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SUSTAINABLE WATER AND WASTEWATER TREATMENT SYSTEMS CONSISTING OF MAGNESIUM COAGULATION-PRECIPITATION, DISSOLVED AIR FLOTATION, RECARBONATION AND FILTRATION

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ABSTRACT

Historical developments, theory and principles of innovative sustainable water and wastewater systems consisting of magnesium coagulation-precipitation, dissolved air flotation (DAF) clarification, filtration and disinfection are introduced with an emphasis on five technology advancements: (a) the use of magnesium carbonate or magnesium chloride for replacing conventional aluminum sulfate coagulant, (b) the use of DAF for replacing conventional sedimentation clarification, (c) the use of magnesium coagulation-precipitation (either magnesium carbonate or magnesium chloride), DAF clarification, recarbonation (if needed), and filtration for water treatment, (d) the use of magnesium carbonate coagulation-precipitation, clarification, recarbonation (if needed), and filtration for wastewater treatment, (e) production and marketing of innovative combined magnesium and calcium sludge for replacing conventional lime as the soil conditioner or for nutrient removal in a biological wastewater treatment plant.

This is one of the authors' professional memoirs aiming at continuous technology transfer and a call for further research. A technical feasibility study of the innovative magnesium carbonate coagulation-precipitation system consisting of mixing, flocculation, dissolved air flotation clarification, and filtration was conducted using a continuous pilot plant. Specifically a raw water having 10 units of color, 13 NTU of turbidity, and 401 mg/L of calcium hardness as $CaCO_3$, was successfully treated by a continuous pilot plant consisting of a static hydraulic flocculation, a dissolved air flotation clarifier (Krofta Supracell DAF SPC-3) , a recarbonation facility and three sand filters. When the raw water was dosed with 42.3 mg/L of magnesium carbonate as coagulant, the pilot plant treatment single-stage efficiency in terms of percent removal became: color, 100 percent; turbidity, 98 percent; and total hardness, 56 percent. A small of amount of soda ash or a two stage treatment may improve the plant effluent further is required. The pilot plant operational conditions were: flocculation detention time = 5.63 minutes; dissolved air flotation diameter = 3 ft and detention time = 3.0 minutes; sand depth = 11 inches of quartz sand; sand filtration rate = 2.5 gpm/sf; continuous influent/effluent water flow rates = 12 gpm; continuous recycle water flow rate = 3 gpm; and continuous air flow rate = 1.5 SCFH at 90 psig. The readers are encouraged to conduct an innovative two-stage water treatment for further improvement.

Examples and case histories of the sustainable process system include: (a) magnesium coagulant for water purification with total chemical sludge recycle; (b) independent physicochemical wastewater treatment using magnesium coagulant and DAF-filtration for treating wastewaters containing toxic substances; (c) simultaneous removal of ammonium ions and phosphate ions from wastewater by magnesium ions for generating useful waste sludge (Struvite) which can be

reused as a fertilizer; (d) chemical sludge reuse elsewhere for toxic chromium reduction; (e) waste chemical sludge reuse for biological nitrification neutralization at chicken and meat processing plants; (f) waste chemical sludge reuse for anaerobic digestion improvement at bakeries; (g) pretreatment of per- and polyfluoroalkyl substance (PFAS) contaminated water prior to granular activated carbon, ion exchange, or membrane filtration; and (h) production and marketing of combined magnesium and calcium sludge as a soil conditioner. The authors' poem (FATE IN THIS LIFE 今世缘) is presented in this publication.

KEYWORDS

Call for Further Research, Memoir, Technology Transfer, Magnesium Carbonate, Recyclable Coagulant, Sedimentation Clarification, Dissolved Air Flotation Clarification, Filtration, Historical Development, Chemical Reactions, Pilot Plant Demonstration, Water Purifications, Hardness Removal, Color Removal, Turbidity Removal, Per- and Polyfluoroalkyl Substance, Independent Physicochemical Wastewater Treatment System, Heavy Metal Reduction, Chromium, Neutralization, Nitrification, Anaerobic Digestion, Poultry Processing, Meat Processing, Bakery, Soil Conditioner, Fertilizer, Sludge Conditioner, Wastewater Treatment, Toxicity Characteristic Leaching Procedure, Lenox Institute of Water Technology, US Environmental Protection Agency, United Nations Industrial Development Organization, Supracell, Sandfloat, AquaDAF, Clari-DAF, Flomagh, Struvite, Magnesium Ammonium Phosphate, Poem, Fate In This Life. 今世缘

ACRONYM

AWWARF:	American Water Works Association Research Foundation
AWT:	Advanced waste treatment
BOD:	Biochemical oxygen demand
COD:	Chemical oxygen demand
CU:	Color units
DAF:	Dissolved air flotation
DGF:	Dissolved gas flotation
DT:	Detention time
GAC:	Granular activated
IPCWWTS:	Independent Physicochemical Wastewater Treatment System
ITRC:	Interstate Technology Regulatory Council
IX:	Ion exchange
KEC:	Krofta Engineering Corporation
LIWT:	Lenox Institute of Water Technology
MAP:	Magnesium ammonium phosphate or $MgNH_4PO_4$, or struvite
MBR:	Membrane bioreactors
MF:	Microfiltration
MGD:	Million gallon per day
MRCS:	Magnesium recycle coagulation system
NF:	Nanofiltration
NFWWPT:	Niagara Falls Wastewater Treatment Plant

O&G:	Oil and grease
PAC:	Powdered activated carbon
PC:	Physicochemical
PFAS:	Per- and polyfluoroalkyl substance
RBC:	Rotating biological contactors
RO:	Reverse osmosis
SBR:	Sequencing batch reactors
SCFH:	Standard cubic fool per hour
TCLP:	Toxicity Characteristic Leaching Procedure
TSS:	Total suspended solids
UF:	Ultrafiltration
UNIDO:	Unted Nations Industrial Development Organization
USEPA:	US Environmental Protection Agency
VOC:	Volatile organic compounds
WTP:	water treatment plants
WWT:	Wastewater treatment
WWTP:	Wastewater treatment plant

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POEM: FATE IN THIS LIFE

By: Lawrence K. Wang 王抗曝 and Mu-Hao Sung Wang宋慕浩

On: June 8, 2023

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SUSTAINABLE WATER AND WASTEWATER TREATMENT SYSTEMS CONSISTING OF MAGNESIUM COAGULATION-PRECIPITATION, DISSOLVED AIR FLOTATION, RECARBONATION AND FILTRATION

Lawrence K. Wang and Mu-Hao Sung Wang

1. INTRODUCTION

1.1 Environmental Problems and Possible Solutions

Over 1 million tons per year of dry chemical solids are produced from an estimated 3,600 water treatment plants (WTP) processing coagulation-precipitation for water purification throughout the USA. Of these, less than 5 percent of chemical solids receive kind of treatment before return to the receiving water. Filter backwash wastewater and the chemical waste sludge from WTP are today recognized as a significant water pollution problem.

Some possible solutions are development of some water and wastewater treatment process systems that may use recycled coagulant and cost-effective facility for water and wastewater treatments. The possible solutions recommended in this publication are: (a) a recycled coagulant -- magnesium carbonate (or magnesium chloride); and (b) an affordable technology --

dissolved air flotation (DAF). Both new chemical and new technology can be applied to potable water treatment, independent physicochemical wastewater treatment, and sludge treatment.

However, the new innovative process system consisting of magnesium coagulation-precipitation (using magnesium carbonate or magnesium chloride), flocculation, clarification (using sedimentation or dissolved air flotation), recarbonation, filtration (using gravity filtration, pressure filtration or membrane filtration), and disinfection (using chemical disinfectant, or physical-chemical disinfectant, such as UV-ozone) may eventually be accepted by the municipalities and industries to be the main stream processes only if the chemical sludge can be recycled for reuse. Therefore, exploration of various applications of chemical sludge (containing mainly magnesium hydroxide and some calcium carbonate) become extremely important. This publication explores some possibilities of chemical sludge recycle and reuse

1.2 Summary

Historical developments, theory and principles of innovative sustainable water and wastewater systems consisting of magnesium coagulation-precipitation, dissolved air flotation (DAF) clarification, filtration and disinfection are introduced with an emphasis on five technology advancements: (a) the use of magnesium carbonate or magnesium chloride for replacing conventional aluminum sulfate coagulant, (b) the use of DAF for replacing conventional sedimentation clarification, (c) the use of magnesium coagulation-precipitation (either magnesium carbonate or magnesium chloride), DAF clarification, recarbonation (if needed), and filtration for water treatment, (d) the use of magnesium carbonate coagulation-precipitation,

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Although a circular Krofta Supracell DAF Model SPC-3 dissolved air flotation clarifier (manufactured and distributed by Krofta Engineering Corporation and its associated companies around the world) was used for this demonstration research, it should be noted , however, that any manufacturers' flotation clarifiers in any shape, such as circular Sandfloat, rectangular AquaDAF, rectangular Clari-DAF, etc. [8] [18] should all work well if magnesium carbonate is used as a coagulant. A pilot plant demonstration of the intended process equipment is always recommended.

2. HISTORICAL DEVELOPMENTS AND OBJECTIVES

2.1 Magnesium Carbonate Coagulation-Precipitation System Consisting of Mixing, Flocculation , Sedimentation Clarification, Filtration and Disinfection.

The development of a new chemical coagulation precipitation water treatment system using magnesium carbonate began in 1957 at the Dayton, Ohio water treatment plant, where a hard, clear, high magnesium water was successfully treated by Dr. A. P. Black, using lime, carbon dioxide, and magnesium carbonate in a lime-softening process facility and the chemical sludges were recovered and recycled. [1]

In 1976 this new magnesium recycle coagulation system involving the use of magnesium carbonate as a recycled coagulant was officially verified and demonstrated in the USA under the grants from the US Environmental Protection Agency (USEPA); the Montgomery, Alabama, Water and Sanitary Sewer Board; the city of Melbourne, Florida; and the American Water Works Association Research Foundation (AWWARF). In addition, the City of Dayton, Ohio, USA, has provided additional support.

The new magnesium recycle coagulation system (MRCS) is a combination of lime-soft softening process and conventional coagulation process which can be applied to both soft water and hard water. This MRCS offers an alternative approach to chemical sludge handling as well as providing for reuse of the chemicals.

