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Chemical and Biochemical Technologies for Environmental Infrastructure Sustainability

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Abstract

Various highly efficient flotation processes and systems are introduced for water and wastewater infrastructure sustainability. This publication covers the following subjects:

1. Flotation types , theories, principles, and “zero velocity concept”;
2. Unit processes of mixing, coagulation, precipitation, flocculation, clarification (flotation or sedimentation), filtration, disinfection, sludge thickening and sludge dewatering;
3. Flotation rising rate, surface loading rate (SLR), & detention time (DT);
4. Dissolved air flotation (DAF) and sedimentation comparison;
5. Various municipal and industrial applications of flotation;
6. Rectangular potable water treatment (WT) package plants at (6a) Lake Bluff, IL, USA and (6b) West Nyack, NY, USA;
7. Circular DAF and DAF-filtration (DAFF) for industrial applications when land space and budget are limited;
8. Roof-top installation of Supracell DAF with almost zero foot-print;

Abstract (continued)

9. First potable water flotation-filtration plant in America (Lenox, MA, USA; 1 MGD; 3.785 MLD; installed in 1982; 22-ft diameter; 15 min. DT);
10. Once the largest potable flotation-filtration in the world (Pittsfield, MA, USA; 37.5 MGD; 142 MLD; 49-ft. diameter each of 6 units; 15 min. DT);
11. Detailed description of Sandfloat DAFF package plant;
12. Upgrading an existing sedimentation to a DAF-sedimentation clarifier;
13. A combination of DAF sludge thickening and screwpress sludge dewatering (Float Press);
14. An innovative Oxyozosynthesis system including oxygenation, ozonation, sludge wet oxidation, and Float Press sludge dewatering;
15. Biological or physicochemical sequencing batch reactor (SBR) using either flotation or sedimentation for clarification;
16. Recent advances in dissolved gas flotation (DGF);
17. Recent development and case histories of primary flotation, secondary flotation, tertiary flotation and flotation sludge thickening;

Abstract (continued)

18. Case history: adding a DAF between aeration basin and sedimentation basin for significant improvement of an existing overloaded biological activated sludge wastewater treatment plant (WWTP);
19. Case history: dairy WWTP using both primary flotation and secondary flotation for cost saving;
20. Adoption of DAF clarification for carbonaceous oxidation, nitrification and denitrification;
21. Combined DAF and filtration (DAFF) for final stage tertiary treatment ;
22. Tannery WWTP using combined physicochemical and biological process system including DAF;
23. DAF wastewater treatment efficiencies for removal of conventional pollutants, heavy metals , and toxic organic substances (US EPA);
24. Dairy wastewater treatment using dissolved carbon dioxide flotation (DCDF) for precipitation of proteins; and
25. Recent academic references. [1-9]

Keywords

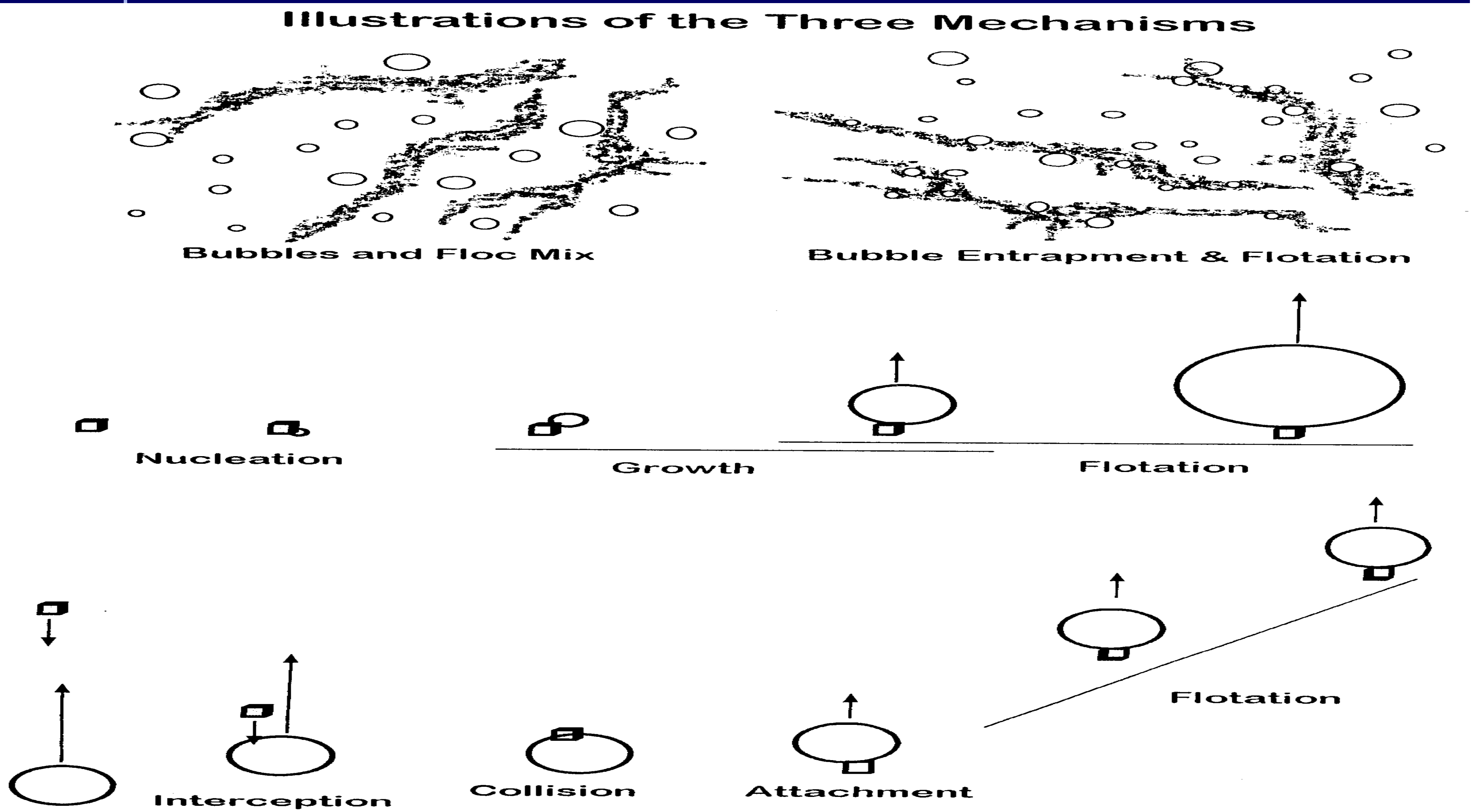
- Water treatment, wastewater treatment, sludge treatment, infrastructure, sustainability, high performance, low costs, small foot-print, dissolved gas flotation, dissolved air flotation (DAF), dissolved carbon dioxide flotation, dissolved oxygen-ozone flotation, theories, zero velocity concept, case histories, existing WWTP improvement, flotation-filtration (DAFF), primary flotation, secondary flotation, tertiary flotation, flotation sludge thickening, dairy WWTP; tannery WWTP; combined physicochemical and biological treatment ; Sequencing batch reactor .

