3 PPM	0.055 PPM	Sept. 2018	0	No	Corrosion of household plumbing system

Contaminant (Units)	Level Detected	MCL	MCLG	Sample Date	Violation	Possible Source of Contamination
Inorganic Contaminants						
Perchlorate*	ND PPM	0.0020 PPM	0 PPM	2018	No	Fireworks, flares, rocket propellants and blasting agents
Barium	0.0064 PPM	2.0 PPM	2.0 PPM	2014	No	Erosion of natural deposits
Unregulated contaminants						
Sodium	9.9 PPM	None	None	2018	No	By-product of corrosion control, naturally occurring.
Disinfection By-Products						
Total Trihalomethane	56 Avg. Range 25.0-110.0 PPB	80 PPB	None	2018	No	By-product of drinking water chlorination
Total Haloacetic Acid	30.0Avg. Range 21.0-46.0 PPB	60 PPB	None	2018	Yes	By-product of drinking water chlorination. See front page.
Microbial Contaminants						
Turbidity	0.091 NTU	TT=0.3 NTU	None	2018	No	Soil runoff
Secondary Contaminants						
Iron	ND	0.3	None	2018	No	Naturally occurring
Manganese	0.0077	0.05	None	2018	No	Naturally occurring

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Figure 3. A bird/s view of a Krofta Engineering Corporation’s DAF-filtration water treatment plant (Sandfloat Type SAF-BP)

Figure 4. Special features and advantages of a DAF-filtration package plant (Krofta Sandfloat Type SAF-BP)

Figure 5. Innovative air dissolving tube (ADT) system

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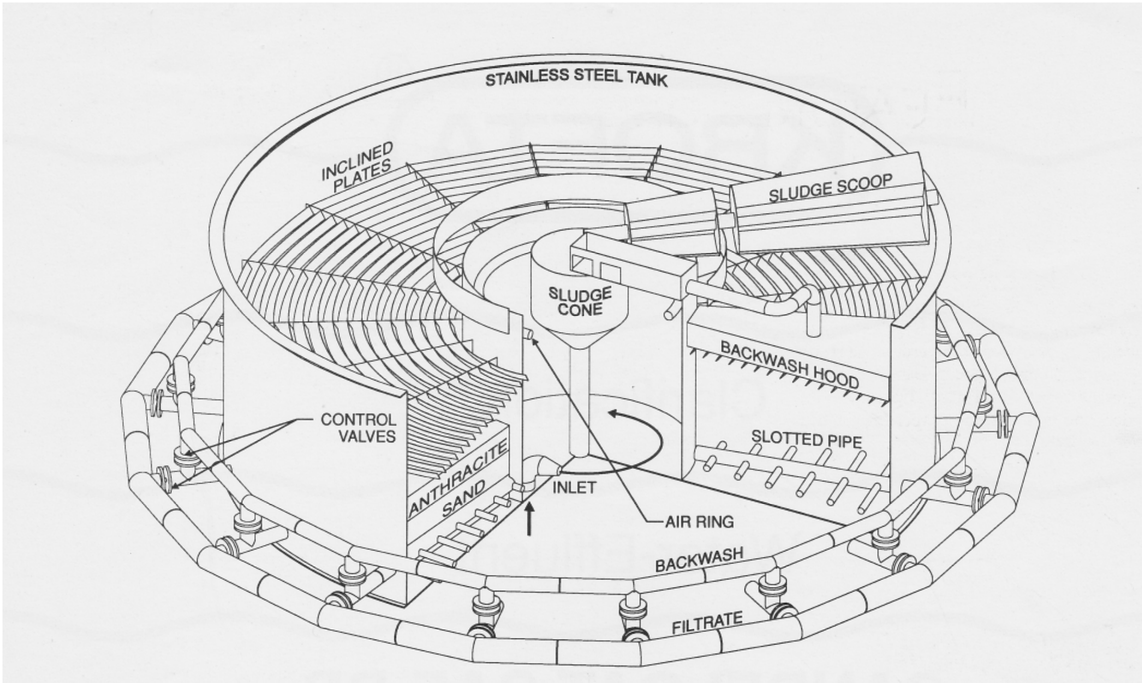
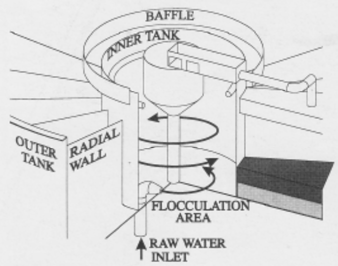


Figure 3. A bird/s view of a Krofta Engineering Corporation's DAF-filtration water treatment plant (Sandfloat Type SAF-BP)

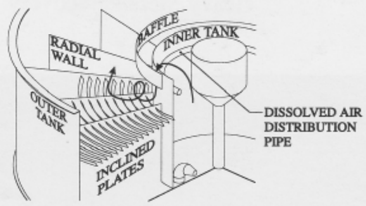
Flocculation

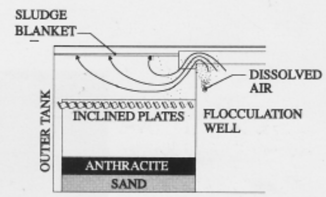
Raw water mixed with flocculating agents enters through a system of nozzles into the flocculating chamber of the unit. The resulting gentle mixing velocity causes solids to aggregate together forming flocs. The extended floc tank assures proper flocculation detention time.