The major areas of significance offered by this new MRCS technology are: (a) Sludge discharges are reduced or completely eliminated and the sludge water, recovered as treated water, is an important saving for large plants; (b) The water is treated primarily by three chemicals (lime, carbon dioxide, and magnesium carbonate), which are recovered or recycled; (c) Significant cost savings are realized for most applications, particularly when sludge disposal costs are considered; (d) Floc characteristics allow significant increases in clarifier loading rates, increasing the clarifier capacity of many plants; (e) The treated water produced is of high chemical and bacteriological quality. Soft waters are made chemically stable, hard waters are softened, and the high pH of the process provides added assurance of disinfection. In addition, many heavy metals are removed in the water treatment process; (f) The process can be readily adapted to the current potable water filtration plant using chemical coagulation, and to conventional lime-soda softening plants.

2.2. Magnesium Carbonate Coagulation-Precipitation System Consisting of Mixing, Flocculation , Dissolved Air Flotation Clarification, Filtration and Disinfection.

On 29 March 1982, Dr. Milos Krofta of Krofta Engineering Corporation (KEC) and Dr. Lawrence K. Wang of the Lenox Institute of Water Technology (LIWT, formerly the Lenox Institute for Research) were invited by the USEPA to testify and comment on the Safe Drinking

Water Act before the Senate Committee on Environment and Public Works, Toxic Substances and Environmental Oversight (chaired by Slade Gorton). In the testimony of Krofta and Wang, alternative water treatment systems using flotation technology instead of conventional sedimentation technology for water quality improvement and cost-saving were introduced: (a) Innovation in the Water Treatment Field and Systems Appropriate and Affordable for Smaller Communities (M. Krofta and LK Wang); (b) Removal of trihalomethane precursor by flotation and filtration (LK Wang, D. Barris, P. Milne, BC Wu and J. Hollen; (c) water treatment by dissolved air flotation using magnesium carbonate as coagulant (LK Wang and BC Wu); and (d) treatment of groundwater by dissolved air flotation system (LK Wang and BD Wu) . [2]. The same Krofta and Wang testimony before the US Senate was also presented at the Annual Spring Meeting of the Berkshire District Board of Health Association, West Stockbridge, MA, USA. The use of magnesium carbonate (or magnesium chloride) and dissolved air flotation (DAF) for wastewater treatment in Berkshire County was also discussed [3]

Under financial sponsorship of KEC, LIWT developed the magnesium carbonate (or magnesium chloride) coagulation-precipitation system consisting of mixing, flocculation, dissolved air flotation (DAF), filtration and disinfection for treating all types of water or wastewater in 1982 [2-3]

2.3 Objectives: Environmental Technology Transfer from the USA to Developing as Well as Industrial Countries

In 1995 Dr. Lawrence K. Wang of LIWT was nominated by the US Department of the State and then appointed by United Nations Industrial Development Organization (UNIDO) to be a Senior Advisor responsible for transferring the affordable US environmental technologies to the developing countries.

The publication is an updated version of one of the UNIDO technical training papers for technology transfer [4], and is also one of the authors' professional memoirs. Technology development is very slow. Both magnesium carbonate coagulation-precipitation technology and flotation clarification technology were developed over 40 years in the USA. The first dissolved air flotation (DAF) potable water treatment was introduced to the Continents of America by the Lenox Institute of Water Technology (formerly Lenox Institute for Research) in 1982 [2-3], [9], but DAF is accepted by the licensed professional engineers as the mainstream water and wastewater treatment technology only in recent years [8]. It takes about thirty to forty years for an innovative new technology to be mature and accepted by all. The magnesium carbonate coagulation-precipitation technology was developed in the USA more than forty years ago [1], but is still not widely accepted by all. Accordingly the authors' memoir-style publication is also intended for both developing and industrial nations.

3. THEORY AND PRINCIPLES OF MAGNESIUM CARBONATE COAGULATION-PRECIPITATION SYSTEM CONSISTING OF MIXING, FLOCCULATION, CLARIFICATION, FILTRATION AND DISINFECTION.

The magnesium carbonate coagulation-precipitation system consisting of mixing, flocculation, sedimentation clarification, filtration and disinfection (see Section 2.1) has been fully developed [1] although the process system is still not widely used for water purification or water pollution control.

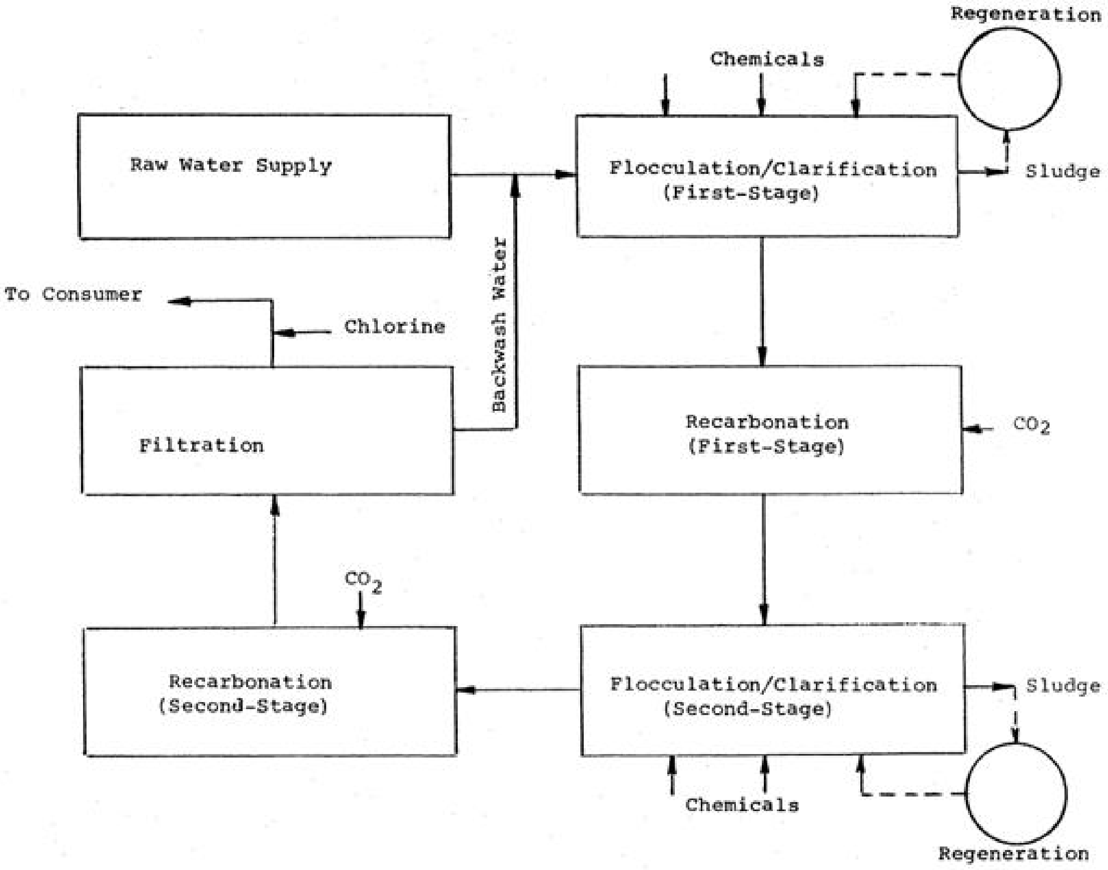
The magnesium carbonate coagulation-precipitation system consisting of mixing, flocculation , dissolved air flotation clarification, filtration and disinfection (see Section 2.2) was also developed long time ago [2-3], but is still in research stage. The section introduces the theories and principles of both systems (Section 2.1 & Section 2.2) because the chemistry of both systems are alike.

The innovative new water or wastewater treatment system (Section 2.2) is the combination of conventional lime-softening process and conventional coagulation-precipitation process [5] except that innovative chemical (magnesium carbonate) and innovative process equipment (dissolved air flotation) are used.

The most common lime-softening process system for water purification/softening is the lime-soda ash clarification process. Figure 1 shows a two-stage lime-soda ash clarification process system feasible for water purification and softening. Lime is applied in first-stage flocculation and clarification to separate both hardness-causing substances and other impurities. Then carbon dioxide is applied to neutralize the excess lime, and soda ash is added to reduce non-carbonate hardness. Suspended solids formed in these chemical reactions are subsequently removed by second-stage flocculation/clarification and subsequent sand filtration. Recarbonation immediately ahead of the sand filters usually is used to prevent scaling of the filter media.

In Figure 1, if sedimentation clarifiers are used for clarification, the system is considered to be conventional, and its construction cost will be high due to the high detention time (DT) of sedimentation clarifiers. If the bulky sedimentation clarifiers are replaced with compact dissolved air flotation (DAF) clarifiers in Figure 1, the process system is innovative and a significant cost saving is expected.

Figure 1. Schematic flow diagram of a two-stage water treatment/softening plant (Source: Lenox Institute of Water Technology)



This research investigates (a) the technical feasibility of using DAF clarification for water purification/softening; and (b) the efficiency of DAF clarification treatment using magnesium carbonate coagulant as well as flotation aid. The experimental results are presented in Section 6.

This section (Section 3) introduces the common process chemistry and process equipment for recycle of magnesium and calcium sludges for reuse because they are identical to the mature process system using sedimentation clarification (Section 2.1) and the research process system using DAF clarification (Section 2.2). The following are the proposed common process chemistry.

