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**INDEPENDENT PHYSICOCHEMICAL
WASTEWATER TREATMENT SYSTEM
CONSISTING OF
PRIMARY FLOTATION CLARIFICATION,
SECONDARY FLOTATION CLARIFICATION
AND TERTIARY TREATMENT**

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NOMENCLATURE

BOD	biochemical oxygen demand
COD	chemical oxygen demand
DAF	dissolved air flotation
DAFF	dissolved air flotation-filtration
DGF	dissolved gas flotation
GAC	granular Activated Carbon
IPCWTS	Independent Physicochemical Wastewater Treatment System
KAMET	Krofta Advanced Municipal Effluent Treatment
KAMWT	Krofta Advanced Municipal Water Treatment
KEC	Krofta Engineering Corporation
LIWT	Lenox Institute of Water Technology
LWWTP	Lee Wastewater Treatment Plant
MGD	million gallons per day
NFWWTP	Niagara Falls Wastewater Treatment Plant
NPDES	National Pollutant Discharge Elimination System
NH ₃	free ammonia
NH ₃ -N	ammonia nitrogen
NO ₂ -N	nitrite nitrogen
NO ₃ -N	nitrate nitrogen
O&M	operational and maintenance
PC	physicochemical
TKN	total Kjeldahl nitrogen
TS	total solids
TSS	total suspended solids
USEPA	United States Environmental Protection Agency
WWTP	wastewater treatment plant

1. INTRODUCTION

1.1 General Objective

The high cost of traditional wastewater treatment approaches has led to the need for improving and discovering alternative methods of treatment techniques. However, sound design and operating criteria for innovative technologies are less certain than those for well-established conventional technologies because practical experience has only begun to provide a basis for design. Therefore, innovative technologies are still not widely accepted by design engineers and regulatory officials, as well as the general public.

Still, there are many treatment plants that have been designed using innovative treatment technologies to treat their “waste streams”. Even though “innovative” does not necessarily imply improved treated water or effluent quality, the main advantage in employing new methods lies in the potential operation and maintenance (O&M) cost savings due to better treatment efficiency.

All wastewater treatment plants in the U.S. need to comply with their final National Pollutant Discharge Elimination System (NPDES) discharge requirements, but many also need some form of improvement to achieve this compliance. Also, a high financial commitment will be required to bring about the nation's wastewater plants into compliance with the prevailing standards. However, expected economic pressure and competition for limited public revenue can result in an increased burden on the designer for solutions that offer greater economy thus requiring more extensive consideration of alternative technologies and management practices.

1.2 Particular Research

Before investigating innovative wastewater treatment systems, it is helpful to know, where to draw the line to so-called conventional treatment applications. Section 2 provides a brief introduction to wastewater treatment units that are considered to be conventional.

Many innovative approaches were made by the Lenox Institute of Water Technology (LIWT) to evaluate the effectiveness of treating raw municipal wastewater applying innovative treatment techniques. In all cases, dissolved air flotation (DAF) was applied to rapidly and significantly reduce wastewater impurity levels. [1-34]. Any innovative systems developed by the authors in this particular research can be in any shape (circular or rectangular), can use any manufacturers' products (Supracell, Sandfloat, KAMET, AquaDAF, clair-DAF, etc.), and is for the entire world.

In this study, the flotation technology was used to treat wastewater entirely by physicochemical means with the purpose of obtaining substantial reduction in total suspended solids (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD) in the treated effluent. For that reason, a pilot plant study was conducted at the Lee Wastewater Treatment Plant (LWWTP) in Massachusetts, USA on raw municipal wastewater using a modular clarification system containing primary flotation followed by secondary flotation-filtration. The feasibility study including both laboratory evaluations and pilot plant demonstrations is described in Section 3.

In order to evaluate the feasibility of this conceptually developed process system, a simulation of the proposed wastewater treatment system was conducted at the Lenox Institute of Water Technology (LIWT) laboratory using the Institute's bench-scale laboratory facilities and its pilot plant units (Krofta Supracell, Sandfloat, KAMET, etc.). The complete description and evaluation of the bench scale study and the pilot plant study are given in Sections 3.3 and 3.4, respectively.

1 CONVENTIONAL WASTEWATER TREATMENT PROCESSES

The variety of unit operations and processes that bring about the purification of wastewater is large in terms of detention time or volume. However, only certain unit operations are repeatedly applied in wastewater treatment, since they have proven to be successful in accomplishing the required regulatory standard limits for wastewater discharge in the past. Therefore, such operations are considered to be conventional. Also, wastewater treatment units, that adopt these conventional techniques to treat the incoming wastewater, are referred to as conventional treatment units.

1.1 Conventional Physicochemical Treatment Plant's Unit Processes

A conventional physicochemical wastewater treatment system generally consists of following components:

- I. Preliminary wastewater handling and treatment facilities (pumps, screens, comminuters, grit chambers, samplers, etc.)
- II. Chemical feeders and rapid mixing tanks
- III. Flocculation basin (with 45-60 minutes detention time)
- IV. Sedimentation clarifiers (with 2-4 hours detention time)
- V. Granular activated carbon beds
- VI. Chlorination chambers (with 30-60 minutes retention time)
- VII. Effluent structure

Physicochemical treatment is mainly applied in industrial wastewater treatment applications, or combined industrial and municipal wastewater treatment applications, due to the toxic substances present in the wastewater (heavy metals, odor-causing substances, oil, grease, foaming substances, etc.), which could not be handled by biological means. Also, the presence of a high percentage of insoluble biochemical

oxygen demand (BOD) can justify a physicochemical treatment. In these cases, a non-biological process is technically and economically feasible. [1-3]

1.2 Conventional Biological Treatment Plant's Unit Processes

A conventional biological wastewater treatment system generally consists of following components incorporating physical and biological processes:

- I. Preliminary wastewater handling and treatment facilities (pumps, screens, comminuters, grit chambers, samplers, etc.)
- II. Primary sedimentation clarifiers (with 2-4 hours detention time)
- III. Biological reactors:
 - Activated sludge (typically about 6 hours detention time)
 - Trickling filter (short detention time but large area)
 - Rotating biological contactors (long detention time)
- IV. Secondary sedimentation clarifiers (with 30-60 minutes detention time)
- V. Chlorination chambers
- VI. Effluent structure

Biological processes are capable to successfully treat wastewater containing mainly biodegradable pollutants, especially in dissolved form, by either removing or reducing them to an acceptable level for discharge to a receiving water body. The implementation of a biological process to municipal wastewater treatment is a common feature, since past experiences have proven it to operate reliably (to a certain degree), economically and acceptably, in terms of current discharge standards.

2 INNOVATIVE PHYSICOCHEMICAL WASTEWATER TREATMENT RESEARCH AND DEVELOPMENT

2.1 Introduction

There are many clarification steps used in the purification of raw municipal wastewater. The general procedure in treating this type of wastewater has manifested itself throughout the years as being a combination of both physical-chemical and biological treatment. This combination is not only thought to be highly successful but also very cost-effective. It is highly successful in terms of efficiently reducing the biodegradable pollutants from municipal wastewater, containing both particulate and dissolved matter. It is cost-effective compared to non-biological, strictly physical-chemical treatment processes, due to their high capital investment and operational and maintenance (O&M) costs.

However, the biological process is extremely sensitive to changes in hydraulic loading (heavy rain, seasonal increase in population in tourist areas) and wastewater composition, which may lead to upsets in the biological treatment process. In this case, the entire wastewater flow has to temporarily be treated physical-chemically, since no wastewater is allowed to be discharged to a receiving water body untreated. This is certainly a less costly alternative to having a second biological reactor on-line for emergency purposes.

In other cases, however, physicochemical treatment is the only practical method that is suitable to purify an incoming municipal wastewater stream. This applies to municipal wastewater treatment plant's (WWTP) that receive wastewater from industrial applications. Most industrial wastewater contain high levels of contaminants and fluctuating levels of certain parameters, such as pH and

toxic chemicals, that make it very difficult to treat biologically. The 48-Million Gallons per Day (MGD; $1\text{MGD} = 3.7854 \times 10^3 \text{ m}^3/\text{d}$) Niagara Falls Wastewater Treatment Plant (NFWWTP), Niagara Falls, NY, U.S.A., built in 1971, is an example for an entire physicochemical treatment facility, which was constructed to treat both, the City of Niagara Falls' combined municipal and industrial wastewater [1- 3]. The type of treatment chosen for this plant were screening, chemical coagulation/precipitation, pH control, sedimentation, Granular Activated Carbon (GAC) adsorption/filtration, and chlorination. The United States Environmental Protection Agency (USEPA) and State of New York, US, required that the equivalent of secondary treatment, pH control, and a high degree of phosphate removal be provided in this plant. The results show that the treatment facility does have these capabilities and is able to meet discharge limits.

In general, physicochemical treatment is a seriously considered treatment method when the wastewater to be treated is industrial or partly industrial in nature. Among municipalities, physicochemical processes are either part of the wastewater treatment design or are applied in emergency situations when the biological process is upset. However, an entirely physicochemical treatment process is seldom applied due to the high capital investment and operational and maintenance costs involved.