How can I separate various pollutants cost-effectively ?

Solution : Flotation Separation Technologies [1]

- Plain Gravity Flotation (oil/wax-water separation)
- Dissolved Air (Gas) Flotation (laminar hydraulic flow pattern using extremely fine gas bubbles)
- Dispersed (Induced) Air Flotation (turbulent hydraulic flow pattern using coarse gas bubbles)
- Vacuum Flotation
- Electroflotation (hydrogen, oxygen, chlorine bubbles)
- Biological Flotation (nitrogen, carbon dioxide gas bubbles)

Insoluble floc (s.g. > 1) mixed with and entrapped by gas bubbles due to interception, collision, floc-bubble attachment (s.g. < 1) causing flotation [2]



Flotation pretreatment: Converting soluble pollutants to insoluble floc by chemical mixing, precipitation & coagulation, and flocculation

- Chemical Feeding & Mixing
- Chemical Precipitation
  - Solute A + Solute B = insoluble flocs
- Chemical Coagulation:
  - Formation of chemical flocs that adsorb, entrap, or bring suspended matter together

    (Soluble Al becomes insoluble aluminum hydroxide flocs)
  - Opposite charge neutralization; particles are destabilized and form visible pin flocs
  - Collector adjustment (hydrophobic nature)

Flocculation (slow mixing) provides the opportunity for pinflocs to contact each other and grow bigger in size [3]

- Flocculation:
  - Enlargement of pinfloc size to speed up floc-bubble attachment and flotation.
  - Addition of long chain polymer to enhance flocculation.
  - Agglomeration of flocs-polymer-bubbles together to facilitate flotation action

Rising rate of flocs-flocculant-bubble agglomerates is much faster than the settling rate of flocs-flocculant agglomerates ; Flotation is highly efficient

- Chemical addition, mixing, chemical precipitation and coagulation
- Flocculation – Formation of stable flocs-flocculant-bubble agglomerates
- Flotation Clarification:
  - Generation of gas bubbles (air, nitrogen, carbon dioxide, ozone, oxygen, hydrogen, chlorine)
  - Flotation (bubble) separation of insoluble particles from an aqueous suspension
  - Collection, harvest or disposal of floats (scums) from top
  - Discharge of clarified clear effluent from bottom