Some possible chemical reactions (Equations 1 to 7) are proposed below for the lime-soda softening process using magnesium carbonate and lime as the coagulant-precipitant:

$(Ca(HCO_3)_2 + Ca(OH)_2 = 2\ CaCO_3 + 2\ H_2O$ (Equation 1)

$Mg(HCO_3)_2 + Ca(OH)_2 = CaCO_3 + MgCO_3 + 2\ H_2O$ (Equation 2)

$MgCO_3 + Ca(OH)_2 = Mg(OH)_2 + CaCO_3$ (Equation 3)

$CaSO_4 + MgCO_3 = CaCO_3 + MgSO_4$ (Equation 4)

$MgSO_4 + Ca(OH)_2 = Mg(OH)_2 + CaSO_4$ (Equation 5)

$CaSO_4 + Na_2CO_3 = CaCO_3 + Na_2SO_4$ (Equation 6)

$CO_2 + Ca(OH)_2 = CaCO_3 + H_2O$ (Equation 7)

Lime-soda softening plants produce considerably more solids per million gallons of water treated than are produced in a typical chemical coagulation plant. It has been estimated that from 0.45 to 0.66 acre-foot per year of 50 percent solids sludge are produced for each 100 mg/L of hardness removed from 1 MGD (1 million gallon per day = 3.785 million liters per day) of water. The sludge produced in water softening plants is primarily calcium carbonate and magnesium hydroxide, which can be concentrated and dewatered more readily than conventional aluminum hydroxide sludge. The major advantage of the new process system is that the produced magnesium-calcium sludges can be recycled for reuse many times. The following chemical equations illustrate the (a) chemical reactions for magnesium sludge carbonation and regeneration (Equations 8 to 10); (b) chemical reaction for calcination of calcium sludge

(Equation 11) ; and (c) chemical reaction for product recovery as magnesium carbon and carbon dioxide gas (Equation 12). [5], [7]

$2\ CO_2 + Mg(OH)_2 = Mg\ (HCO_3)_2$ (Equation 8)

$CO_2 + Mg(OH)_2 = MgCO_3 + H_2O$ (Equation 9)

$CO_2 + H_2O + MgCO_3 = Mg(HCO_3)_2$ (Equation 10)

$CaCO_3 = CaO + CO_2$ (gas) (Equation 11)

$2\ H_2O + Mg(HCO_3)_2$ (35-45 ^{o}C with air) = $MgCO_3 * 3\ H_2O + CO_2$ (gas) (Equation 12)

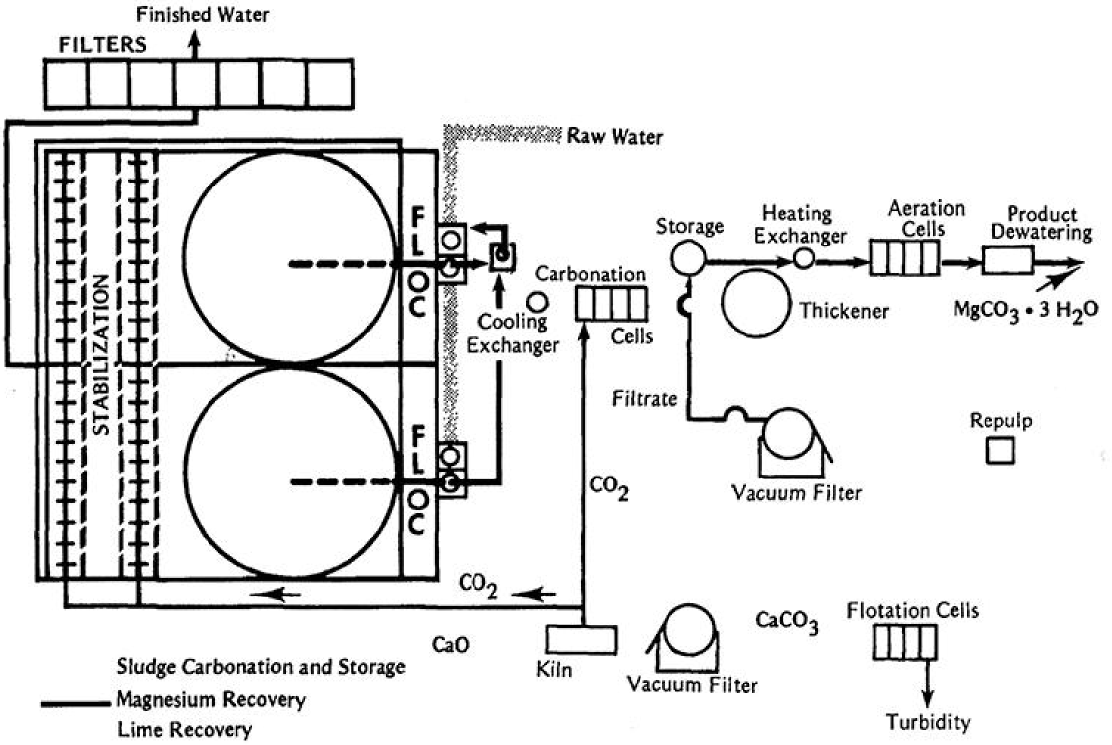
For all types of water, magnesium carbonate is precipitated as magnesium hydroxide, which then becomes the active coagulant. The resulting sludge is composed of calcium carbonate $CaCO_3$, magnesium hydroxide $Mg(OH)_2$ and, in the case of turbid waters, the turbidity removed from the raw water. Equations 8 , 9 and 10 describe how the chemical sludge is carbonated by injecting carbon dioxide CO_2 gas which selectively dissolves the $Mg(OH)_2$. The carbonated sludge is then filtered by filtration process (Figure 1) with the magnesium being recovered as soluble magnesium bicarbonate in the filtrate, which is recycled to the point of addition of chemicals to the raw water, reprecipitated as $Mg(OH)_2$ (Equations 3 and 4), and a new treatment cycle begin. The filter cake now contains $CaCO_3$ and the raw water turbidity.

In large plants, it is possible to reduce the waste solids even further by slurrying the filter cake and separating the raw water turbidity from the $CaCO_3$ by flotation. The purified $CaCO_3$ is dewatered and recalcined as high quality quicklime as shown in Equation 11. The stack gases from the recalcining operation then provide the CO_2 gas for carbonating the sludge for magnesium recovery and to recarbonate the water in the water treatment plant (WTP). When this latter lime recovery step is practiced, the waste solids are reduced to only those which constitute raw water turbidity. Figure 2 illustrates the flotation, recalcination, and recarbonation recovery process.

If magnesium is to be recovered, the magnesium bicarbonate solution, clarified by either clarification (dissolved air flotation clarification or sedimentation clarification), or filtration, passes to a heat exchange unit where it is warmed to 35° C - 45° C after which it is aerated by compressed air in a mechanically mixed basin. The $MgCO_3 \cdot 3H_2O$ (Equation 12) precipitation is complete in about 90 minutes and the resulting product is vacuum filtered, dried, and sold. Dawson [10] discussed the unit processes (including flotation process) used for recovery of chemical sludge for reuse within the water treatment plant.

As the readers can see that although the lime-soda softening plants using magnesium carbonate will produce considerably more solids per million gallons of water treated than are produced in a typical alum chemical coagulation plant, recycle and reuse of magnesium carbonate coagulant will make the new innovative process system more cost-effective.

Figure 2. Schematic flow diagram of a magnesium carbonate coagulation, clarification, recarbonation and filtration plant (with total chemical sludge recycle) for treatment of hard, high magnesium, clear or turbid water. (Source: USEPA)



4. INNOVATIVE MAGNESIUM CARBONATE COAGULANT VERSUS CONVENTIONAL ALUMINUM SULFATE COAGULANT

4.1 pH of Optimum Coagulation

1. Conventional aluminum sulfate coagulant: Usually in the range pH 5.2 through 5.7 for organic color, somewhat higher for turbidity.
2. Innovative magnesium carbonate coagulant: pH 11.3 when magnesium recovery is to be made. For magnesium recycle only pH 10.9 through 11.1, but may be pH 11.3.

4.2 Chemical Coagulation, Precipitation and Flocculation

1. Conventional aluminum sulfate coagulant: Hydrolysis product. Forms slowly, more so at low temperatures. Sensitive to high velocity gradients.
2. Innovative magnesium carbonate coagulant: Large, dense, the $Mg(OH)_2$ coagulant weighed down by the coprecipitated $CaCO_3$. Less sensitive to temperature changes.

4.3 Chemical Sludge Characteristics

1. Conventional aluminum sulfate coagulant: Gelatinous sludge normally 1 to 2 percent solids. Thickens to only about 6 percent solids.
2. Innovative magnesium carbonate coagulant: Primary sludge 3 to 5 percent solids. Carbonated sludge thickens to 40 to 50 percent solids.

4.4. Sludge Water

1. Conventional aluminum sulfate coagulant: Rarely, if ever, recovered.

2. Innovative magnesium carbonate coagulant: About 90 percent recovered, recycled and added to plant effluent as treated water. This represents a significant saving for large plants.

4.5 Finished Effluent

1. Conventional aluminum sulfate coagulant: Low total hardness. Low alkalinity, usually in range 10 to 25 ppm. Not possible to stabilize by pH adjustment. “Red water” problems common.

2. Innovative magnesium carbonate coagulant: Somewhat higher total hardness. Alkalinity 35 to 50 ppm. May be stabilized by pH adjustment to produce non-corrosive effluent. Total hardness depends upon noncarbonate hardness present.

4.6 Filtration

1. Conventional aluminum sulfate coagulant: Fine gelatinous floc may reduce length of filter runs.

2. Innovative magnesium carbonate coagulant: $CaCO_3$ turbidity of stablized water does not reduce filter runs. Filter runs at Montgomery consistently longer than with alum. Filtered turbidities lower.

4.7 Adaptability to Existing Plants

1. Conventional aluminum sulfate coagulant: Usually designed for the use of alum or a ferric salt.

2. Innovative magnesium carbonate coagulant: Readily adaptable without plant changes in most areas. When coagulation is at pH 11.3, two-stage carbonation used; stage 1 to pH 10.3; stage 2 to final pH of water.

4.8 Bacteriological Quality Of Treated Water

1. Conventional aluminum sulfate coagulant: Dependent upon quality of raw water and type of residual carried.
2. Innovative magnesium carbonate coagulant: High pH of coagulation provides complete disinfection and should eliminate pre-chlorination. [1]

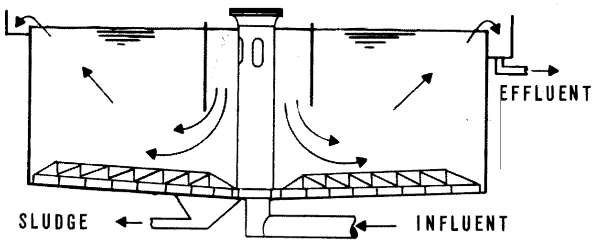
5. INNOVATIVE DISSOLVED AIR FLOTATION CLARIFICATION VERSUS CONVENTIONAL SEDIMENTATION CLARIFICATION

5.1 Conventional Sedimentation Clarification

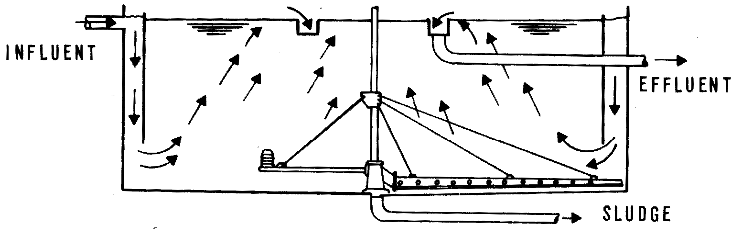
It is a tank used to settle the chemical precipitation/coagulation process generated chemical sludge, and/or the bio-oxidation process generated activated sludge for removing dissolved organic/inorganic substances from wastewater. The main objectives of a sedimentation clarifier are removal of settleable 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 other 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 influent 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. [8]

Figure 3 shows the typical clarifier configurations of three common types of circular sedimentation clarifiers. The top clarifier in Figure 3 is a circular center-feed clarifier with a scraper sludge removal system. The middle clarifier in Figure 3 is a circular rim-feed center take-off clarifier with a hydraulic suction sludge removal system. The bottom clarifier in Figure 3 is a circular rim-feed, rim take-off clarifier.