New developments in the field of physicochemical treatment methods make the cost for a physicochemical treatment plant comparable or more economical than a conventional biological treatment plant. The sedimentation unit, which requires a large area due to long detention times, and a separate flocculation tank, can be replaced by a flotation clarifier. This replacement would significantly reduce investment costs and also the operating costs can often be lower. The types of treatment processes involved in a physicochemical treatment plant design can not only be replaced by more efficient technologies, but are also more compact and require less space. [4-34]. Many cost-effective physicochemical treatment systems based on flotation technology have been

developed. The most recent innovation in this regard was the development of a municipal wastewater treatment system using primary-secondary flotation and filtration. Initially, this installation was developed to further treat municipal wastewater effluent for reuse. To evaluate the systems performance when applied as an entire wastewater treatment application, a pilot plant was designed and installed at the Lee Wastewater Treatment Plant (LWWTP) in Lee, MA, U.S.A. The purpose of the study was to determine the systems performance efficiencies and limitations. The pilot plant performed well and the test results showed excellent overall removal efficiencies for TSS (99.6%), COD (74%), BOD (76%) and Total P (83%). However, after significant reduction, the BOD level in the final effluent was still too high to meet regulatory effluent discharge standards of 30mg/L. The high Ammonia-Nitrogen levels present in the effluent indicated that no significant reduction to nitrogen gas was occurring. A possibility to alter the effluent quality would be to add granular activated carbon filtration as a tertiary polishing stage after the secondary flotation-filtration clarification step. In the case of the Niagara Falls Wastewater Treatment Plant (NFWWTP) the use of a GAC unit showed good removal efficiencies. [1-3]

3.2 Experimental Materials and Apparatus

The following experimental equipment and materials have been used.

3.2.1 Pilot Plant:

Dissolved Air Flotation (DAF, Supracell) Unit and Dissolved Air Flotation-Filtration (DAFF, Sandfloat) Unit from the Lenox Institute of Water Technology (LIWT) were used.

3.2.2 Bench Scale Flotation Unit:

Laboratory Dissolved Air Flotation Apparatus from the Lenox Institute of Water Technology shown in Figure 1 was used.

3.2.3 Wastewater Supply:

Raw wastewater from the Lee Wastewater Treatment Plant (LWWTP), Lee, Massachusetts, USA, was used.

3.2.4 Chemical Supply:

Inorganic Coagulant (Ferric Sulfate) used in the experiments was from Holland Company Inc., Adams, MA., USA, (413) 743-1292.

Organic Flocculant (Magnifloc 496) used in the experiments was from American Cyanamid Company, Wayne, New Jersey, USA.

3.3 Laboratory Experimental Procedures [11]

The following experimental laboratory procedures have been used.

3.3.1 Chemical Dosing Experiments

Determining the most effective chemistry at the optimal dosage is the most important and time consuming aspect of the DAF simulation process.

Chemical dosing can be conducted using 20 mL of sample in a 50 mL test tube (20 mL Workup) or 1000 mL of sample in a beaker (Jar Test, 1000 mL Workup). Tests are often conducted at a 20 mL level and then the chemistry producing the best overall result is evaluated at the 1000 mL level.

For both workups, the most important observations to note following chemical addition are the rapidity and consistency of floc formation, the water clarity between the flocs, the size of the floc (generally, 1 to 2 mm in diameter is optimum for a flotation clarifier) and the stability (shear resistance) of the floc.

For a 20 mL test, shear resistance can be determined by giving the test tube a vigorous shake. For a 1000 mL workup, the paddle stirrer is turned to the maximum RPM (revolutions per minute) or the sample is manually mixed rapidly for a brief period. With either test, the flocs may exhibit signs of breaking up into smaller aggregates. If these smaller particles reform to or near the initial floc size with gentle mixing, the floc is considered to be shear resistant.

When the choice of chemicals and dosages has been optimized, dissolved air flotation simulations are conducted to evaluate their performance.

3.3.2 Bench Scale DAF Simulation

Observing the flotation characteristics of a sample at various recycled flow rates can quickly be accomplished with bench scale DAF tests.

The dissolved air flotation unit can be operated under the following three conditions:

- (1) full flow pressurization (entire influent feed stream is pressurized),

(2) partial flow pressurization (30-50% of influent feed stream is pressurized), and

(3) recycle flow pressurization (portion of clarified effluent is recycled and pressurized).

In this study, a recycle flow pressurization was employed in all laboratory dissolved air flotation experiments.

To start a DAF recycle flow pressurization experiment, a 1000-mL plastic graduated cylinder (see Figure 1) is initially filled with desired volume (V_i) of prepared liquid sample. The value of V_i is decided based on the desired percentage of recycle flow as follows:

Table 1: Recycle Flow Rates

Recycle Rate [%]	Influent Volume (V_i) [mL]	Recycle Water Volume (V_e) [mL]
15	869	131
20	833	167
25	800	200
33	750	250
50	666	334
75	571	429
100	500	500

Figure 1: Laboratory Dissolved Air Flotation Apparatus

The compressed air tank (see Figure 1) is filled half full with recycle water (i.e. clarified water or any source of clean water). The canister is then pumped to 60 psig and shaken for 2 to 3 minutes to allow the air to dissolve in the clean water. The first 100 mL of pressurized water is discharged to purge bound air from the system and to clear the outlet. The remaining pressurized clear water (V_c) is then released into the 1000-mL plastic graduated cylinder (which is initially filled with V_i mL of the influent) by inserting the nozzle at or near the bottom of the cylinder and moving the nozzle upward with the upward flow of the sample ($V_i + V_c$). The rising velocity (in/min) of the flocculated solids is timed with a stop watch. The total flotation period is three minutes. The key observations to be made during this time are floc stability, first minute solids rise rate, evidence of settling or straggler floc in the water column, sludge blanket compaction and sludge stability.

With a DAF simulation that produces acceptable results, the volume of sludge at the end of the three minute flotation period is noted in mL/L. Then, before collecting the supernatant for water quality analysis, the first 50 mL of effluent are discarded from the drain hose at the cylinder bottom, because solids that may accumulate in the barbed end and drain line are not representative of the effluent.

3.3.3 Laboratory Analytical Testing Procedures

The laboratory analytical experiments were conducted in accordance with the Standard Methods for the Examination of Water and Wastewater, Hach Water Analysis Handbook, and the LIWT Laboratory Manual. [11, 40-43]

3.4 Pilot Plant Installation, Operation and Experimental Demonstration

3.4.1 Primary Flotation Clarification Pilot Plant

The basic principles of primary flotation clarification, bubble dynamics, can be found from the literature [4-34] while the operational procedures of the primary flotation clarification pilot units are as follows.

The primary DAF unit used in the pilot study is four foot (1.20 m) in diameter, less than two foot (0.56 m) in depth, and constructed in 304 stainless steel. A pressure pump draws from the clarifier effluent a regulated flow to be used as recycle water. This water flow is pressurized and fed into the air dissolving tube (ADT), saturated with compressed air, and released (decompressed) into the influent stream as it enters the primary flotation unit. The recycle flow used in Lee was 20% to 25% of the influent flow. After pressure release, the aerated water is mixed with the treated raw water just before the raw water inlet. Fine bubbles generated in this manner attach to the suspended particles in the wastewater and float them to the surface. The spiral scoop removes the floated sludge and discharges it to the sludge drain pipe, from where it is pumped back to the plant's wastewater treatment.

Figure 2: KROFTA Mobile Pilot Trailor

Figure 3: Dissolved Air Flotation Clarifier for Primary Treatment

3.4.2. Secondary Flotation Clarification and Filtration (DAFF) Pilot Unit

The secondary DAFF unit provides both flotation and filtration clarification in combination. The main floatation tank is five feet (1.52 m) in diameter with 36 inches (0.90 m) of effective water depth (flotation zone). Beneath the flotation tank are 23 filter segments utilizing dual media of 7 inches of Anthracite ($\text{Ø}=1.0 \text{ mm}$) on top of 7 inches of Sand ($\text{Ø}=0.35\text{mm}$). Additionally, there is a carriage mounted backwash system with suspended hood which allows for backwashing of each of the filter segments individually while the balance of the segments are providing filtered water. The backwash waste stream can be directed to return to the base of the internal flocculator tank

for retreatment by flotation or diverted to waste. Floated solids are collected by the spiral scoop and directed to the central sludge cone for discharge from the DAF-F clarifier. As with the primary flotation unit, a portion of the clarified water is directed to a pressure pump for feed to the Air Dissolving Tube (ADT), saturated with compressed air, and returned as recycle flow to be released (decompressed) near the top of the floc tank as the source of the aerated water stream for flotation.

The summary of the technical data is provided in Table 2 of the next section.

Figure 4: Dissolved Air Flotation and Dissolved Air Flotation-Filtration Clarifier

3.4.3 Pilot Plant System Design

The 6-month (27 week) pilot test was conducted from June 8 to December 7, 1992. A flow diagram of the existing Lee Wastewater Treatment Plant (LWWTP) plus the location of the pilot plant is shown in Figure 5.