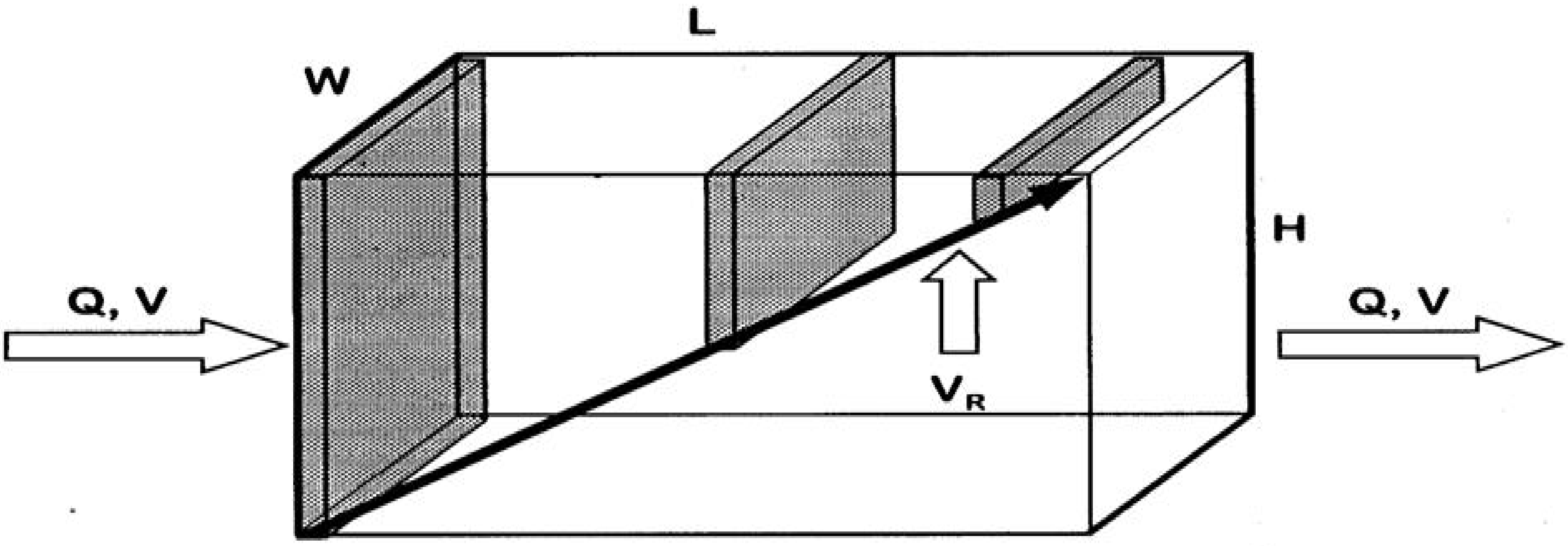
Before flotation: the entire water phase is cloddy
After flotation: the clarified water is clear

Water-Solids Separation by Flotation

Before Flotation

After Flotation

Flocs travel horizontally and upward vertically in flotation chamber; Rising velocity $V_R = H/T_R$; Horizontal velocity $V = L/T$; When $T_R = T$, flotation surface loading rate (SLR) = Q/LW ($m^3/min/m^2$)



Q is the flow rate (m^3/ min)

V (Flow Velocity) = m / min = Q / WH

V_R = Rise Velocity

Bulky Sedimentation Versus Thin Flotation (Roof-top , Zero Foot-print) When Treating Same Hydraulic Flow

Practical flotation applications:

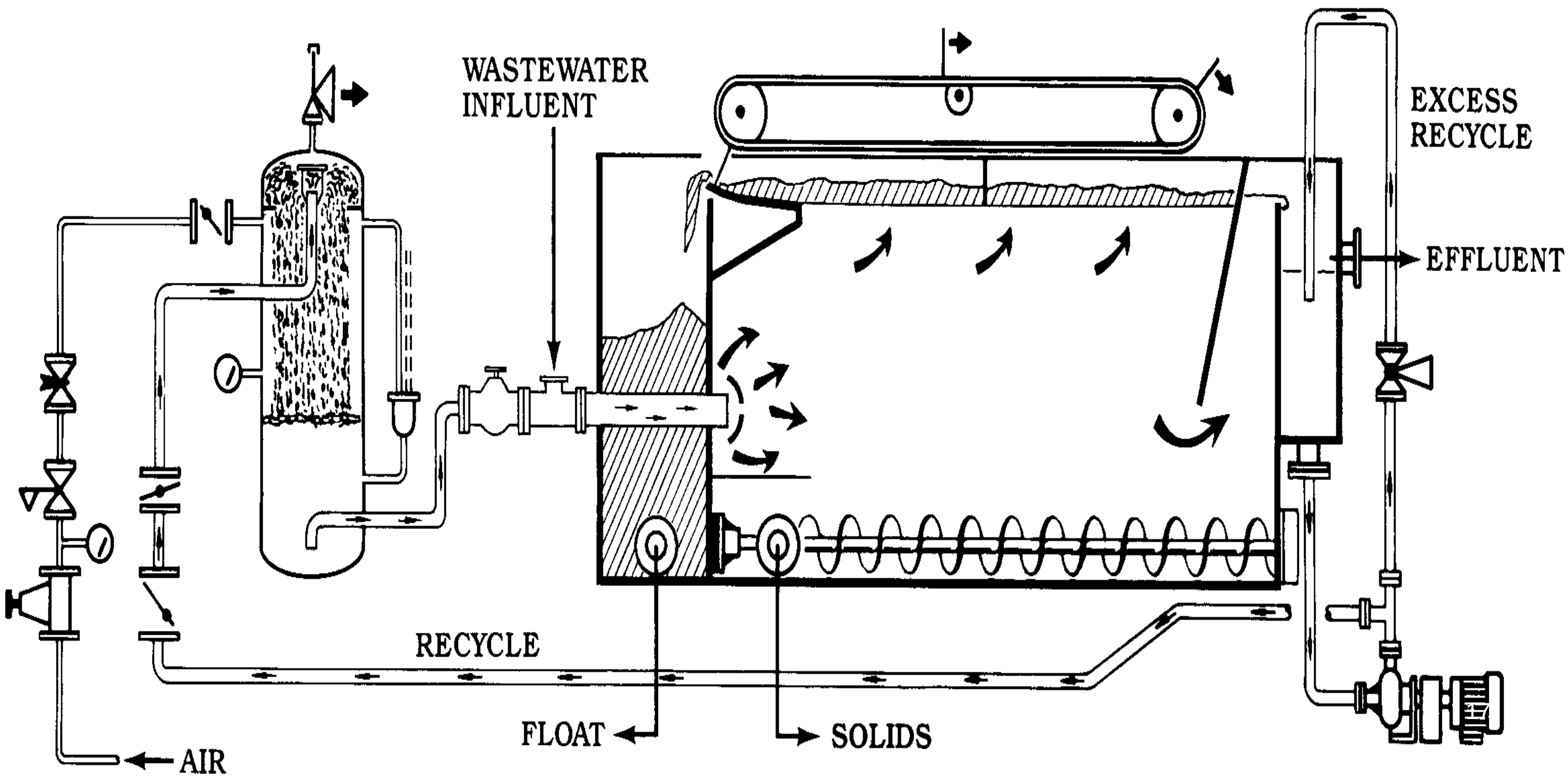
- Potable water treatment
- Industrial water purification
- Industrial effluent treatment
- Municipal sewage & sludge treatment
- Ore mining
- Groundwater decontamination
- De-inking waste paper pulp
- Algae harvesting and lake restoration
- Separating plastics from shredded solid wastes

A Small Complete Package DAF Plant Can be Built to Treat Small Industrial Water or Wastewater Flows

Rectangular Dissolved Air Flotation (DAF)

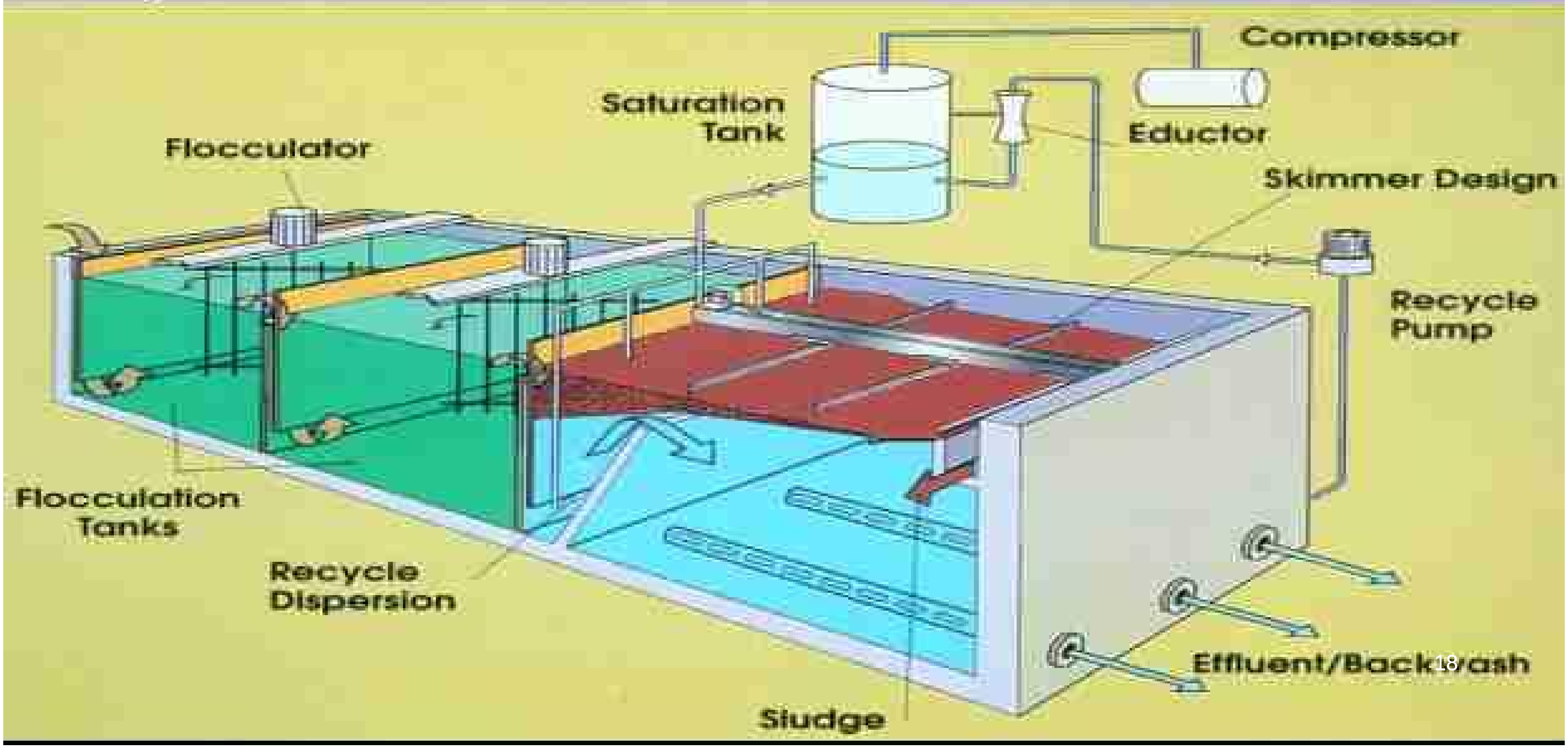
- Chemical addition, mixing, coagulation-flocculation
- Flotation
- Flotation effluent discharge
- Float discharge