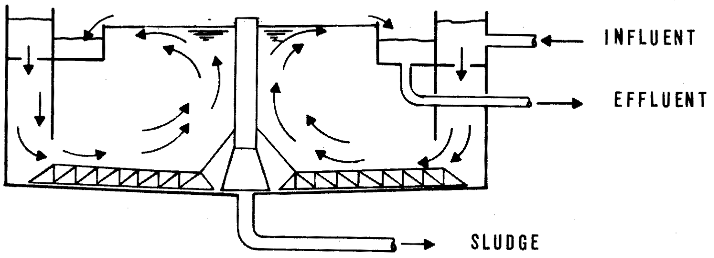
Figure 3. Three different types of typical circular clarifier configurations (Source: USEPA)



CIRCULAR CENTER-FEED CLARIFIER WITH A SCRAPER SLUDGE REMOVAL SYSTEM



CIRCULAR RIM-FEED, CENTER TAKE-OFF CLARIFIER WITH A HYDRAULIC SUCTION SLUDGE REMOVAL SYSTEM

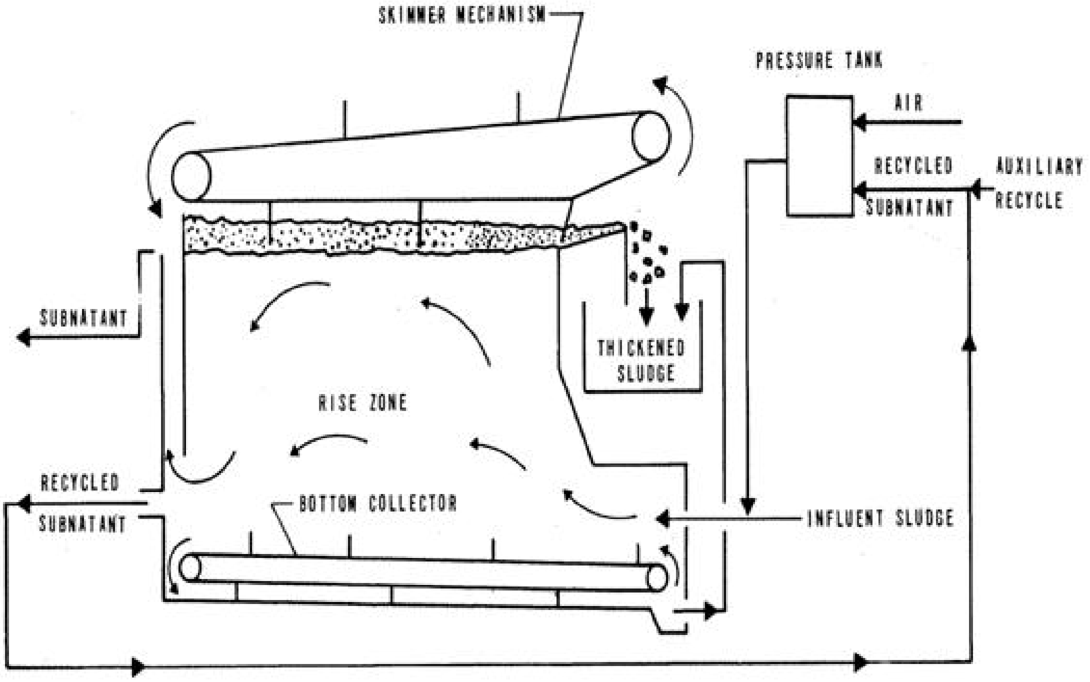


CIRCULAR RIM-FEED, RIM TAKE-OFF CLARIFIER

5.2 Innovative Dissolved Air Flotation Clarification

Dissolved gas flotation (DGF) is a process involving pressurization of gas at 25 to 95 psig for dissolving gas into water, and subsequent release of pressure (to one atm) under laminar flow hydraulic conditions for generating extremely fine gas bubbles (20-80 microns) which become attached to the impurities to be removed and rise to the water surface together. The impurities or pollutants to be removed are on the water surface are called float or scum which scooped off by sludge collection means. The clarified water is discharged from the flotation clarifier's bottom. The gas flow rate is about one percent of influent liquid flow rate. The attachment of gas bubbles to the impurities can be a result of physical entrapment, electrochemical attraction, surface adsorption, and/or gas stripping. The specific gravity of the bubble-impurity agglomerate is less than one, resulting in buoyancy or non-selective flotation (i.e. Save-All). DGF becomes dissolved air flotation (DAF) when air is used as a gas for flotation. Figure 4 is a simplified schematic of a rectangular DAF process unit although the authors used a circular DAF process unit, commercially known as Krofta Supracell DAF. [9] Either rectangular or circular DAF can be adopted for the newly developed magnesium carbonate coagulation-precipitation system consisting of mixing, flocculation , dissolved air flotation, filtration and disinfection.

Figure 4. Schematic of a typical rectangular dissolved air flotation clarifier (Source: USEPA)



5.3 Comparison Between Sedimentation Clarification and Dissolved Air Flotation Clarification.

Different manufacturer's DAF process equipment will have different special features and advantages. In this publication the authors only discuss some specific advantages of circular DAF that was operated continuously for water treatment in this demonstration research.

In comparison with conventional sedimentation clarifier, a modern Krofta clarifier will have the following advantages: [8-9]

5.3.1 Clarification Rate

1. Conventional sedimentation clarifier: It treats water at the rate of 0.2 to 1.0 gpm/ft^2 (10 to 20 $L/min/m^2$)

2. Innovative circular dissolved air flotation clarifier: It treats water at the rate of 6 gpm/ft^2 (240 $L/min/m^2$), meaning DAF clarifies approximately 10 times more water with the same surface area than sedimentation. Small DAF surface area will save heating energy in winter.

5.3.2 Clarifier Depth and Detention Time

1. Conventional sedimentation clarifier: Its operation requires a depth of at least 80 inches (2 m), and detention time (DT) of 60 to 100 minutes.

2. Innovative circular dissolved air flotation clarifier: It operates with only 16 inches of depth (0.4 m), with a DT of 2 to 3 minutes. The shallow depth makes the DAF operation and maintenance (O&M) much easier and save the overall O&M costs.. Shallow DAF depth means lighter weight and will allow a DAF clarifier to be installed on the top of another clarifier or even on the building roof for further space saving.

5.3.3 Clarifier Volume and Construction Costs

1. Conventional sedimentation clarifier: It requires a clarifier with a volume of 75 gallons to clarify a water flow of 1 gpm

2. Innovative circular dissolved air flotation clarifier: It requires only 1.67 gallons of volume to clarify a water flow of 1 gpm. Therefore the volume of a conventional sedimentation clarifier is 45 times larger than DAF clarifier volume. Since the equipment cost and construction cost are almost proportional to the volume of a process equipment, adoption of a DAF clarifier instead of a sedimentation clarifier will significantly save the equipment and construction costs.

5.3.4 Recarbonation Facility

1. Conventional sedimentation clarifier: A separate recarbonation facility is needed.

2. Innovative circular dissolved air flotation clarifier: Carbon dioxide gas can be introduced to the flotation clarifier together with the compressed air if necessary.

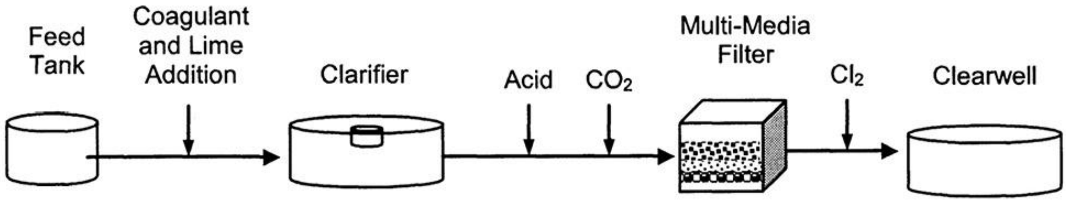
Although a comparison between conventional sedimentation clarification and innovative dissolved air flotation clarification has been made, it is important to note that both sedimentation and flotation work well for clarification. Traditionally the municipalities prefer to adopt sedimentation clarification while the industries prefer to adopt flotation clarification for water and wastewater treatment. Some sedimentation clarifiers with built-in inclined plates may also perform well for high-rate clarification and be in competition with flotation clarifiers.

6. DEMONSTRATION OF MAGNESIUM CARBONATE COAGULATION-PRECIPITATION SYSTEM CONSISTING OF MIXING, FLOCCULATION , DISSOLVED AIR FLOTATION, FILTRATION AND DISINFECTION

6.1 Continuous Pilot Plant and Operation

A continuous pilot plant documented in the U.S. Dept, of Commerce, National Technical Information Service (NTIS) Technical Report No. PB82-182064, was used in this investigation [10]. The pilot plant consisted of a rectangular static hydraulic flocculator (detention time = 5.63 minutes), a dissolved air flotation clarifier (Krofta Supracell Model SPC-3; diameter = 3 ft; detention time = 3 minutes) and three sand filters (quartz sand depth = 11 inches; filtration rate = 2.5 gpm/ft^2) [11]. Figure 5 shows the flow diagram of this innovative magnesium carbonate process system consisting of flocculation, coagulation-precipitation, dissolved air flotation clarification, recarbonation, filtration and disinfection.

Figure 5. Schematic flow diagram of an innovative water treatment process system consisting of chemical feeding, mixing/flocculation, dissolved air flotation clarification, carbon dioxide recarbonation, multi-media filtration, chlorine disinfection, and clearwell storage of finished water.



A recarbonation facility was also used when necessary. The plant was operated continuously at 12 gpm of influent/effluent flow rate, and 3 gpm of recycle flow rate. The dissolved gas (such as air and/or carbon dioxide) was supplied at 1 to 1.5 standard cubic fool per hour (SCFH) at 90 psig. Characteristics of synthetic raw water and chemical treatment are presented below:

6.2 Raw Influent Water Characteristics and Chemical Treatment

Characteristics of raw influent water and chemical treatment are presented below:

1. Influent water characteristics: Color = 10 units; turbidity = 13 NTU; calcium hardness = 401 mg/L as $CaCO_3$; and magnesium hardness = 0 mg/L as $CaCO_3$.
2. Chemical treatment: pH adjustment = adjusted to pH 11.3; magnesium carbonate dosage = 42.3 mg/L; and recarbonation with carbon dioxide = as needed.