Figure 5: Flow Diagram of Lee Wastewater Treatment Plant (LWWTP) with Pilot Plant Location

The modular clarification system containing primary dissolved air flotation and secondary dissolved air flotation-filtration in sequence was located on-site in a trailer next to the wastewater treatment plant's grit chamber. The wastewater to be treated was pre-screened (grit chamber) before it was pumped to the primary and secondary clarification units in the trailer. The effluent from the pilot installation was returned together with the floated sludge to the plant's wastewater treatment.

The flow rate treated was 40 gallons per minute (gpm; $1\text{gpm} = 6.3090 \times 10^{-5} \text{ m}^3/\text{s}$) and the recycle rates for the primary and secondary clarifier were 25% and 20% respectively. The hydraulic loading rate for this flow was 5.2 gpm/ft^2 ($1\text{gpm/ft}^2 = 40.7458 \text{ L/m}^2\text{min}$) for the Flotation unit and 3.5 gpm/ft^2 for the flotation-filtration unit. The following table gives an overview of the operational parameters applied in the pilot study.

Table 2: Operational Parameters of Treatment Units

Parameter			DAF	DAF-F
Tank Diameter	m		1.20	1.52
(ft)			(4)	(5)
Tank Depth	m		0.56	0.90
(ft)			(2)	(3)
Influent	Flow		151	151
L/min			(40)	(40)
(gal/min)				
Recycle	Flow		38	30
L/min			(10)	(8)
(gal/min)				
ADT	Pressure	In/Out	5.9/5.2	6.5/5.3
bar			(86/76)	(96/78)
(psi)				
ADT	Air	Feed	2.36	2.36
L/min			(5)	(5)
(SCFH)				

Carriage	min/rev	1:50	-
Scoop Speed	rpm	2	-
Backwash L/min (gal/min)	Flow	- - -	39.7 (10.5)
Backwash Time	sec	-	50
Backwash Frequency		-	1:12
Backwash Recycle	%	-	100
Head Loss (inches)	cm	- -	25.4 - 45.7 (10 – 18)
Hydraulic Loading Rate L/min/m ² (gal/min/ft ²)		215.71 (5.3)	142.5 (3.5)

A flocculant alone was needed in the flotation unit to remove the larger suspended material. For the secondary flotation-filtration unit a coagulant/flocculant dosing combination was needed to achieve the best removals. Many chemicals at various dosages were tested, but the following table shows the optimal chemicals used and the optimal dosage range for this study.

Table 3: Chemical Dosage after Optimization

Unit	Chemical ⁽¹⁾	Dosage Range ⁽²⁾
DAF	Magnifloc 496C	1 – 2 ppm
DAF-F	Ferric Sulfate	50 – 60 ppm
DAF-F	Magnifloc 496C	1 – 2 ppm

Notes: (1) See Appendix for Specification of Chemicals

(2) ppm = parts per million; 1ppm = 1mg/L

Laboratory tests were conducted daily on composite samples of raw influent, primary DAF unit effluent and secondary DAFF unit effluent. The testing consisted of pH, TSS, COD and BOD. Testing for Phosphorous, TKN, NO₃-N, NO₂-N, NH₃-N and Sludge TS (on DAF and DAFF samples) were done on a weekly basis. The data generated from this testing is presented graphically in the following section.

4. EXPERIMENTAL RESULTS AND DISCUSSION

The composition of the raw municipal wastewater (collected after the grit chamber) is presented in Table 4.

Table 4: Raw Influent (Grit Chamber Effluent) Wastewater Parameters

Parameter	Low	Avg	High
pH, Units	6.97	7.29	8.11
TSS, mg/L	98	315	1191
COD, mg/L	251	585	1196
BOD, mg/L	116	247	497
Total P, mg/L	1.6	5.2	12.8
TKN, mg/L	25	40	77
NO ₃ -N, mg/L	0.7	2.4	5.3
NO ₂ -N, mg/L	0.011	0.020	0.049
NH ₃ -N, mg/L	20	23	31

Temperature (C°) = 15-20

The results from the daily tests (pH, TSS, COD, BOD) are averaged for every week. The test results from influent (RAW), primary flotation clarification (DAF) effluent and secondary flotation clarification-filtration (DAFF) effluent and the overall removal efficiencies for every parameter are documented in the following graphs.

Test results in the first few weeks of the pilot study show varying degrees of removal efficiencies. This is due to normal start-up problems. This variation was less after a satisfactory testing

procedure had been established. Also, the optimum chemical dosage had yet to be determined for the pilot study. In the course of the pilot study, changes to the chemical dosage had to be made due to flow variations and influent composition. Also, different chemicals were tried during this study which explains the presence of any “strange” values throughout the graphs. In general, removal efficiencies do not show any tendency to be climate related. Since the 6-month testing

Figure 6: COD Reduction

period took place during the summer and winter months, variations in the test results are expected. However, this does not apply when using strictly physicochemical treatment.

Figure 7: BOD Reduction

The large variations were due to the extreme fluctuations in the incoming raw feed. These fluctuations were due to the cleaning of the sewer collection mains throughout the Town of Lee by the municipality. Cleaning of these mains had only previously been performed twenty years prior to this period. Especially the second through sixth week showed significant absolute and relative peak values, as applied to the weeks 9/21-9/25 and 11/2-11/6. Here, there was a strong correlation between TSS, COD and BOD values in the wastewater which was obvious. It can be also seen, that primary flotation very efficiently reduced these parameters to a constant low level, regardless of how high the influent value was. The overall performance of the Modular Dissolved Air Flotation-Filtration System was very good, effectively reducing TSS (99.6%), COD (74%) and BOD (76%) levels in a relatively short treatment time.

Removal efficiencies of Total P reached an average value of 83%, most of it being reduced by secondary flotation-filtration through the precipitation of phosphorus by application of the coagulant.

Figure 8: Total P Reduction

Figure 9: TKN Reduction

Figure 10: NH₃-N Reduction

Figure 11: NO₂-N Reduction

Figure 12: NO₃-N Reduction

Primary DAF clarification and secondary DAFF clarification were for clarification only, not designed for removal of nitrogens. Any reductions in TKN, $\text{NH}_3\text{-N}$, $\text{NO}_2\text{-N}$ and $\text{NO}_3\text{-N}$ were surprised accomplishments.

The efficient removal of Nitrate-Nitrogen was mainly achieved by secondary clarification and reached an overall average reduction of 65%. Nitrite-Nitrogen was effectively reduced by 56%. Average removals for TKN and $\text{NH}_3\text{-N}$ were 36% and 18%, respectively.

A summary of the test results from the pilot study is presented in the following table, showing the average test results from the entire 6 months testing period.

	RAW			DAF			DAF-F			Total Reduction
Parameter	Low	Average	High	Low	Average	High	Low	Average	High	Average
pH, Units	6.9	7.32	8.1	6.8	7.40	7.9	6.2	7.30	7.8	-
TSS, mg/l	98	315	1191	15	73	240	ND	4	23	99.6%
COD, mg/l	251	585	1196	142	290	475	74	145	342	74%
BOD ₅ , mg/l	116	247	497	68	122	222	30	59	127	76%
Total P, mg/l	1.60	5.20	12.80	1.10	4.10	5.80	0.04	0.98	3.30	83%
TKN, mg/l	25.0	40.0	77.0	23.0	32.0	61.0	8.4	27.0	50.0	36%
NH ₃ -N, mg/l	20	23	31	17	21	26	10	19	23	18%
NO ₂ -N, mg/l	0.011	0.020	0.049	0.010	0.050	0.370	ND	0.020	0.060	56%
NO ₃ -N, mg/l	0.70	2.40	5.30	0.10	1.50	10.60	ND	0.74	8.60	65%
Sludge TS, mg/l	-	-	-	1800	12400	30000	200	4400	33300	-

Table 5: Evaluation of DAF/DAFF for Wastewater Treatment: Summary of Parameter Test Results

Table 5 includes the low and high values for each parameter in all three stages. The variations within these limits are still acceptable for most of the parameters. BOD and Nitrogen levels, though significantly reduced by the modular treatment system, do not meet the regulatory standards for river discharge.