Frequent choice of municipalities [4] : Rectangular Dissolved Air Flotation (DAF) – Waterlink Separation Inc, Lake Bluff, IL, USA



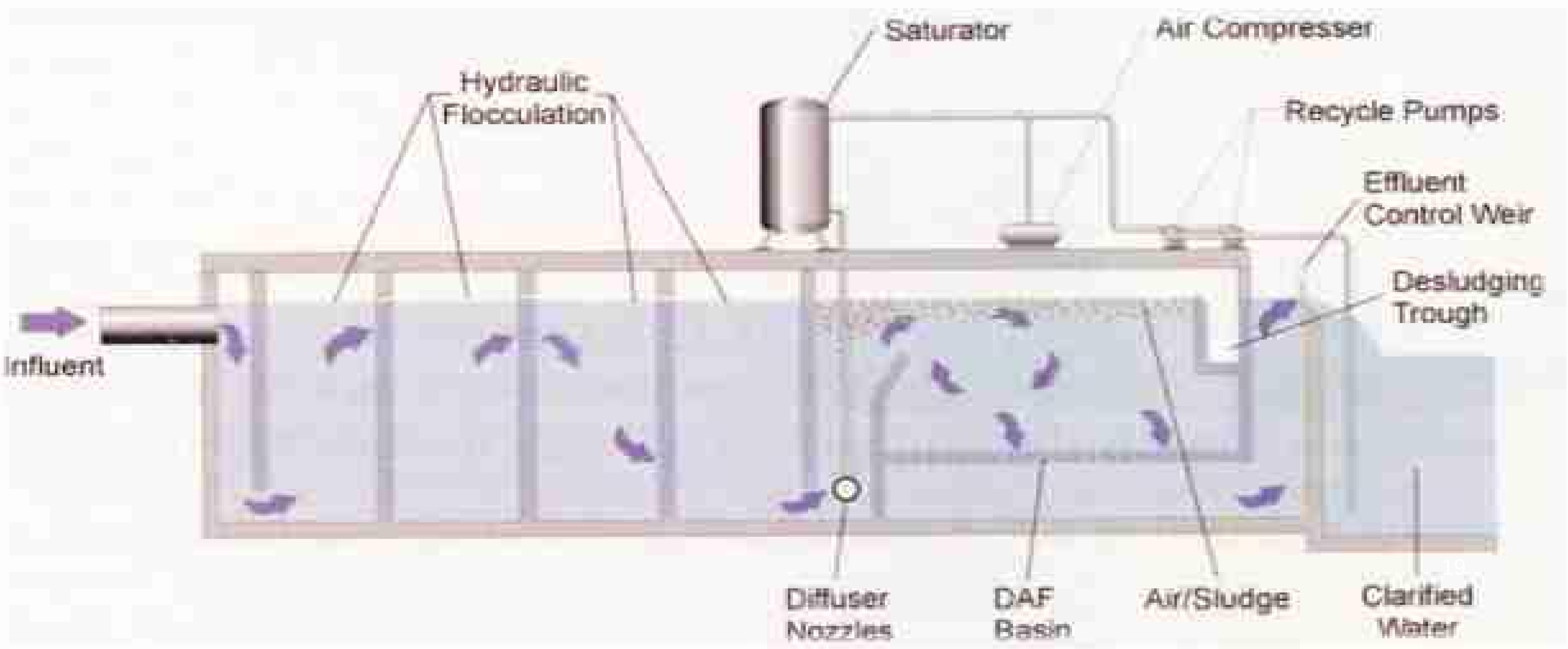
Suitable for Municipal Drinking Water Treatment

Rectangular Dissolved Air Flotation (DAF) – Waterlink Separation Inc, Lake Bluff, Illinois