6.3. Experimental Results

After the pilot plant reached its steady state condition, the pilot plant was continuously operated for an additional four hours, the water samples from each treatment unit were taken for analyses. The experimental results were recorded as follows:

6.3.1 Flocculator Influent Quality

The water quality results were: pH = 11.3; turbidity = 93 NTU; color = 10 CU; and hardness = 401 mg/L as $CaCO_3$

6.3.2 Flocculator Effluent Quality

The water quality results were: pH = 11.3; turbidity = 83 NTU; color = NA CU; and hardness = 480 mg/L as $CaCO_3$

6.3.3 Flotation Effluent Quality

The water quality results were: pH = 11.3; turbidity = 36 NTU; color = NA CU; and hardness = 400 mg/L as $CaCO_3$

6.3.4 Recarbonation Effluent Quality

The water quality results were: pH = 7.2; turbidity = NA NTU; color = NA CU; and hardness = NA mg/L as $CaCO_3$

6.3.5 Filter Effluent Quality

The water quality results were: pH = 7.2; turbidity = 0.3 NTU; color = 0 CU; and hardness = 176 mg/L as $CaCO_3$

6.4 Pilot Plant Performance Results Discussion

A continuous pilot plant of a magnesium carbonate coagulation-precipitation system consisting of mixing, flocculation , dissolved air flotation, and filtration was continuously operated for 4 hours and the water samples of flocculator influent, flocculator effluent, dissolved air flotation effluent, recarbonation effluent and filter effluent were taken for water quality analyses. The experimental data are presented in Section 6.3, Experimental Results. It can be seen that the performance of the innovative magnesium carbonate coagulation-precipitation system (consisting of mixing, flocculation , dissolved air flotation, and filtration) in terms of percent removal was excellent: color removal = 100 percent; turbidity removal = 98 percent; and total hardness removal = 56 percent.

The continuous pilot plant tested was of an one-stage treatment using magnesium carbonate coagulant plus carbon dioxide only. Soda ash was not added. The hardness removal efficiency of 56 percent (with a filter effluent turbidity of 176 mg/L as $CaCO_3$) was excellent if the filter effluent's residual total hardness of 176 mg/L as $CaCO_3$ is acceptable for domestic consumption.

In case the treated water is intended for industrial applications, the filter effluent's residual total hardness should be lower than 176 mg/L as $CaCO_3$, then the second-stage flotation/recarbonation/filtration treatment using soda ash Na_2CO_3 (see chemical Equations 4, 5 and 6) might be needed.

It is concluded that dissolved air flotation (DAF) clarifier is feasible for replacing conventional sedimentation clarifiers for water purification/softening, and magnesium carbonate is an excellent chemical aid for treatment of water with high calcium hardness. Due to the limitations of the available continuous flocculation-flotation-filtration pilot plant, only a single state treatment was conducted. The readers are encouraged to conduct an innovative two-stage water treatment for further improvement. It is expected that the efficiency for hardness removal can increase significantly if a two-stage flotation/recarbonation/filtration system is used, and soda ash is dosed.

Due to the unique feature of dissolved air flotation (DAF) clarifier, the recarbonation facility can be incorporated into the DAF system easily for cost saving. Bubbling carbon dioxide in a flotation clarifier can treat the water as a recarbonation unit. Alternately a separate carbonation flotation clarifier can be used as a coagulant regeneration unit for conversion of magnesium hydroxide to magnesium carbonate (see chemical reactions of Equations 9 and 10).

Although a circular Krofta Supracell Model SPC-3 dissolved air flotation clarifier (manufactured and distributed by Krofta Engineering Corporation and its associated companies around the world) was used for this demonstration research [11], it should be noted , however, that any manufacturers' flotation clarifiers in any shape, such as circular Sandfloat, rectangular AquaDAF, rectangular Clari-DAF, etc. [8] [18] should all work well if magnesium carbonate is used as a coagulant. A pilot plant demonstration of the intended process equipment is always recommended.

7. APPLICATIONS OF THE INNOVATIVE MAGNESIUM COAGULATION-PRECIPITATION, CLARIFICATION, FILTRATION AND DISINFECTION PROCESS SYSTEM.

The process applications introduced in this Section 7 are applicable to both the mature system using sedimentation clarification (see Section 2.1) and the research system using flotation clarification (see Section 2.2).

7.1 Water Purification Applications

Either magnesium carbonate or magnesium chloride can be used for the step of magnesium coagulation-precipitation of the new process system. In accordance with the US Environmental

Protection Agency (USEPA), there are three general applications of this innovative magnesium coagulation-precipitation, clarification, filtration and disinfection process system technology in water purification dependent upon the quantity and character of the raw water treated. Either sedimentation clarification, or dissolved air flotation clarification can be used. Three applications are recommended for water purification. [1] These applications are:

7.1.1 Soft, Turbid and/or Colored Waters

Magnesium is used as the coagulant, with the recycle of magnesium bicarbonate and sludge dewatering as an integral part of the process. The USEPA study [1] demonstrated this application to be successful.

7.1.2 Moderately Hard, Turbid and/or Colored Waters

USEPA has demonstrated that magnesium can be used as a recycled coagulant when treating the moderately hard, turbid, and/or colored waters, but lime recovery is also included. Carbon dioxide produced in lime recovery is used for softened water stabilization and carbonation of the sludge. [1]

7.1.3 Hard, High Magnesium, Clear or Turbid Waters

In this application for treating the hard, high magnesium, clear or turbid raw waters, both calcium and magnesium can be recovered, as shown in Figure 2. Part of the lime is recycled and the remainder is sold. In addition, the magnesium carbonate is sold. Figure 2 further illustrates the unit operations necessary for this application when treating a hard (125 to 300 mg/L), turbid, high magnesium (10 to 30 mg/L) water.

There are a number of major cities which fall into this category. Dayton, Ohio, USA, where a clear, high magnesium, hard water is softened, is a good illustration of an application in this category. Lime recovery is now practiced, with magnesium recovery soon to be added.

The primary emphasis of each of these applications is the elimination of sludge disposal problems by the recycle or recovery of the three water treatment chemicals used (lime, carbon dioxide, and magnesium).

7.2. Independent Physicochemical Wastewater Treatment Using Innovative Chemical and Process Equipment

Traditionally biological treatment processes, such as activated sludge, trickling filter, rotating biological contactors (RBC), sequencing batch reactors (SBR), and membrane bioreactors (MBR), flotation bioreactors, etc. are used for wastewater treatment not because independent physicochemical (PC) processes are not technically feasible for wastewater treatment (WWT), but because independent PC processes are not economically feasible for WWT.

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 oxygen demand (BOD), chemical oxygen 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. Both phosphors removal and nitrogen removal are inherent in this physicochemical (PC) process system as follows:

$$Mg^{2+} + NH_4^+ + PO_4^{3-} \text{ ---------->} \ MgNH_4PO_4 \qquad \text{(Equation 13)}$$

where $MgNH_4PO_4$ is magnesium ammonium phosphate (MAP) or struvite. MAP can be reused as an excellent fertilizer because it has high contents of N and P.

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 MGD = 3.7854×10^3 m^3/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 [12-14]. 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 advanced 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.

It is now concluded that when an industrial effluent, or a combined industrial and domestic wastewater contains toxic heavy metals and/or volatile organic compounds (VOC), an IPCWWTS will be the only choice, and the new IPCWWTS consisting of magnesium carbonate coagulation-precipitation, clarification and filtration will be very promising.

Besides, due to recent development of innovative low-cost flotation clarification technology (with only 3 minutes of detention time) and the chemical sludge recovery technology, IPCWWTS can now even compete with biological treatment processes for treating non-toxic wastewaters. The innovative chemical, magnesium carbonate, teaming up with the innovative low-cost flotation process and sludge recovery method will provide an excellent solution for water pollution control.

7.3. Improved Biological Wastewater Treatment Using Innovative Chemical and Process Equipment for Phosphate and Heavy Metal Removals

The inability of conventional biological treatment to effectively remove nutrients, i.e., nitrogen and phosphorus, and other organic and inorganic pollutants, paved the way for combined physicochemical-biological treatment. These combined processes have put the goal of wastewater reclamation and reuse well within the confines of present day environmental technology. The use of magnesium carbonate and lime as coagulants in advanced waste treatment (AWT) is due to its well established efficacy in removing phosphorus and heavy metals from raw wastewaters. Additional benefits derived from magnesium carbonate coagulation in the primary treatment stage include the increased removal of organic matter, which decreases the organic load on subsequent biological processes; the enhanced removal of heavy metals and viruses; and, as the pH value is raised above 9.5, precipitation of magnesium as magnesium hydroxide. For most wastewaters, magnesium is not precipitated until enough lime is added to raise the pH above 10.0. The chemical reaction (Equation 14, which is similar to Equation 3) involved is:

$$Mg^{2+} + Ca(OH)_2 \text{ -----------> } Mg(OH)_2 + Ca^{2+} \qquad \text{(Equation 14)}$$

Soluble magnesium levels are a function of pH and typical values follow: (a) Soluble Mg at pH 10 = 370 mg/L as $CaCO_3$; (a) Soluble Mg at pH 10 = 370 mg/L as $CaCO_3$; (b) Soluble Mg at pH 10.2 = 145 mg/L as $CaCO_3$; (c) Soluble Mg at pH 10.4 = 57 mg/L as $CaCO_3$; (d) Soluble Mg at pH 10.6 = 22 mg/L as $CaCO_3$;(e) Soluble Mg at pH 10.8 = 9 mg/L as $CaCO_3$; and (f) Soluble Mg at pH 11 = 4 mg/L as $CaCO_3$. A simplified Equation 15 shows how phosphate can be removed by calcium ions in wastewater treatment when using lime as a pH adjustment chemical:

$$3\ Ca(OH)_2 + 2\ PO_4^{3-} \text{ -----------> } Ca_3(PO_4)_2 + 6\ OH^- \qquad \text{(Equation 15)}$$

It is understood that there are many different kinds of soluble phosphorus compounds in various wastewaters. The solubility of magnesium phosphate $Ca_3(PO_4)_2$ in water is extremely low.