	RAW			DAF			Primary Clarification Reduction
Parmeter	Low	Average	High	Low	Average	High	Average
pH, Units	6.9	7.32	8.1	6.8	7.40	7.9	-
TSS, mg/l	98	315	1191	15	73	240	76.6%
COD, mg/l	251	1196	585	142	290	475	48%
BOD5, mg/l	116	247	497	68	122	222	49%
Total P, mg/l	1.60	5.20	12.80	1.10	4.10	5.80	25%
TKN, mg/l	25.0	40.0	77.0	23.0	32.0	61.0	20%
NH3-N, mg/l	20	23	31	17	21	26	9%
NO2-N, mg/l	0.011	0.020	0.049	0.010	0.050	0.370	25%
NO3-N, mg/l	0.70	2.40	5.30	0.10	1.50	10.60	35%
Sludge TS, mg/l	-	-	-	1800	12400	30000	-

Table 6: Evaluation of DAF for Primary Clarification

	Secondary Influent			DAF-F			Secondary Clarification Reduction
Parmeter	Low	Average	High	Low	Average	High	Average
pH, Units	6.8	7.40	7.9	6.2	7.30	7.8	-
TSS, mg/l	15	73	240	ND	4	23	98.2%
COD, mg/l	142	290	475	74	145	342	48%
BOD5, mg/l	68	122	222	30	59	127	51%
Total P, mg/l	1.10	4.10	5.80	0.04	0.98	3.30	75%
TKN, mg/l	23.0	32.0	61.0	8.4	27.0	50.0	22%
NH3-N, mg/l	17	21	26	10	19	23	10%
NO2-N, mg/l	0.010	0.050	0.370	ND	0.020	0.060	47%
NO3-N, mg/l	0.10	1.50	10.60	ND	0.74	8.60	43%
Sludge TS, mg/l	1800	12400	30000	200	4400	33300	-

Table 7: Evaluation of DAF-F for Secondary Evaluation

4. INDEPENDENT PHYSICOCHEMICAL WASTEWATER TREATMENT SYSTEM

4.1 Independent Physicochemical Wastewater Treatment System Description

An Independent Physicochemical Wastewater Treatment System (IPCWWTS) utilizes physicochemical (PC) process technology other than biological process technology to obtain combined primary and secondary treatment efficiency for removals of mainly biochemical oxidation demand (BOD), chemical oxidation demand (COD), total suspended solids (TSS), and phosphate. Typically, an IPCWWTS uses combinations of preliminary treatment (flow equalization, bar screening, comminution, grit chamber, ammonia stripping), chemical precipitation/coagulation, primary clarification (primary sedimentation clarification or primary flotation clarification), secondary clarification (secondary sedimentation clarification, or secondary flotation clarification, without biological treatment), tertiary wastewater treatment (filtration, and/or granular activated carbon adsorption, ion exchange, PC oxidation, etc.), and disinfection. An innovative efficient primary flotation clarifier or a secondary flotation clarifier can be in any shape, circular or rectangular. In general this IPCWWTS requires much less land area than conventional biological secondary treatment systems. Phosphorus removal is inherent in this physicochemical process system.

4.2 Independent Physicochemical Wastewater Treatment System Applications

IPCWWTS can be used in some applications where standard biological treatment applies, namely typical municipal wastewater, industrial wastewater, or combined municipal and industrial wastewater. IPCWWTS is a very flexible process system and can be tailored to specific

pollutant problems, such as high background levels of toxic heavy metals, or refractory organic substances. In most cases, phosphorus and many toxic organic and inorganic substances will be simultaneously removed.

4.3 Independent Physicochemical Wastewater Treatment System Chemical Requirements

Chemicals such as alum, ferric chloride, ferric sulfate, polymers, and lime are used to aid in BOD, COD, TSS and P removals in the clarification process, and granular activated carbon (GAC) is usually used in the tertiary treatment process step. Sodium nitrate, or equivalent, may be used for hydrogen sulfide control.

4.4 Independent Physicochemical Wastewater Treatment System Residuals Generation and Limitations

The first IPCWWTS limitation is that large quantities of chemical sludge will be produced by the treatment system resulting in sludge disposal problem. The chemical sludge is quite voluminous. Filter backwash water, spent GAC and carbon bed backwash water may be the additional wastes generated from the IPCWWTS.

A second limitation is that the treatment costs of IPCWWTS in general is higher than biological wastewater treatment systems for treating the same flow of normal municipal wastewater that containing negligible quantities of phosphate, toxic heavy metals and toxic organics. When primary flotation clarification and secondary flotation clarification are used to replace primary sedimentation clarification and secondary sedimentation clarification, an IPCWWTS may

compete well with biological treatment system for treating a normal municipal wastewater because the flotation clarifier costs are much lower than the sedimentation clarifier costs. IPCWWPS is very suitable for treating certain combined municipal and industrial wastewater (such as the wastewater of the City of Niagara Falls, NY, USA), or industrial wastewater containing phosphate, toxic organic and inorganic substances (such as tannery wastewater, hydrofracking wastewater, metal finishing wastewater, etc.).

4.5 Independent Physicochemical Wastewater Treatment System Performance and Management

Treatment of a screened degrittied domestic wastewater by IPCWWTS can result in the following estimated process effluent quality if the IPCWWYS consists of the following unit process and unit operation combinations:

4.5.1 IPCWWTS Includes Chemical Precipitation/Coagulation and Clarification (Flotation Clarification or Sedimentation Clarification)

The expected effluent quality will be: BOD = 50-100 mg/L; COD = 80-180 mg/L; Turbidity = 5-20 NTU; Phosphate = 1-4 mg/L; TSS = 10-30 mg/L; color = 30-60 units; Ammonia Nitrogen = 20-30 mg/L.

4.5.2 IPCWWTS Includes Chemical Precipitation/Coagulation, Clarification (Flotation Clarification or Sedimentation Clarification), and Tertiary Mixed-Media Filtration.

The expected effluent quality will be: BOD = 30-70 mg/L; COD = 50-150 mg/L; Turbidity = 1-2 NTU; Phosphate = 0.5-2 mg/L; TSS = 2-10 mg/L; color = 30-60 units; Ammonia Nitrogen = 20-30 mg/L.

4.5.3 IPCWWTS Includes Chemical Precipitation/Coagulation, Clarification (Flotation Clarification or Sedimentation Clarification), Tertiary Mixed-Media Filtration, and Granular Activated Carbon Adsorption

The expected effluent quality will be: BOD = 10-30 mg/L; COD = 25-45 mg/L; Turbidity = 1-2 NTU; Phosphate = 0.5-2 mg/L; TSS = 2-10 mg/L; color = 5-20 units; Ammonia Nitrogen = 20-30 mg/L.

4.5.4 IPCWWTS Includes Chemical Precipitation/Coagulation, Clarification (Flotation Clarification or Sedimentation Clarification), Ammonia Stripping, Tertiary Mixed-Media Filtration, and Granular Activated Carbon Adsorption

The expected effluent quality will be: BOD = 5-10 mg/L; COD = 25-45 mg/L; Turbidity = 1-2 NTU; Phosphate = 0.5-2 mg/L; TSS = 2-10 mg/L; color = 5-20 units; Ammonia Nitrogen = 1-10 mg/L.

It should be noted that the lower effluent ammonia nitrogen value of 1 mg/L is estimated at wastewater temperature of 18 degree C, while the upper value of 10 mg/L is estimated at wastewater temperature of 13 degree C. Many (but not all) non-biodegradable organic

compounds can be removed by the IPCWWTS. An IPCWWTS is most effective for non-polar, high molecular weight, slightly soluble compounds in wastewater. The US Environmental Protection Agency (USEPA) has developed activated carbon adsorption isotherms for 60 toxic organic materials []. The isotherms demonstrates removal of 51 of these organic compounds by activated carbon technology. another study [] demonstrated that PCB levels can be reduced from 50 micrograms per liter to less than 1 microgram per liter, and other work showed that aldrin, dieldrin, endrin, DDE, DDT, DDD, toxaphene, and Aroclors 1242 and 1254 can be removed to values less than 1 microgram per liter []. Toxicity measured by bioassays was also significantly reduced. Phosphorus removal is inherent in this IPCWWTS .

5. CONCLUSIONS AND RECOMEBNDATIONS

The objective of this study was to treat raw municipal wastewater using a physicochemical treatment process with the intent to rapidly and significantly reduce Total Suspended Solids (TSS), Biochemical Oxygen Demand (BOD) and Chemical Oxygen Demand (COD).

For that purpose, a pilot study was conducted by the Lenox Institute of Water Technology (LIWT) at the Wastewater Treatment Plant in Lee, Massachusetts, USA, on raw municipal wastewater using a modular clarification system containing primary flotation clarification (DAF) followed by secondary flotation clarification-filtration (DAFF). Both treatment steps adopt the Dissolved Air Flotation (DAF) principle to float solids and impurities out of the wastewater. However, the secondary flotation clarification step employs dual media filtration after flotation. Chemical coagulants and flocculants were added to enhance particle formation for rapid removal by physical means. Before the pilot testing started, samples of wastewater were tested in the

laboratory, on a bench scale level, to serve as a guide for the type and dosage of chemical needed in the full-scale pilot study. The pilot plant constellation showed excellent treatment efficiencies of DAF.

There are three conclusions drawn from this research:

1. The combination of primary flotation clarification (DAF) and secondary flotation clarification-filtration (DAFF) was able to reduce 99% of TSS, 74% of COD and 76% of BOD₅ from a typical municipal wastewater. Therefore, it would be an excellent technology for emergency municipal wastewater treatment, municipal wastewater treatment facility renovation (replacing the existing old primary sedimentation clarification and secondary sedimentation clarification), storm run-off treatment, industrial wastewater pre-treatment, , ground water decontamination, hydrofracking effluent treatment, or combined industrial and municipal wastewater treatment.
2. The feasibility of using primary flotation clarification (DAF) for primary treatment of municipal wastewater has been positively demonstrated: 76.6% of TSS, 48% of COD, 49% of BOD₅, 25% of total P, and 20% of TKN were removed from raw municipal wastewater by DAF when dosing 1-2 mg/L of a polymer. Primary flotation clarification (DAF) is superior to conventional primary sedimentation clarification due to the fact that flotation clarification will remove at least 40% of the influent BOD₅ and TSS. Therefore, the aeration basin influent will have a much lower BOD₅ and TSS, the activated sludge in the aeration basin will have much less amount of inert TSS, and the biological treatment will be more efficient.
3. The feasibility of using secondary flotation clarification-filtration (DAFF) for secondary and tertiary municipal wastewater treatment has also been established by its excellent reductions in TSS (98.2%), COD (48%), BOD₅ (51%), total P (75%), and TKN (22%) from its influent.