A historical DAF drinking water treatment plant installed in West Nyack, New York, USA with a design capacity of 30 MGD or 113.55 MLD

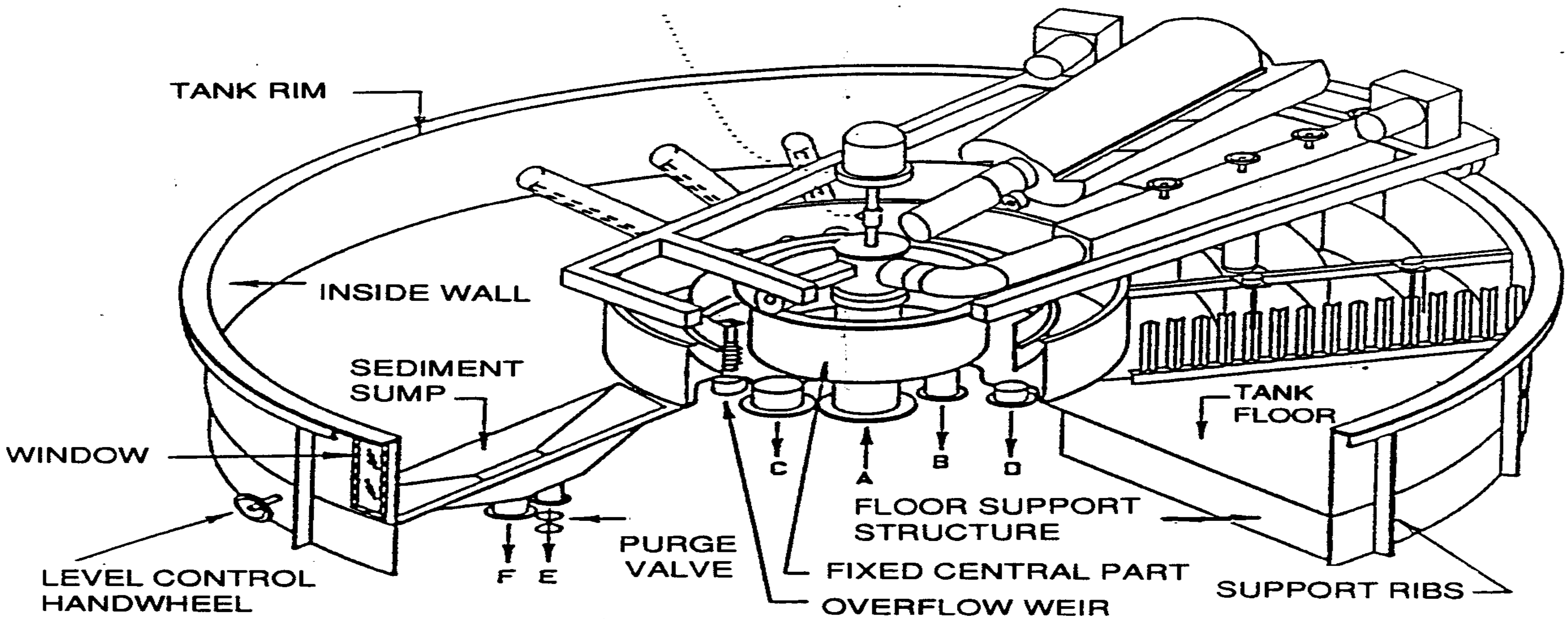
Rectangular Dissolved Air Flotation (DAF) – West Nyack-NY potable water plant (30 MGD)



Frequent choice of industry when the space and the budget are limited; Roof-top construction with zero foot-print [3]

Circular Dissolved Air Flotation (DAF)
– Krofta Engineering Corp., Mass.
55-ft Diameter; 7290 GPM.
Petrochemical Wastewater Treatment