Of all unit processes available for waste treatment today, high pH chemical coagulation-precipitation (such as magnesium carbonate and lime) is one of the most cost-effective methods for removing heavy metals. Trace heavy metals are of significance in water pollution control because many are toxic to the biota in the receiving waters, either at their discharge concentration or through concentration in living cell tissue, although some other metals are micronutrients essential for biological growth. High pH chemical reactions removes trace heavy metals from wastewater through adsorption, flocculation, or by conversion of soluble metals to an insoluble precipitate. Most metals form insoluble hydroxides, oxides, carbonates, sulfates, or chlorides. Solubility data of heavy metals are available in the literature for the common trace heavy metals and their precipitates. Silver, cadmium, cobalt, copper, iron, mercury, manganese, nickel, lead and zinc ought to form relatively insoluble hydroxides or oxide precipitates when magnesium-lime treatment is practiced.

7.4 Waste Chemical Sludge Recycle and Reuse Within the Plant

The US Environmental Protection Agency (USEPA) has demonstrated [1] that the produced magnesium-calcium sludges (containing mainly magnesium hydroxide and calcium carbonate) from the high pH magnesium carbonate coagulation-precipitation process system can be recycled for reuse many times. Equations 8, 9 and 10 illustrate chemical reactions for magnesium sludge carbonation and regeneration. Equation 11 is the chemical reaction for calcination of calcium sludge for reuse. Equation 12 shows the chemical reaction for product recovery as magnesium carbon and carbon dioxide gas. Theoretically the chemical sludges produced from the innovative process systems can be regenerated for reuse many times within the treatment plant

7.5 Chemical Sludge Reuse Elsewhere for Toxic Chromium Reduction

The chemical sludges produced from the innovative high pH magnesium carbonate process system contain two main compounds: magnesium hydroxide and calcium carbonate. Both are very useful for removal of heavy metals, such as chromium.

Banerjee and Blumenschein [16] have conducted research to reduce chromium concentrations in an industrial plant's chromium-bearing sludge to less than the 5-mg/L Toxicity Characteristic Leaching Procedure (TCLP) regulatory limit (i.e. a nonhazardous level) using the magnesium hydroxide and calcium carbonate. The following are their experimental results.

7.5.1 Chromium Reduction Using Waste Magnesium Hydroxide in a Sludge Conditioning Process.

Banerjee and Blumenschein's experimental data [16] from magnesium hydroxide slurry dosages of 0, 15, 30, 40, 50, and 90 g/L of sludge indicate that as the magnesium hydroxide dosage increases, the chromium concentration in the Toxicity Characteristic Leaching Procedure (TCLP) extract decreases:

(a) chromium concentration in TCLP extract = 12 mg/L when magnesium hydroxide dosage = 0 g/L of toxic chemical sludge;

(b) chromium concentration in TCLP extract = 7 mg/L when magnesium hydroxide dosage = 15 g/L of toxic chemical sludge;

(c) chromium concentration in TCLP extract = 4.5 mg/L when magnesium hydroxide dosage = 30 g/L of toxic chemical sludge;

(d) chromium concentration in TCLP extract = 3 mg/L when magnesium hydroxide dosage = 40 g/L of toxic chemical sludge;

(e) chromium concentration in TCLP extract = 2.5 mg/L when magnesium hydroxide dosage = 50 g/L of toxic chemical sludge; and

(f) chromium concentration in TCLP extract = 2 mg/L when magnesium hydroxide dosage = 90 g/L of toxic chemical sludge.

Conclusion: chromium concentration in TCLP extract = 5 mg/L (which is the TCLP limit for chromium) when magnesium hydroxide dosage = 25 g/L of toxic chemical sludge. Initially, the effect of magnesium hydroxide dosage is significant, then the effect eventually reaches a plateau. An approximate magnesium hydroxide dosage of over 25 g/L reduced the chromium concentration in the TCLP extract from 12 mg/L to less than the TCLP toxicity limit of 5 mg/L.

7.5.2 Possible Chromium Reduction Using Waste Calcium Carbonate in a Sludge Conditioning

Process.

Banerjee and Blumenschein's experimental data [16] from calcium carbonate slurry dosages of 0, 15, 25, 50, and 90 g/L of sludge indicate that as the calcium carbonate dosage increases, the chromium concentration in the Toxicity Characteristic Leaching Procedure (TCLP) extract rapidly decreases:

(a) chromium concentration in TCLP extract = 12 mg/L when calcium carbonate dosage = 0 g/L of toxic chemical sludge;

(b) chromium concentration in TCLP extract = 3.7 mg/L when calcium carbonate dosage = 15 g/L of toxic chemical sludge;

(c) chromium concentration in TCLP extract = 1.5 mg/L when calcium carbonate dosage = 25 g/L of toxic chemical sludge;

(d) chromium concentration in TCLP extract = 0.7 mg/L when calcium carbonate dosage = 50 g/L of toxic chemical sludge;

(e) chromium concentration in TCLP extract = 0.6 mg/L when calcium carbonate dosage = 90 g/L of toxic chemical sludge; and

<u>Conclusion:</u> chromium concentration in TCLP extract = 5 mg/L (which is the TCLP limit for chromium) when calcium carbonate dosage = 10 g/L of toxic chemical sludge. The data reveal that increasing the calcium carbonate dosage decreases the chromium concentration in TCLP extract to 1 mg/L or less. The effect of reagent dosage becomes insignificant after that point. The data also reveal that, for this type of sample, a calcium carbonate dosage of about over 10 g/L is required to reduce the chromium concentration below the regulatory limit of 5 mg/L. However,

the reagent dosage depends on sludge characteristics, the concentration of chromium in the sludge, and the presence and concentrations of other metals, among other factors.

7.6 Possible Waste Chemical Sludge Reuse for Improvement of Biological Nitrification at Chicken Processing Plants .

A chicken processing plant in midwestern USA has a 2-MGD activated sludge nitrification wastewater treatment plant (WWTP) for removal of biochemical oxygen demand (BOD), oil and grease (O&G) and ammonia. [17] Caustic soda was historically used to control pH and maintain sufficient alkalinity in the system for nitrification. The wastewater is clarified prior to discharge directly to a receiving river. The WWTP [17] had been using 50% caustic soda for an alkalinity source and pH control for years. The plant was converted to magnesium hydroxide which provided the following benefits to their WWTP operation: (a) significantly reduced chemical cost for alkalinity and pH control; (b) improved pH control and stability throughout plant; (c) improved solids settling in secondary clarifier; and (d) improved chemical handling safety because magnesium hydroxide is a nonhazardous product as compared to hazardous caustic soda. The application of the commercially available magnesium hydroxide slurry for improving biological nitrification process by neutralization has been demonstrated.

The chemical sludge from the innovative magnesium coagulation-precipitation, dissolved air flotation clarification, recarbonation, and filtration contains mainly magnesium hydroxide and some calcium compounds. Apparently the magnesium-containing sludge can be recovered for reuse as an alkalinity supplement or neutralization agent in biological nitrification process. The following paragraphs introduce the chemical reactions involved if the chemical sludge (magnesium hydroxide + calcium carbonate) is recycled and reused in nitrification process.

Wang et al [18] [19] have presented the chemistry of nitrification-denitrification processes and the kinetics and stoichiometry of respiration in biological treatment processes. Initially ammoonia is oxidized and converted to nitrite by nitrosomonas, a nitrite-forming bacteria (Equation 16); then nitritrite is converted to nitrate by nitrobacgtor, a nitrate-forming bacteria (Equation 17). An overall energy reaction in nitrification is described by Equation 18. Some of the ammonia-nitrogen also can be autotrophically assimilated into microorganisms' cell tissue along with obtaining energy according to Equation 19, in which $C_5H_7NO_2$. is the empirical formula of microorganism cell. Combination of Equations 18 and 19 gives an overall energy-assimilation reaction in nitrification (Equation 20). The nitrification process destroys alkalinity and the pH of wastewater may fall to the levels that will inhibit nitrification, unless (a) excess alkalinity is present in the wastewater, or (b) alkalinity is added to maintain favorable pH levels, in accordance with Equations 21 and 22 due to the fact that the chemical sludges generated from the innovative process system of magnesium coagulation-precipitation, clarification, recarbonation and filtration contain both magnesium and calcium ions.

Either one mole of calcium bicarbonate (Equation 21) or one mole of magnesium bicarbonate (Equation 22) is needed to neutralize every two moles of nitric acid produced from the nitrification process. The optimum pH for the nitrification reaction is in the range of 8.4 to 8.6. Assuming calcium bicarbonate or magnesium bicarbonate is added for providing alkalinity and maintaining the optimum pH for bacterial synthesis, there are two "overall nitrification-neutralization reactions" (Equations 23 and 24). If microorganism synthesis (Equation 19) in the nitrification process unit is considered to be negligible, the combination of Equation 18 and Equations 21-22 yields two "simplified nitrification-neutralization reactions" (Equations 25 and 26). [18], [19]

First Step Nitrification:

$2\ NH_4^+ + 3\ O_2 + 2\ HCO_3^-$

$\text{----------->}\ 2\ CO_2 + 2\ NO_2^- + 2\ H^+ + 4\ H_2O$ (Equation 16)

Second Step Nitrification:

$2\ NO_2^- + O_2\ \text{------------->}\ 2\ NO_3^-$ (Equation 17)

Overall Energy Reaction in Nitrification:

$NH_4^+ + 2\ O_2 + HCO_3^-\ \text{----------->}\ CO_2 + NO_3^- + H^+ + 2\ H_2O$ (Equation 18)

Assimilation Reaction in Nitrification:

$NH_4^+ + 4\ CO_2 + HCO_3^- + H_2O\ \text{-------->}\ C_5H_7NO_2 + 5\ O_2$ (Equation 19)

Overall Energy Assimilation Reaction in Nitrification:

$22\ NH_4^+ + 37\ O_2 + 22\ HCO_3^-$

$\text{-------->}\ C_5H_7NO_2 + 21\ NO_3^- + 21\ H^+ + 41\ H_2O + 17\ CO_2$ (Equation 20)

Neutralization Reactions in Nitrification:

$2\ H^+ + 2\ NO_3^- + Ca(HCO_3)_2\ \text{--------->}\ Ca(NO_3)_2 + 2\ CO_2 + 2\ H_2O$ (Equation 21)

$2\ H^+ + 2\ NO_3^- + Mg(HCO_3)_2\ \text{-------->}\ Mg(NO_3)_2 + 2\ CO_2 + 2\ H_2O$ (Equation 22)

Overall Nitrification Neutralization Reactions:

$44\ NH_4^+ + 44\ HCO_3^- + 74\ O_2 + 21\ Ca(HCO_3)_2$

$\text{----------->}\ 2\ C_5H_7NO_2 + 21\ Ca(NO_3)_2 + 76\ CO_2 + 124\ H_2O$ (Equation 23)

$44\ NH_4^+ + 44\ HCO_3^- + 74\ O_2 + 21\ Mg(HCO_3)_2$

$\text{----------->}\ 2\ C_5H_7NO_2 + 21\ Mg(NO_3)_2 + 76\ CO_2 + 124\ H_2O$ (Equation 24)

Simplified Nitrification Neutralization Reactions:

$2\ NH_4^+ + 2\ HCO_3^- + 4\ O_2 + Ca(HCO_3)_2$

$\text{------------>}\ Ca(NO_3)_2 + 4\ CO_2 + 6\ H_2O$ (Equation 25)

$2\ NH_4^+ + 2\ HCO_3^- + 4\ O_2 + Mg(HCO_3)_2$

$\text{------------>}\ Mg(NO_3)_2 + 4\ CO_2 + 6\ H_2O$ (Equation 26)

7.7 Possible Waste Chemical Sludge Reuse for Improvement of Biological Nitrification at Meat Processing Plants .

Martin Marietta has a case history of magnesium hydroxide slurry application for improvement of biological nitrification [21]. A meat processing plant produces approximately 1.3 million gallons per day (MGD) of wastewater containing fatty tissue, oils, and animal scraps. [21]. The wastewater is treated by a complete-mix diffused air activated sludge (CMAS) process system. Biological single-stage nitrification is employed in this process system to convert the ammonia to nitrates. Based on the chemical reactions (Equations and) presented in Section 7.8, sufficient alkalinity must be provided and the pH must be maintained at 6.5 to 7.0 in order to support nitrification bacterial growth. After nitrification, the nitrifying bacteria is clarified in a sedimentation clarifier and the supernatant is disinfected and subsequently discharged.

Previously, this meat processing plant consumed 200 gallons a day (gpd) of 50% caustic soda (NaOH) in the CMAS system. The plant switched to magnesium hydroxide slurry, and reduced its alkali consumption to approximately 100 gpd of magnesium hydroxide slurry giving the plant an economic advantage. Magnesium hydroxide was able to maintain pH and satisfy the 90 mg/L alkalinity needed for the nitrification process.

7.8 Possible Waste Chemical Sludge Reuse for Improvement of Biological Anaerobic Digestion at Bakeries

Another Martin Marietta case history involves the application of magnesium hydroxide slurry for improvement of a bakery's biological anaerobic digestion [21]. This bakery produces 75,000 gpd of wastewater containing mainly organic flour, yeast, and other ingredients. The bakery has two anaerobic digesters at their wastewater treatment plant (WWTP).

In anaerobic digestion, microorganisms (such as bacteria) are used to break down complex colloidal and dissolved carbonaceous organic matter into simple methane, carbon dioxide, hydrogen sulfide, ammonia, and cellular materials. Anaerobic digestion is a two-stage process in which complex organic substances are first converted into simple organic acids or volatile acids (acetogenesis; Equation 27), and then converted to methane and carbon dioxide (methanogenesis; Equation 28) [21, 26].

Anaerobic Digestion Stage 1 Acetogenesis:

Complex Organics + Acid Forming Bacteria

------------> Simple Organic Acids + More Acid Forming Bacteria (Equation 27)

Anaerobic Digestion Stage 2 Methanogenesis:

Simple Organic Acids + Methane Forming Bacteria

--------> Methane (CH_4) + More Methane Bacteria + Other End Products (Equation 28)

Although the acetogenesis steps (Equation 27) can proceed over a broad range of environmental conditions such as pH and temperature, the acid-forming bacteria produces a significant amount of organic acids that lowers pH and destroys alkalinity. The methane-forming bacteria in the methanogenesis stage (Equation 28) are more sensitive to environmental conditions such as pH, temperature, and inhibitory compounds than are the acid-forming bacteria. So, the methane-forming bacteria are the key bacteria in biological anaerobic digestion.

The optimum pH for methane-forming bacterial growth (Equation 28) lies between 6.5 and 7.5. The lower the pH and the longer the pH is maintained at that level, the more likely a digester upset can occur. For proper process control, the pH of methanogenesis stage (Equation 28) should be maintained above 6.5 and that sufficient alkalinity should be present to ensure that the pH will not drop below this point.

As a result, an alkali (such as sodium hydroxide, calcium hydroxide, or magnesium hydroxide) can be introduced into the digester in Anaerobic Digestion Stage 2 Methanogenesis (Equation 28) to neutralize any excess organic acids (from Equation 27) that can not be consumed by the methane-forming bacteria.

The bakery [21] often overshot the optimum pH of 7.0 when utilizing caustic soda in their anaerobic digestion system and as a result, caused adverse effects on the methane-forming bacteria which led to septic conditions. Later the bakery switched to magnesium hydroxide slurry (FloMag®H) for safer handling and providing better pH control in their anaerobic digestion system with no cases of overshooting pH. In addition, less alkali was consumed since only 61 gallons of magnesium hydroxide slurry were required compared to 75 gallons of caustic soda. This magnesium hydroxide dosage imparted approximately 270 mg/L of magnesium into the digestion process which was well below the range to cause bacterial growth inhibition. To date, the bakery is still using magnesium hydroxide slurry in their anaerobic digester. Additional technical information can be found from the literature [24], [25].

In summary, the waste sludge generated from the innovative magnesium carbonate coagulation-precipitation process system contains magnesium hydroxide and calcium carbonate. It appears that the waste sludge can be reused as (a) a sludge conditioning chemical for chromium reduction (Section 7.5), (b) an alkalinity supplement (pH adjustment or neutralization) chemical in a poultry processing plant for biological nitrification improvement (Section 7.6), (c) an alkalinity supplement (pH adjustment or neutralization) chemical in a meat processing plant for biological nitrification improvement (Section 7.7); or (d) an alkalinity supplement (pH adjustment or neutralization) chemical in a bakery for biological digestion improvement (Section 7.8).

7.9 Potential Application in Pretreatment of PFAS Contaminated Water Prior to Granular Activated Carbon, Ion Exchange, or Membrane Filtration

This is a call for further research because no one has attempted to use the innovative magnesium carbonate coagulation-precipitation, clarification and filtration process system to remove per- and polyfluoroalkyl substances (PFAS) prior to granular activated carbon (GAC), ion exchange (IX), or membrane filtration (MF, UF, NF, and RO).

The stability and surfactant nature of PFAS make a few treatment technologies effective, such as dissolved air flotation (DAF), powdered activated carbon (PAC), GAC, IX, MF, UF, NF, or RO. DAF is one of the best process for surfactant removal because surfactant is a flotation aid itself [8], [9]. PAC can be added to a DAF reactor directly when needed. [4], [8].

The Interstate Technology Regulatory Council (ITRC) has reported [20] that adsorption is a physical mass transfer process that uses Van der Waals and/or other weak ionic forces to bind the entire PFAS molecule to the surface areas of the adsorptive media, while ion exchange is the exchange of ions of the same charge. Ion exchange targets and binds to the hydrophilic ionized or functional end of the molecule (for example, the sulfonate in PFOS) while releasing an equivalent amount of an innocuous ion (for example, chloride) into the treated water. Pretreatment steps such as coagulation-precipitation, clarification and filtration may be necessary to optimize the performance of PAC, GAC, or IX. [20]

The use of reverse osmosis (RO) and nanofiltration (NF) for effective removal of PFAS from water has also been reported by ITRC [20]. Again ITRC has suggested that the pretreatment steps of coagulation-precipitation (flocculation), clarification and filtration prior to RO and NF for PFAC removal will be necessary.

7.10. Production and Marketing of Chemical Sludge as Soil Conditioner or Fertilizer

7.10.1 Recycle of Chemical Sludge Containing Struvite as a Fertilizer

Section 7.2 introduces an independent physicochemical wastewater treatment system (IPCWWTS; using magnesium coagulant and dissolved air flotation) developed by the Lenox Institute of Water Technology (LIWT) for treatment of combined industrial-municipal wastewater or any industrial effluent containing toxic substances. In general this IPCWWTS requires much less land area than conventional biological secondary treatment systems. Both phosphors removal and nitrogen removal are inherent in this physicochemical (PC) process system as follows:

$$Mg^{2+} + NH_4^{+} + PO_4^{3-} \text{ ---------->} \ MgNH_4PO_4 \qquad \text{(Equation 13)}$$

The chemical sludge containing $MgNH_4PO_4$ (magnesium ammonium phosphate, MAP, or Struvite) can be collected, dried, processed an reused as an excellent fertilizer because it contains nitrogen N and phosphorus P.

7.10.2 Recycle of Chemical Sludge Containing Magnesium and Calcium as a Soil Conditioner

Although total recycle and reuse of chemical sludge containing magnesium and calcium within a water treatment plant has been investigated and proven to be both technically and economically feasible, but the water treatment plants (WTP) will always hesitate to do so within the WTS. Recycle and reuse the chemical sludge elsewhere for improvement of biological nitrification, anaerobic digestion, heavy metal precipitation, toxicity reduction, sludge conditioning, or soil conditioning, etc. perhaps will be more acceptable.

LIWT collected the chemical sludge (containing mainly magnesium hydroxide and some calcium carbonate) that was generated from the DAF-filtration pilot plant demonstration research, and dried the collected sludge on sludge drying sand beds. The dried chemical sludge was then successfully used as soil conditioner (instead of commercial lime) on the LIWT campus lawn. It has been discovered from the simple case study that the dried chemical sludge containing mainly magnesium hydroxide and some calcium carbonate provides the following advantages over the commercially available lime for lawn care applications: (a) it supplies more alkalinity per unit weight than commercial hydrated lime which means less dry magnesium hydroxide sludge is needed to treat the same unit area of lawn; (b) it buffers to a moderately alkaline pH of 9.0, even with an over-addition. With this buffering ability, the pH can be better controlled making burning lawn grass less likely to occur; (c) it is safer to handle than hydrated lime; (d) it provides soluble magnesium and calcium for the growth of grass; (e) Due to lower solubility than commercial hydrated lime, the dry magnesium-calcium hydroxide provides long lasting alkalinity. In summary, the chemical sludge containing magnesium hydroxide is a safe alternative lawn care chemical to use as a replacement for lime and may be readily available as both a dry powder and as 63 % solids slurry for marketing purpose.