The secondary flotation clarification-filtration (DAFF) may be adopted by an existing aged biological wastewater treatment plant which urgently needs improvement in performance.

Although the results from the pilot plant study show very good removal efficiencies for all parameters tested and these reductions occur over a wide range of influent concentrations with only slight variations in the final effluent levels, BOD₅ and Nitrogen values are still too high to meet regulatory standards. A possibility to improve the systems performance would be by adding a tertiary polishing stage after the flotation-filtration clarifier (DAFF) using a granular activated carbon filter. GAC is a commonly applied technology in drinking water purification and can also be used in wastewater treatment systems. The main advantage of GAC is that it is able to remove refractory organics from water by adsorption. The addition of GAC filtration as an additional tertiary treatment stage can produce a colorless and odorless effluent, free of bacteria and viruses, with a BOD of less than 1 mg/L and a COD of less than 20 mg/L, according to Wang et. al. [1-3].

The application of GAC is successfully incorporated in the physicochemical treatment design of the Niagara Falls Wastewater Treatment Plant (NFWWTP). [1-3] The following flow diagram shows the physicochemical treatment sequence applied at the Niagara Falls Plant.

Figure 13: Flow Diagram of the Niagara Falls Wastewater Treatment Facility

The implementation of Granular Activated Carbon filtration as a tertiary treatment stage to the modular clarification system containing primary Dissolved Air Flotation and secondary flotation-filtration seems promising in terms of improving the systems removal efficiencies. The advantages of Dissolved Air Flotation over sedimentation have been discussed earlier in this study. The combination of these highly successful features, flotation, flotation-filtration and GAC filtration, will undoubtedly achieve best results in wastewater purification performance. However, the overall treatment efficiencies of the Modular Dissolved Air Flotation-Filtration System by adding GAC filtration after the secondary clarification step has to be evaluated in a further study.

The main drawback of Granular Activated Carbon implementation to the highly cost-effective treatment process of the modular flotation-filtration system is that GAC is a very costly application. In order to achieve further reduction of wastewater contaminants such as BOD and Nitrogen, and, at the same time, limit the cost of treatment, the adoption of a biological process in addition to the physicochemical system should be equally considered as a highly effective possibility to purify a plant's wastewater. The Lenox Institute of Water Technology (LIWT) has adopted this feature in a proposal to the Lee Wastewater Treatment Facility for improving the plant's performance. This innovative wastewater treatment system, containing both improved physicochemical and biological treatment processes, has been evaluated in a separate study and has proven to be the most efficient wastewater treatment method in terms of contaminants removal and cost effectiveness.

6. GLOSSARY OF INDEPENDENT PHYSICOCHEMICAL WASTEWATER TREATMENT SYSTEM (IPCWWTS) [35-39]

Ammonia stripping: It is a physicochemical desorption process for removing ammonia content from a wastewater by a gas stripping operation. In the process, wastewater at elevated pH is pumped to the top of a packed tower with a countercurrent flow of air drawn through the bottom openings. Free ammonia (NH_3) is stripped from the falling water droplets into the air stream which is then discharged to the atmosphere. Lime or caustic soda is added prior to the stripping to raise the pH of the wastewater to the range of 10.8 to 11.5 converting essentially all ammonium ions to ammonia gas which can then be stripped by air. Process controls required for the operation are the proper pH adjustment of the influent wastewater, and maintenance of proper air and water flows. Ammonia removal efficiency is highly dependent on air temperature and air/water ratios. As the air temperature decreases, the efficiency drops significantly. For instance, the ammonia removal efficiency can be 75% at air temperature of 10 degree C, while the ammonia removal efficiency can be 90-95 % at air temperature of 20 degree C. Very poor ammonia removal efficiency will be experienced in cold weather location (0 to 10 degree C). The influent wastewater should always be clarified before stripping. Residual ammonia in the ammonia stripping effluent can be removed by breakpoint chlorination. The countercurrent flow ammonia stripping process is technically and economically feasible for a wastewater containing about 10-100 mg/L of ammonia.

AquaDAF: It is a rectangular dissolved air flotation (DAF) clarifier commercially available from SUEZ Water Technologies and Solutions, Richmond, VA 23229, USA.

Bar screens: There are two types of bar screens (or racks). The most commonly used, and oldest technology, consists of hand-cleaned bar racks. These are generally used in smaller wastewater treatment plants (WWP). The second type of bar screen is the type that is mechanically cleaned, which is commonly used in larger facilities.

Clari-DAF: It is rectangular dissolved air flotation (DAF) clarifier commercially available from Xylem Water and Wastewater, Zelienople, PA 16063, USA.

Coagulant: A chemical (alum or iron salts) added to water to destabilize particles, allowing subsequent floc formation and removal by clarification (flotation or sedimentation) and/or filtration.

Coagulation: A process of destabilizing charges of suspended and colloidal particles in water by adding chemicals (coagulants). In coagulation process, positively charged chemicals are added to neutralize or destabilize these negative charges and allow the neutralized particles to accumulate and be removed by clarification (flotation or sedimentation) and/or filtration.

Collector: A device or system designed to collect filter backwash water, or other treatment unit.

Comminuting: It is a grinding or shredding operation for reducing the particle size of objects or debris in the influent wastewater. They are installed with a screen directly in the influent wastewater flow's channel, with the shredded particles returned to the flow downstream of the

screen. The influent flow is channeled to and through these units. The debris is collected against the screen, or outside drum, and the teeth which penetrate this screen cut up the solids. When the solids are reduced to the size of the screen or drum openings, they pass through and on for additional downstream wastewater treatment. The barminutor is a comminuting device that incorporates revolving cutters that move up and down the upstream face of a bar screen, shredding and cutting whatever debris has accumulated against the screen. The screenings are transported to the cutting device, shredded and then allowed to fall back into the influent channel downstream of the bar screen.

Conventional biological wastewater treatment system: It normally includes (a) preliminary treatment units (i.e. screen, comminutor, grit chamber etc. for removal of sand, gravel, cinders, coffee grounds, small stones, cigarette filter tips, logs, cans, and other large-sized unwanted materials from raw wastewater), (b) primary sedimentation clarification for removing mainly total suspended solids from preliminary effluent, (c) secondary biological treatment units (such as activated sludge aeration or equivalent plus secondary sedimentation clarification) for removing dissolved organic/inorganic pollutants from primary effluent, and (d) tertiary treatment plant units (i.e. filtration, granular activated carbon adsorption, ion exchange, oxidation, nitrification, denitrification, and/or disinfection) for final polishing the secondary effluent in order to meet the effluent discharge standards.

Conventional physicochemical wastewater treatment system: It normally includes (a) preliminary treatment units (i.e. screen, comminutor, grit chamber etc. for removal of sand, gravel, cinders, coffee grounds, small stones, cigarette filter tips, logs, cans, and other large-sized unwanted materials from raw wastewater), (b) primary sedimentation clarification for

removing mainly total suspended solids from preliminary effluent, (c) secondary physicochemical treatment units (such as chemical precipitation/coagulation or equivalent plus secondary sedimentation clarification) for removing dissolved organic/inorganic pollutants from primary effluent, and (d) tertiary treatment plant units (i.e. filtration, granular activated carbon adsorption, ion exchange, oxidation, nitrification, denitrification, and/or disinfection) for final polishing the secondary effluent in order to meet the effluent discharge standards. In the nitrification and denitrification steps, only tertiary sedimentation clarification will be used for solid-water separation.

Denitrification followed by flotation clarification: The process involves the reduction of nitrates and nitrites to nitrogen gas through the action of facultative heterotrophic bacteria. In suspended-growth separate stage denitrification processes, nitrified wastewater containing primarily nitrates is passed through a mixed anaerobic vessel containing denitrifying bacteria. Since the nitrified feed-water contains very little carbonaceous materials, a supplemental source of carbon (such as, methanol, sugar, acetic acid, ethanol, or other compounds) is required to maintain the denitrifying biomass. This supplemental energy is provided by feeding methanol, for instance, to the biological reactor along with the nitrified wastewater. Mixing in the anaerobic denitrification reaction vessel may be accomplished using low speed paddles analogous to standard flocculation equipment. Flotation clarification follows the denitrification step with the floated sludge being either returned to the head end of the denitrification system, or wasted. An intermediate aeration step for stabilization (much less than 40 minutes) may be needed to guard against carryover of carbonaceous materials. The denitrification reactor may be covered but not air tight to assure anaerobic conditions.