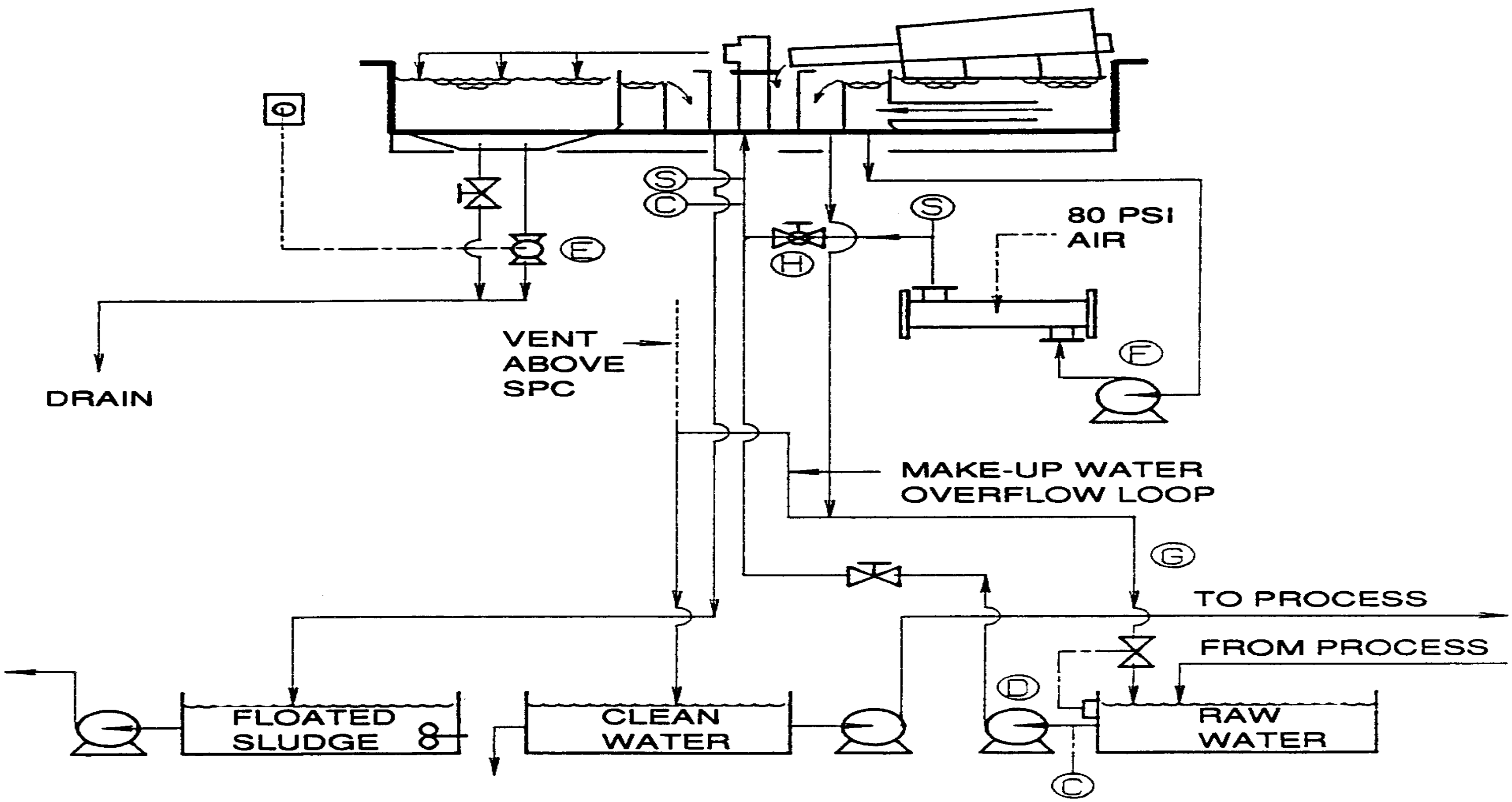
Secret "zero velocity concept" [4] of a circular DAF: When the influent enters DAF chamber clockwisely, the influent distribution system moves counter clockwisely at the same velocity, so the influent stays in the tank floor without horizontal movement.



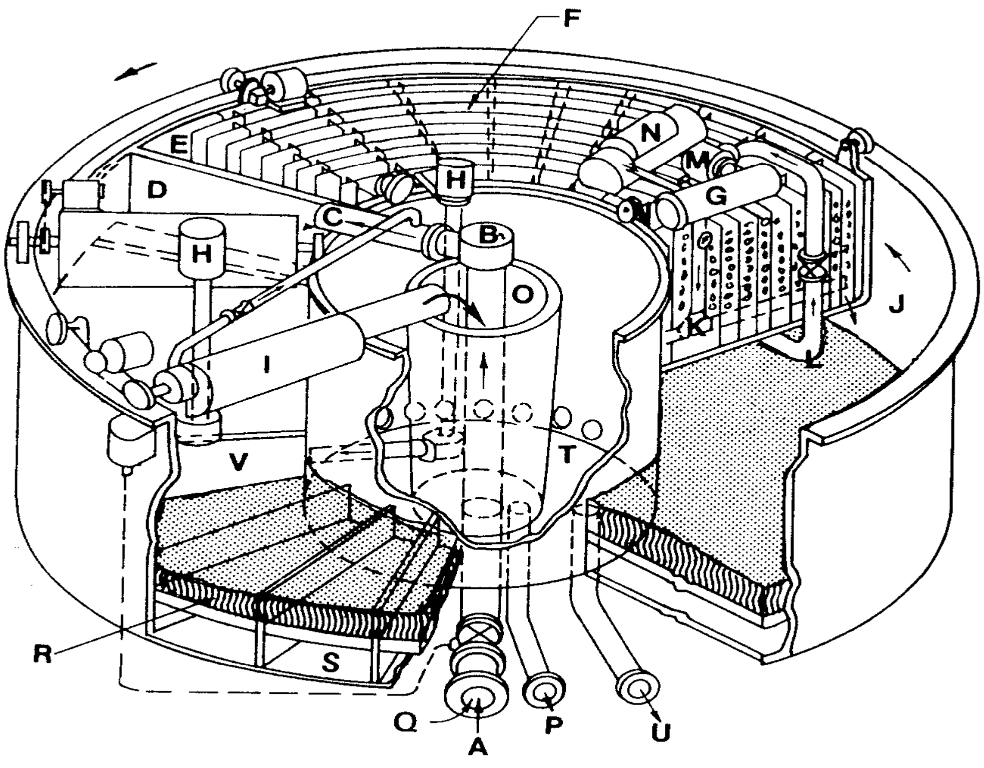
PIPE CONNECTIONS

A - Unclarified Water Inlet
B - Floated Sludge Outlet
C - Clarified Water Outlet
D - Recycle Outlet
E - Purge
F - Drain