The researchers are invited to conduct further research in the areas of recycling and reuse of chemical sludges generated from the newly developed innovative water and wastewater treatment process systems. It is important to note that there must be some ways to market and reuse the magnesium-containing sludge. Otherwise it would take a very long time for environmental engineers to adopt any innovative process systems.

8. CONCLUSIONS

The new innovative process system consisting of magnesium coagulation-precipitation (using magnesium carbonate or magnesium chloride), flocculation, clarification (using sedimentation or dissolved air flotation), recarbonation, filtration (using gravity filtration, pressure filtration or membrane filtration), and disinfection (using chemical disinfectant, or physical-chemical disinfectant, such as UV-ozone) may eventually be accepted by the municipalities and industries to be the main stream processes only if the chemical sludge can be recycled for reuse. Therefore, exploration of various applications of chemical sludge (containing mainly magnesium hydroxide and some calcium carbonate) become extremely important.

Section 7 (Applications of the Innovative Magnesium Coagulation-Precipitation, Clarification, Filtration and Disinfection Process System) introduces various potential process applications and chemical sludge applications.

Lenox Institute of Water Technology (LIWT) has developed (a) an innovative process system consisting of magnesium coagulation-precipitation, dissolved air flotation, recarbonation, filtration and disinfection for potable water treatment; (b) an independent physicochemical wastewater treatment using innovative chemicals (magnesium carbonate or magnesium chloride), clarification (sedimentation or dissolved air flotation), recarbonation, and filtration for treatment of combined industrial-municipal wastewater or industrial effluent containing toxic substances such as heavy metals and VOCs; and (c) a cost-effective method for processing the chemical sludge and reusing it as a soil conditioner or fertilizer. The researchers around the world are invited for further research for further process improvement and chemical sludge applications.

GLOSSARY

Alkali: It is a chemical , such as caustic soda, hydrate lime, or magnesium hydroxide, that can provide alkalinity to a water or wastewater.

Alkalinity: It is defined as the ability of a water or wastewater to neutralize acid or to absorb hydrogen ions. Alkalinity is the sum of all acid neutralizing bases in the water or wastewater.

Caustic soda: It is sodium hydroxide, or NaOH.

Hydrate lime: It is calcium hydroxide , or $Ca(OH)_2$

Magnesium hydroxide: (a) magnesium hydroxide, or $Mg(OH)_2$, is a non-hazardous white powder that is produced by the addition of calcium hydroxide in seawater. This raw material forms “milk of magnesia” in water, which is used as a laxative and an anti-acid agent. (b) magnesium hydroxide has several applications in water treatment systems, independent physicochemical wastewater treatment systems (IPCWWTS), biological nitrification neutralization, anaerobic digestion, sludge conditioning, and soil conditioning.

Softening: Water softening is the removal of bivalent calcium and magnesium ions (Ca^{+2}, Mg^{+2}) from water. These ions come from the dissolved compounds of calcium and magnesium. Their presence is known as hardness of water. Hard water is usually defined as water which contains a high concentration of calcium and magnesium ions.

Struvite: MAP, magnesium ammonium phosphate or $MgNH_4PO_4$

Toxicity Characteristic Leaching Procedure (TCLP): TCLP is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes. (See Appendix)

Treatment: The term “treatment” refers to the application of certain technologies to specific impacted media to achieve desired remedial action goals or objectives.

"今世缘"
"FATE IN THIS LIFE"

By: Lawrence K. Wang 王抗曝 and Mu-Hao Sung Wang宋慕浩

On: June 8, 2023

前世緣未盡,今世缘再續.

江浙本同鄉,台湾隔巷隣.

大碩博三校,各校都同窗.

隣座讀工程,携手建世界.

英崙结連理,新州成家室.

逵兒乘机来,行兒骑牛来.

玫兒纽约客,合家欢乐聲.

爱情甜蜜蜜,花甲過八十.

我說好爱妳,妳說好爱我.

问君如何爱,但愿常厮守.

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APPENDIX A: § 261.24 TOXICITY CHARACTERISTIC

Toxicity Characteristic Leaching Procedure (TCLP) is designed to determine the mobility of both organic and inorganic analytes present in liquid, solid, and multiphasic wastes.

(a) A solid waste (except manufactured gas plant waste) exhibits the characteristic of toxicity if, using the Toxicity Characteristic Leaching Procedure, test Method 1311 in “Test Methods for Evaluating Solid Waste, Physical/Chemical Methods,” EPA Publication SW–846, as incorporated by reference in § 260.11 of this chapter, the extract from a representative sample of the waste contains any of the contaminants listed in table 1 at the concentration equal to or greater than the respective value given in that table. Where the waste contains less than 0.5 percent filterable solids, the waste itself, after filtering using the methodology outlined in Method 1311, is considered to be the extract for the purpose of this section.

(b) A solid waste that exhibits the characteristic of toxicity has the EPA Hazardous Waste Number specified in Table 1 which corresponds to the toxic contaminant causing it to be hazardous.

Table 1 —Maximum Concentration of Contaminants for the Toxicity Characteristic

EPA HW No.[1]	Contaminant	CAS No.[2]	Regulatory Level (mg/L)
D004	Arsenic	7440–38–2	5.0
D005	Barium	7440–39–3	100.0
D018	Benzene	71–43–2	0.5
D006	Cadmium	7440–43–9	1.0
D019	Carbon tetrachloride	56–23–5	0.5
D020	Chlordane	57–74–9	0.03
D021	Chlorobenzene	108–90–7	100.0
D022	Chloroform	67–66–3	6.0
D007	Chromium	7440–47–3	5.0

EPA HW No.[1]	Contaminant	CAS No.[2]	Regulatory Level (mg/L)
D023	o-Cresol	95–48–7	[4] 200.0
D024	m-Cresol	108–39–4	[4] 200.0
D025	p-Cresol	106–44–5	[4] 200.0
D026	Cresol		[4] 200.0
D016	2,4-D	94–75–7	10.0
D027	1,4-Dichlorobenzene	106–46–7	7.5
D028	1,2-Dichloroethane	107–06–2	0.5
D029	1,1-Dichloroethylene	75–35–4	0.7
D030	2,4-Dinitrotoluene	121–14–2	[3] 0.13
D012	Endrin	72–20–8	0.02
D031	Heptachlor (and its epoxide)	76–44–8	0.008
D032	Hexachlorobenzene	118–74–1	[3] 0.13
D033	Hexachlorobutadiene	87–68–3	0.5
D034	Hexachloroethane	67–72–1	3.0
D008	Lead	7439–92–1	5.0
D013	Lindane	58–89–9	0.4
D009	Mercury	7439–97–6	0.2
D014	Methoxychlor	72–43–5	10.0
D035	Methyl ethyl ketone	78–93–3	200.0
D036	Nitrobenzene	98–95–3	2.0
D037	Pentachlorophenol	87–86–5	100.0
D038	Pyridine	110–86–1	[3] 5.0
D010	Selenium	7782–49–2	1.0
D011	Silver	7440–22–4	5.0
D039	Tetrachloroethylene	127–18–4	0.7
D015	Toxaphene	8001–35–2	0.5
D040	Trichloroethylene	79–01–6	0.5
D041	2,4,5-Trichlorophenol	95–95–4	400.0
D042	2,4,6-Trichlorophenol	88–06–2	2.0
D017	2,4,5-TP (Silvex)	93–72–1	1.0
D043	Vinyl chloride	75–01–4	0.2

[1] Hazardous waste number.

[2] Chemical abstracts service number.

[3] Quantitation limit is greater than the calculated regulatory level. The quantitation limit therefore becomes the regulatory level.

[4] If o-, m-, and p-Cresol concentrations cannot be differentiated, the total cresol (D026) concentration is used. The regulatory level of total cresol is 200 mg/l.

[55 FR 11862, Mar. 29, 1990, as amended at 55 FR 22684, June 1, 1990; 55 FR 26987, June 29, 1990; 58 FR 46049, Aug. 31, 1993; 67 FR 11254, Mar. 13, 2002; 71 FR 40259, July 14, 2006]

APPENDIX B

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

1. Editor Lawrence K. Wang

Editor Lawrence K. Wang has served the society as a professor, inventor, chief engineer, chief editor and public servant (UN, USEPA, New York State) for 50+ years, with experience in entire field of environmental science, technology, engineering and mathematics (STEM). He is a licensed NY-MA-NJ-PA-OH Professional Engineer, a certified NY-MA-RI Laboratory Director, a licensed MA-NY Water Operator, and an OSHA Instructor. He has special passion, and expertise in developing various innovative technologies, educational programs, licensing courses, international projects, academic publications, and humanitarian organizations, all for his dream goal of promoting world peace. He is a retired Acting President/Professor of the Lenox Institute of Water Technology, USA, a Senior Advisor of the United Nations Industrial Development Organization (UNIDO), Vienna, Austria, and a former professor/visiting professor of Rensselaer Polytechnic Institute, Stevens Institute of Technology, University of Illinois, National Cheng-Kung University, Zhejiang University, and Tongji University. Dr. Wang is the author of 750+ papers and 50+ books, and is credited with 29 invention patents. He holds a BSCE degree from National Cheng- Kung University, Taiwan, ROC, a MSCE degree from the University of Missouri-Rolla, a MS degree from the University of Rhode Island and a PhD degree from Rutgers University, USA. Currently he is the book series editor of CRC Press, Springer Nature Switzerland, Lenox Institute Press, World Scientific Singapore, and John Wiley. Dr. Wang has been a Delegate of the People to People Internatonal Foundation, a Diplomate of the American Academy of Environmental Engineers, a member of ASCE, AIChE, ASPE, WEF, AWWA, CIE and OCEESA, and a recipient of many US and international engineering and science awards.

2. Editor Mu-Hao Sung Wang

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

Island, RI, USA, and a PhD degree from Rutgers University, NJ, USA. She is the Co-Series Editor of the Handbook of Environmental Engineering series (Springer Nature Switzerland), Coeditor of the Advances in Industrial and Hazardous Wastes Treatment series (CRC Press of Taylor & Francis Group) and the Coeditor of the Environmental Science, Technology, Engineering and Mathematics series (Lenox Institute Press). She is a member of AWWA, NYWWA, NEWWA, WEF, NEWEA, CIE and OCEESA.

3. Editor Yuriy I. Pankivskyi

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

University (Ukraine), ME degree from Lenox Institute of Water Technology (MA, USA), and his PhD degree from Lviv National Ivan Franko University (Ukraine). He is a member of National Ecological Center of Ukraine (Lviv Department).