Denitrification followed by membrane clarification: Same as "denitrification followed by flotation clarification" except that the flotation clarification is replaced by a membrane filtration reactor.

Denitrification followed by sedimentation clarification: The process involves the reduction of nitrates and nitrites to nitrogen gas through the action of facultative heterotrophic bacteria. In suspended-growth separate stage denitrification processes, nitrified wastewater containing primarily nitrates is passed through a mixed anaerobic vessel containing denitrifying bacteria. Since the nitrified feed-water contains very little carbonaceous materials, a supplemental source of carbon (such as, methanol, sugar, acetic acid, ethanol, or other compounds) is required to maintain the denitrifying biomass. This supplemental energy is provided by feeding methanol, for instance, to the biological reactor along with the nitrified wastewater. Mixing in the anaerobic denitrification reaction vessel may be accomplished using low speed paddles analogous to standard flocculation equipment. Following the reactor, the denitrified effluent is aerated for a short period (5 to 10 minutes) to strip out gaseous nitrogen formed in the previous step which might otherwise inhibit sludge settling. Sedimentation clarification follows the gas stripping step with the collected sludge being either returned to the head end of the denitrification system, or wasted. An intermediate aeration step for stabilization (about 50 minutes) between the denitrification reactor and the stripping step may be used to guard against carryover of carbonaceous materials. The denitrification reactor may be covered but not air tight to assure anaerobic conditions.

Dispersion: A uniform and maximum separation of extremely fine particles, often of colloidal size.

Dissolved air flotation (DAF): One of dissolved gas flotation (DGF) processes when air 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).

Filtration: It is usually a granular medial filtration process which involves the passage of wastewater or water through a bed of filter media with resulting deposition of suspended solids. Eventually the pressure drop across the bed becomes excessive or the ability of the bed to remove suspended solids is impaired. Cleaning is then necessary to restore operating head and effluent quality. The time in service between cleanings is termed the filter run time or run length. The head loss at which filtration is interrupted for cleaning is called the terminal head loss, and this head loss is maximized by the judicious choice of media sizes.

Dual media filtration involves the use of both sand and anthracite as filter media, with anthracite being placed on top of the sand. Gravity filters operate by either using the available head from the previous treatment unit, or by pumping to a flow split box after which the wastewater flows by gravity to the filter cells. Pressure filters utilize pumping to increase the available head. A filter unit generally consists of a containing vessel, the filter media, structures to support the media, distribution and collection devices for filter influent, effluent, and backwash water flows, supplemental cleaning devices, and necessary controls for flows, water levels and backwash sequencing. Backwash sequences can include air scour or surface wash steps. Backwash water can be stored separately or in chambers that are integral parts of the filter unit. Backwash water can be pumped through the unit or can be supplied through gravity head tanks.

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

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

Flocculator: A process device to enhance the formation of floc in a water. Mixing energy can be provided by slow turning mechanical means or head loss.

Granular activated carbon adsorption: Granular activated carbon (GAC) is used in wastewater substances. GAC systems generally consist of vessels in which the carbon is

placed, forming a "filter" bed. These systems can also include carbon storage vessels and thermal regeneration facilities. Vessels are usually circular for pressure systems or rectangular for gravity flow systems. Once the carbon adsorptive capacity has been fully utilized, it must be disposed of or regenerated. Usually multiple carbon vessels are used to allow continuous operation. Columns can be operated in series or parallel modes. All vessels must be equipped with carbon removal and loading mechanisms to allow for the removal of spent carbon and the addition of new material. Flow can be either upward or downward through the carbon bed. Vessels are backwashed periodically. Surface wash and air scour systems can also be used as part of the backwash cycle. Small systems usually dispose of spent carbon or regenerate it offsite. Systems above about 3 to 5 MGD (million gallons per day) usually provide on-site regeneration of carbon for economic reasons.

Grinding: It is a unit operation for reducing the particle size of objects or debris in the influent wastewater, also termed shredding or comminuting. These devices may be installed with a screen directly in the wastewater flow or separately out of the wastewater flow, with the shredded particles returned to the flow downstream of the screen. Only those shredding and grinding devices that are installed directly in the influent channel are termed comminuting devices.

Grit chamber: It is a grit removal device that is designed to allow the settling out of this material. Grit removal is an important process for several reasons: (1) to prevent cementing effects at the bottom of sludge digesters and primary clarification tanks; (2) to reduce the potential for clogging of pipes and sludge hoppers; (3) to protect moving mechanical equipment and pumps from unnecessary wear and abrasion; (4) to reduce accumulations of

materials in aeration tanks and sludge digesters which would result in a loss of usable volume; and (5) to reduce accumulations at the bases of mechanical screens. There are two types of grit chambers. The velocity controlled grit chambers limit the velocity in the rectangular channels to a maximum of 1 foot per second (fps). This velocity is low enough to allow the grit to settle but fast enough to maintain a majority of the organic material in suspension. The aerated grit chambers are normally sized on the basis of both detention time and volume of air. Typically, the detention time is in the range of 2 to 5 minutes and the air flow is in the range of 0.04 to 0.06 cu ft/ gallon of wastewater. The constant head type of system is normally designed using an overflow rate of 15,000 gallons per day per square foot and a 1 minute detention time at peak day flows.

Grit: It includes sand, gravel, cinders, coffee grounds, small stones, cigarette filter tips, and other large-sized unwanted materials in wastewater.

Independent physicochemical wastewater treatment system (IPCWWTS): An Independent Physicochemical Wastewater Treatment System (IPCWWTS) utilizes physicochemical (PC) process technology other than biological process technology to obtain combined primary and secondary treatment efficiency for removals of mainly biochemical oxidation demand (BOD), chemical oxidation demand (COD), total suspended solids (TSS), and phosphate. Typically, an IPCWWTS uses combinations of preliminary treatment (flow equalization, bar screening, comminution, grit chamber, ammonia stripping), chemical precipitation/coagulation, primary clarification (primary sedimentation clarification or primary flotation clarification), secondary clarification (secondary sedimentation clarification, or secondary flotation clarification, without biological treatment), tertiary wastewater treatment (filtration, and/or granular

activated carbon adsorption, ion exchange, PC oxidation, etc.), and disinfection. An innovative efficient primary flotation clarifier or a secondary flotation clarifier can be in any shape, circular or rectangular. In general this IPCWWTS requires much less land area than conventional biological secondary treatment systems. Phosphorus removal is inherent in this physicochemical process system.

Innovative biological wastewater treatment system: It normally includes (a) preliminary treatment units (i.e. screen, comminutor, grit chamber etc. for removal of sand, gravel, cinders, coffee grounds, small stones, cigarette filter tips, logs, cans, and other large-sized unwanted materials from raw wastewater), (b) primary flotation clarification for removing mainly total suspended solids from preliminary effluent, (c) secondary biological treatment units (such as activated sludge aeration or equivalent plus secondary flotation clarification) for removing dissolved organic/inorganic pollutants from primary effluent, and (d) tertiary treatment plant units (i.e. filtration, granular activated carbon adsorption, ion exchange, oxidation, nitrification, denitrification, and/or disinfection) for final polishing the secondary effluent in order to meet the effluent discharge standards.

Innovative physicochemical flotation wastewater treatment system: It includes (a) preliminary treatment units (i.e. screen, comminutor, grit chamber etc. for removal of sand, gravel, cinders, coffee grounds, small stones, cigarette filter tips, logs, cans, and other large-sized unwanted materials from raw wastewater), (b) primary flotation clarification for removing mainly total suspended solids from preliminary effluent, (c) secondary physicochemical treatment units (such as chemical precipitation/coagulation or equivalent plus secondary flotation clarification) for removing dissolved organic/inorganic pollutants

from primary effluent, and (d) tertiary treatment plant units (i.e. filtration, granular activated carbon adsorption, ion exchange, oxidation, nitrification, denitrification, and/or disinfection) for final polishing the secondary effluent in order to meet the effluent discharge standards. In the nitrification and denitrification steps, only tertiary flotation clarification will be used for solid-water separation.

Innovative physicochemical flotation-membrane wastewater treatment system: It includes (a) preliminary treatment units (i.e. screen, comminutor, grit chamber etc. for removal of sand, gravel, cinders, coffee grounds, small stones, cigarette filter tips, logs, cans, and other large-sized unwanted materials from raw wastewater), (b) primary flotation clarification for removing mainly total suspended solids from preliminary effluent, (c) secondary physicochemical treatment units (such as chemical precipitation/coagulation or equivalent plus secondary membrane clarification) for removing dissolved organic/inorganic pollutants from primary effluent, and (d) tertiary treatment plant units (i.e. filtration, granular activated carbon adsorption, ion exchange, oxidation, nitrification, denitrification, and/or disinfection) for final polishing the secondary effluent in order to meet the effluent discharge standards. In the nitrification and denitrification steps, only tertiary membrane clarification will be used for solid-water separation.

KAMET: It is the abbreviation of Krofta Advanced Municipal Effluent Treatment (KAMET), and is a circular package plant consisting of both Supracell and Sandfloat with Supracell on the top. KAMET can be used for either water treatment or wastewater treatment, but is advertised for wastewater treatment.