Flotation/Clarification

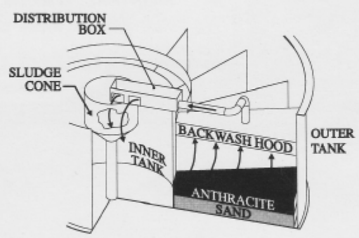
Water with flocculated solids flows out of the flocculation tank, passing over an area where air saturated water is released. An air dissolving tube system located outside the SANDFLOAT unit generates microscopic, entrained air bubbles which attach themselves to the floc particles, causing them to float to the surface. Laminar plates located under the main flotation zone allow hydraulic loading to 4-5 GPM/SF. (1 GPM/SF = 40 LPM/M²)

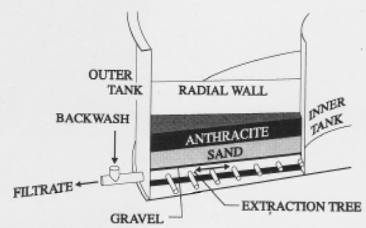




Filtration/ On-Line Backwashing

One dual media sandfilter section is individually backwashed while the other sections continue to filter water. Water from the first filtrate water reservoir is pumped from below, through the filter media, washing out impurities. Backwash water is recycled back to the flocculation chamber. The first filtrate (after backwash) isolation system allows for meeting potable water design standards.





Sludge Removal

The rotating KROFTA *Spiral Scoop* mounted on the carriage, circulates around the unit, gently lifting the floated impurities from the water surface. The sludge, at 1-3% consistency, is emptied into the central collector for removal from the SANDFLOAT unit.

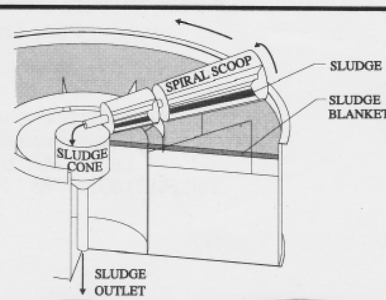


Figure 4. Special features and advantages of a DAF-filtration package plant (Krofta Sandfloat Type SAF-BP)

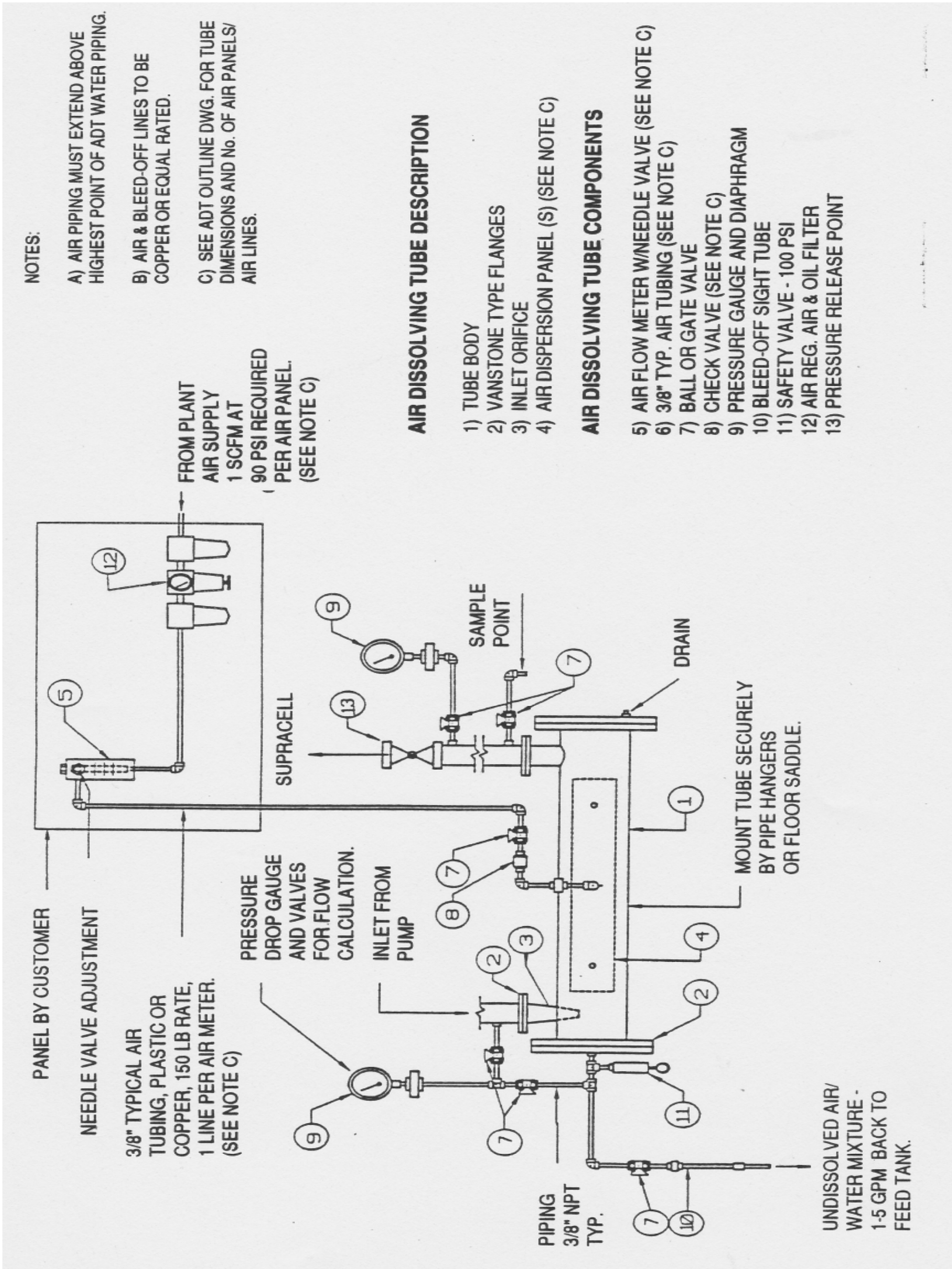


Figure 5. Innovative air dissolving tube (ADT) system