KAMWT: It is the abbreviation of Krofta Advanced Municipal Water Treatment (KAMWT), and is a circular package plant consisting of both Supracell and Sandfloat with Supracell on the top. KAMWT can be used for either water treatment or wastewater treatment, but is advertised for water treatment.

Nitrification: It is a biological process by which ammonia in wastewater is converted by *Nitrosomonas* and *Nitrobacter* to nitrite, then to nitrate in the presence of oxygen. The biological reactions involved in these conversions may take place during activated sludge treatment, or as a separate stage following removal of carbonaceous materials. Separate stage nitrification may be accomplished via suspended growth or attached growth unit processes. In either case, the nitrification step is preceded by a pretreatment sequence (i.e. preliminary treatment, primary treatment, and secondary treatment). Possible secondary treatment may be (a) biological secondary treatment, such as activated sludge, trickling filter, roughing filter, plus secondary clarification; or (b) physicochemical secondary treatment, such as chemical precipitation/coagulation plus secondary clarification. Low BOD (i.e. BOD_5/TKN ratio of less than 3) in the secondary effluent will assure a high concentration of nitrifiers (*Nitrosomonas* and *Nitrobacter*) in the nitrification biomass. The most common separate stage nitrification process is the plug flow suspended growth configuration with clarification. In this process, pretreatment effluent (i.e. nitrification influent) is pH adjusted as required, and aerated, in a plug flow mode. Because the carbonaceous demand is low, nitrifiers predominate. A clarifier (either sedimentation clarifier or flotation clarifier) follows aeration, and nitrification sludge is returned to the aeration tank. A possible modification is the use of pure oxygen in place of conventional aeration during the plug flow operation.

Preliminary effluent: The effluent from a preliminary treatment system (i.e. bar screen, comminutor, and grit chamber) by which most of large objects, such as rocks, logs and cans, grit, etc. in raw wastewater have been removed.

Preliminary treatment: It is the first treatment step, or preliminary step of either a conventional wastewater treatment system or an independent physicochemical treatment system. Preliminary treatment consists of bar screen, comminutor, and grit chamber mainly for removing large objects, such as rocks, logs and cans, grit, etc. from raw wastewater. Comminutor is an option depending on the nature and characteristics of raw wastewater.

Primary effluent: The effluent from a primary treatment system (either primary sedimentation clarification or primary flotation clarification) by which most of total suspended solids in wastewater have been removed.

Primary flotation clarification: It is a unit process or unit operation for removal of mainly total suspended solids (settleable solids and floatable solids) from screened wastewater using a primary flotation clarifier.

Primary flotation clarifier: A dissolved air flotation (DAF) reactor is used to float total suspended solids (TSS) from screened wastewater by decreasing their apparent density. DAF consists of saturating a portion or all of the wastewater feed, or a portion of recycled effluent with air at a pressure of 25 to 90 lb/square inch (gage). The pressurized wastewater is held at this pressure for 0.5 to 3 minutes in a retention tank and then released to atmospheric pressure to the flotation chamber. The sudden reduction in pressure results in

the release of microscopic air bubbles which attach themselves to TSS and oil particles in the wastewater in the flotation chamber. This results in agglomeration which, due to the entrained air, have greatly increased vertical rise rates of about 0.5 to 2 ft/min. The floated materials rise to the surface to form a froth layer (float). Specially designed scrapers or other skimming devices continuously remove the froth (or float) . The retention time in the flotation chambers is usually about 20-60 minutes for rectangular flotation clarifier, and about 3-15 minutes for circular flotation clarifier using zero-horizontal velocity design. The effectiveness of dissolved air flotation depends upon the attachment of bubbles to the suspended solids and/or oil which are to be removed from the waste stream. The attraction between the air bubble and particle is primarily a result of the particle surface charge and bubble-size distribution. The more uniform the distribution of water and micro-bubbles, the shallower the flotation clarifier can be. Generally, the depth of effective flotation units is between 3 and 9 feet.

Primary sedimentation clarification: It is a unit process or unit operation for removal of mainly total suspended solids (settleable solids and floatable solids) from screened wastewater using a primary sedimentation clarifier.

Primary sedimentation clarifier: It is a tank used to settle mainly total suspended solids (TSS) from screened raw wastewater by gravity. The main objectives of a primary sedimentation clarifier are removal of settleable solids by settling them to the clarifier bottom, and removal of floatable solids by skimming them from the clarifier's wastewater surface. In a rectangular sedimentation clarifier, the wastewater flows from one end to the other and the settled sludge is moved to a hopper at on end, either by scrapers called "flights" set on parallel chains, or by

a single bottom scraper set on a traveling bridge. Floating materials,, such as grease and oil, are collected by a surface skimmer and then removed from the rectangular sedimentation clarifier. In a circular sedimentation clarifier, the wastewater usually enters in the middle and flows toward the outside edge. Settled sludge is pushed to the hopper that is in the middle of the circular clarifier's tank bottom. Floating material is removed by a surface skimmer connected to the sludge collector.

Primary treatment: It is an important wastewater treatment step (either primary sedimentation clarification or primary flotation clarification mainly for removing total suspended solids from preliminary treatment effluent) after the preliminary treatment (i.e. bar screen, comminutor, and grit chamber mainly for removing large objects from raw wastewater), but before secondary treatment (either biological treatment or physicochemical treatment mainly for removing dissolved organic/inorganic pollutants from primary effluent).

Rapid mixing: A water treatment unit process of quickly mixing a chemical solution uniformly through the process water.

Sandfloat: It is combined circular dissolved air flotation and filtration (DAFF) clarifier designed by the Lenox Institute of Water Technology (LIWT) and manufactured by Krofta Engineering Corporation (KEC).

Secondary effluent: The effluent from a secondary treatment step which may be either (a) biological treatment, such as activated sludge aeration or equivalent plus secondary clarification; or (b) physicochemical treatment, such as chemical precipitation/coagulation

plus secondary clarification. Secondary treatment step removes most of dissolved organic/inorganic pollutants from primary effluent. Since secondary clarification (either secondary sedimentation clarification or secondary flotation clarification) is the final step of secondary treatment, the secondary effluent is also the secondary clarification effluent.

Secondary flotation clarification: It is a unit process or unit operation for removal of the bio-oxidation process generated activated sludge, and/or the chemical precipitation/coagulation process generated chemical sludge using a secondary flotation clarifier.

Secondary flotation clarifier: A dissolved air flotation (DAF) reactor is used to float biological sludge (activated sludge) from biologically oxidized wastewater (such as aeration tank effluent) and/or and/or chemical sludge from chemically coagulated /flocculated wastewater (such as flocculator effluent) by decreasing the sludge's apparent density. DAF consists of saturating a portion or all of the wastewater feed, or a portion of recycled effluent with air at a pressure of 25 to 90 lb/square inch (gage). The pressurized wastewater is held at this pressure for 0.5 to 3 minutes in a retention tank and then released to atmospheric pressure to the flotation chamber. The sudden reduction in pressure results in the release of microscopic air bubbles which attach themselves to suspended solids and other particles in the wastewater in the flotation chamber. This results in agglomeration which, due to the entrained air, have greatly increased vertical rise rates of about 0.5 to 2 ft/min. The floated materials rise to the surface to form a froth layer (float). Specially designed scrapers or other skimming devices continuously remove the froth (or float) . The retention time in the flotation chambers is usually about 20-60 minutes for rectangular flotation clarifier, and about 3-15 minutes for circular flotation clarifier using zero-horizontal velocity design. The

effectiveness of dissolved air flotation depends upon the attachment of bubbles to the suspended solids which are to be removed from the waste stream. The attraction between the air bubble and particle is primarily a result of the particle surface charge and bubble-size distribution. The more uniform the distribution of water and micro-bubbles, the shallower the flotation clarifier can be. Generally, the depth of effective flotation units is between 3 and 9 feet.

Secondary membrane clarification: A water-solid separation/clarification process uses membrane device instead of conventional sedimentation clarification in the secondary wastewater treatment step.

Secondary sedimentation clarification: It is a unit process or unit operation for removal of the bio-oxidation process generated activated sludge, and/or the chemical precipitation/coagulation process generated chemical sludge using a secondary sedimentation clarifier.

Secondary sedimentation clarifier: It is a tank used to settle the chemical precipitation/coagulation process generated chemical sludge, and/or the bio-oxidation process generated activated sludge for removing dissolved organic/inorganic substances from wastewater. The main objectives of a secondary sedimentation clarifier are removal of settleable chemical and/or biological sludge solids by settling them to the clarifier bottom. In a rectangular sedimentation clarifier, the wastewater flows from one end to the other and the settled sludge is moved to a hopper at one end, either by scrapers called "flights" set on parallel chains, or by a single bottom scraper set on a traveling bridge. In a circular

sedimentation clarifier, the wastewater usually enters in the middle and flows toward the outside edge. Settled sludge is pushed to the hopper that is in the middle of the circular clarifier's tank bottom.

Secondary treatment: It is a wastewater treatment step after primary treatment (either primary sedimentation clarification or primary flotation clarification). Secondary treatment may be either biological treatment (such as activated sludge aeration plus secondary clarification) or physicochemical treatment (such as chemical precipitation/coagulation plus secondary clarification) mainly for removing dissolved organic/inorganic pollutants from primary effluent.

Shredding: It is a unit operation for reducing the particle size of objects or debris in the influent wastewater, also termed grinding or comminuting. These devices may be installed with a screen directly in the wastewater flow or separately out of the wastewater flow, with the shredded particles returned to the flow downstream of the screen. Only those shredding and grinding devices that are installed directly in the influent channel are termed comminuting devices.

Supracell: It is a circular dissolved air flotation (DAF) clarifier designed by the Lenox Institute of Water Technology (LIWT) and manufactured by Krofta Engineering Corporation (KEC).

Tertiary membrane clarification: A water-solid separation/clarification process uses membrane device instead of conventional sedimentation clarification in the tertiary wastewater treatment step, such as nitrification and denitrification.

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APPENDIX A. EDITORS PAGE

"ENVIRONMENTAL SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM)" Series Editors Lawrence K. Wang, Mu-Hao Sung Wang and Nazih K. Shammass

1. Dr. Lawrence K. Wang (王抗曝)

Dr. Lawrence K. Wang has over 30+ years of professional experience in facility design, environmental sustainability, natural resources, STEM/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 Acting President/Director/Dean/Professor 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 and National Cheng Kung University, Taiwan, ROC. 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 high school 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), Co-editor of the Environmental Science, Technology, Engineering and Mathematics series (Lenox Institute Press), and Co-editor of the Evolutionary Progress in Science, Technology, Engineering, Arts, and Mathematics series (Lenox Institute Press). Dr. Wang is active in professional activities of AWWA, WEF, NEWWA, NEWEA, AIChE, ACS, OCEESA, etc. He is a licensed/certified Professional Engineer, Water Operator, Water Quality Laboratory Director, Hazardous Waste Manager, and HAZWOPER Trainer..

2. Dr. Mu-Hao Sung (宋慕浩)

Dr. Mu-Hao Sung Wang has been an environmental engineer, an editor, and a professor serving private firms, New York State government, and universities in the United States and Taiwan, ROC, for over 27 years. She is a licensed professional engineer, a diplomate of American Academy of Environmental Engineers, and ex-Professor of the Lenox Institute of Water Technology, MA, USA, Stevens Institute of Technology, Hoboken, NJ, USA, and National Cheng Kung University, Taiwan, ROC. Her research and publications have been in the areas of water quality control, mathematical modeling, environmental sustainability, waste management, NPDES (National Pollutant Discharge Elimination System) permit management, flotation technology, STEM/STEAM education, and analytical methods. Dr. Wang is the author of over 70 publications and an inventor of 14 US and foreign patents. She earned her BSCE degree from National Cheng Kung University, Taiwan, ROC, her MSCE degree from the University of Rhode Island, USA, and her PhD degree from Rutgers University, New Jersey, USA. She is the co-series editor of the Handbook of Environmental Engineering series (Springer/Humana Press) and Handbook of Industrial and Hazardous Wastes Treatment series (CRC Press/Taylor and Francis), and the Environmental Science, Technology, Engineering and Mathematics (STEM) series (Lenox Institute Press). She is a member of American Water Works Association, New England Water Works Association, Water Environment Federation, New England Water Environment Association, and Overseas Chinese Environmental Engineers and Scientists Association.

3. Dr. Nazih K. Shammās (夏馬斯)

Dr. Nazih K. Shamas is an environmental consultant and professor for over 47 years. He is an ex-Dean/Director/Professor of the Lenox Institute of Water Technology, Massachusetts, USA, and an Engineering Advisor to Krofta Engineering Corporation, Massachusetts, USA. Dr. Shamas is the author of over 270 academic publications and 16 books in the field of environmental engineering. He has experience in environmental planning, curriculum development, university teaching, scholarly research, and STEM/STEAM education, and has professional expertise in water quality control, wastewater reclamation and reuse, physicochemical processes, biological processes, water treatment plant design, wastewater treatment plant design, and biosolids management. He earned his BE degree from the American University of Beirut, Lebanon, his MS degree from the University of North Carolina at Chapel Hill, and his PhD degree from the University of Michigan, USA. Currently he is the coeditor of many books in the Handbook of Environmental Engineering series (Springer), the Advances in Industrial and Hazardous Wastes Treatment series, (CRC Press, Taylor & Francis), the Handbook of Environment and Waste Management series (World Scientific), and the Environmental Science, Technology, Engineering and Mathematics series (Lenox Institute Press). He is also the coauthor of the Water and Wastewater Engineering textbook series (John Wiley & Sons).

APPKENDIX B. E-BOOK SERIES INTRODUCTION

"ENVIRONMENTAL SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM)" Edited by: Dr. Lawrence K. Wang, Dr. Mu-Hao Sung Wang and Dr. Nazih K. Shammass, and published by the Lenox Institute Press, Newtonville, NY 12128-0405, USA.

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. 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. Lenox Institute Press is publishing an eBook series, entitled, "Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics (STEAM)" which is edited by Dr. Lawrence K. Wang and Dr. Hung-ping Tsao. In the STEAM ebook series, entire academic areas of science, technology, engineering, arts and mathematics are included.

In this environmental STEM ebook series, only the narrow academic areas of environmental science, environmental technology, environmental engineering and environmental mathematics will be covered. Dr. Lawrence K. Wang, Dr. Mu-Hao Sung Wang and Dr. Nazih K. Shammass, who are three environmental STEM professors of the Lenox Institute of Water Technology

(LIWT), are the coeditors of this special environmental STEM ebook series. For over two decades, LIWT had offered innovative humanitarian STEM education to young STEM students (all with at least BA/BS/BE degrees) around the world, totally free of charge. All Lenox students learned innovative knowledge from their Lenox professors. Most of the students successfully completed the requirements of advanced graduate education, and received their Master of Engineering degree from the LIWT, in turn, they distributed their learned innovative knowledge to the entire world with emphasis on under-developed and developing countries.. Due to untimely passing of the LIWT President, Dr. Milos Krofta, the funding of the Institute's humanitarian STEM education was stopped, Lenox professors have no financial resources to continuously offer the humanitarian STEM education to international students, but have managed to continuously publish academic STEM reference books and textbooks for the benefit of the humanity. These books include, but are not limited to: (a) the Handbook of Environmental Engineering series (now up to 18 books; Springer), (b) the Advances in Industrial and Hazardous Wastes Treatment series (3 handbooks, 9 small books, 1 foreign language book; CRC Press/Taylor & Francis); (c) the Handbook of Environment and Waste Management (3 books, World Scientific), (d) Water and Wastewater Engineering series (2 textbooks and 1 foreign language book; Wiley); (e) Evolutionary Progress in Science, Technology, Engineering, Arts and Mathematics (STEAM) ebooks series (Lenox Institute Press) ; and (f) Environmental Science, Technology, Engineering and Mathematics (STEM) ebooks series (Lenox Institute Press).

This particular publication is in the "Environmental Science, Technology, Engineering and Mathematics (STEM)" ebooks series. It is published in memory of Dr./Prof. Milos Krofta, Dr./Prof. Donald B. Aulenbach, and Dr./Prof. William A. Selke who had worked closely with Professors Lawrence K. Wang, Mu-Hao Sung Wang, Nazih K. Shammass, and Daniel Guss since

1981 for developing a humanitarian engineering program at the Lenox Institute of Water Technology (LIWT; formerly Lenox Institute for Research), teaching/researching at the Institute for several decades, and publishing many research papers and books together for academic contribution to the humanity. We salute and will forever remember our ex-colleagues.

The faculty, research staff and graduate students of the Lenox Institute of Water Technology have developed many innovative STEM projects which have created many revolutionary waves for environmental protection, resources conservation, water purification, wastewater treatment, analytical methods improvement, air pollution control, infrastructure sustainability, resources recovery, mathematical model improvements, flotation technology improvement, etc. The LIWT's most famous first wave of evolutionary development is application of dissolved air flotation (DAF) technology for improving drinking water treatment. Today DAF has been adopted by the world's largest city, New York, for its successful and cost-effective potable water treatment. This book chapter introduces the LIWT's second wave of evolutionary development in wastewater flotation applications: primary flotation clarification, secondary flotation clarification, total physicochemical DAF wastewater treatment, multi-stage municipal wastewater treatment, tertiary wastewater treatment, combined municipal and industrial wastewater, DAF process equipment development, DAF process system development, etc. Specific coverage includes: conceptual development of independent physicochemical wastewater treatment systems (IPCWWTS), process glossary, commercial development process equipment, laboratory process evaluation, chemical optimization, pilot plant installation, BOD removal, TSS removal, nutrient removal, and pilot plant system operation and demonstration using actual screened raw wastewater from Lee Wastewater Treatment Plant, Lee, Massachusetts, USA.

The IPCWWTS developed by the authors can be in any shape (circular or rectangular), can use any manufacturers' products (Supracell, Sandfloat, KAMET, AquaDAF, clair-DAF, etc.), and is for the entire world.