Over 2000 units of zero foot-print circular dissolved air flotation (Supracell DAF) installed for various industrial applications around the world [3]

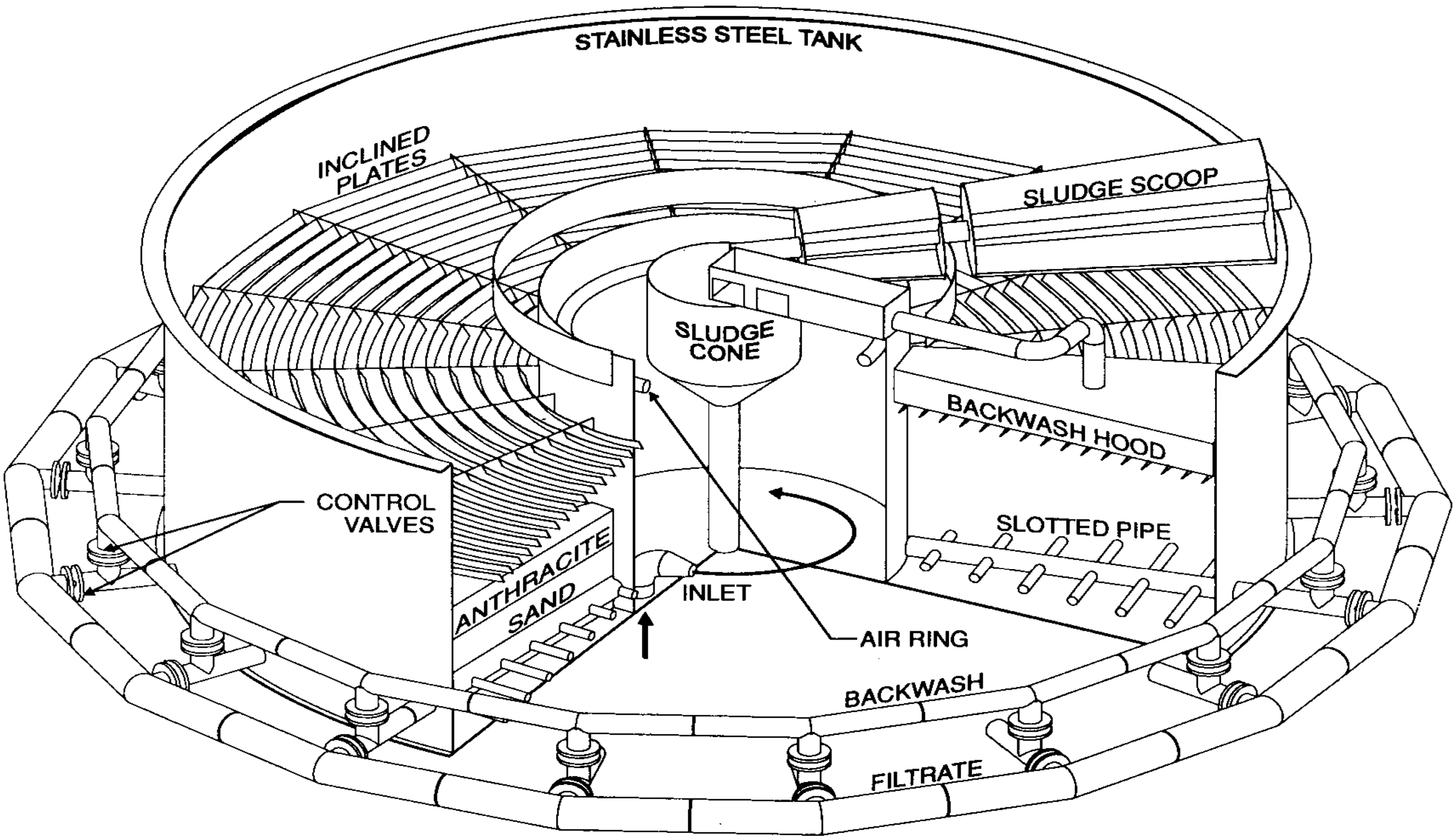


(1) The 1st USA 1-MGD Lenox potable water DAF-filtration plant (Sandfloat) built in 1981; (2) Once world's largest 37.5-MGD Pittsfield-MA potable water DAF filtration plant built in 1986. [4]

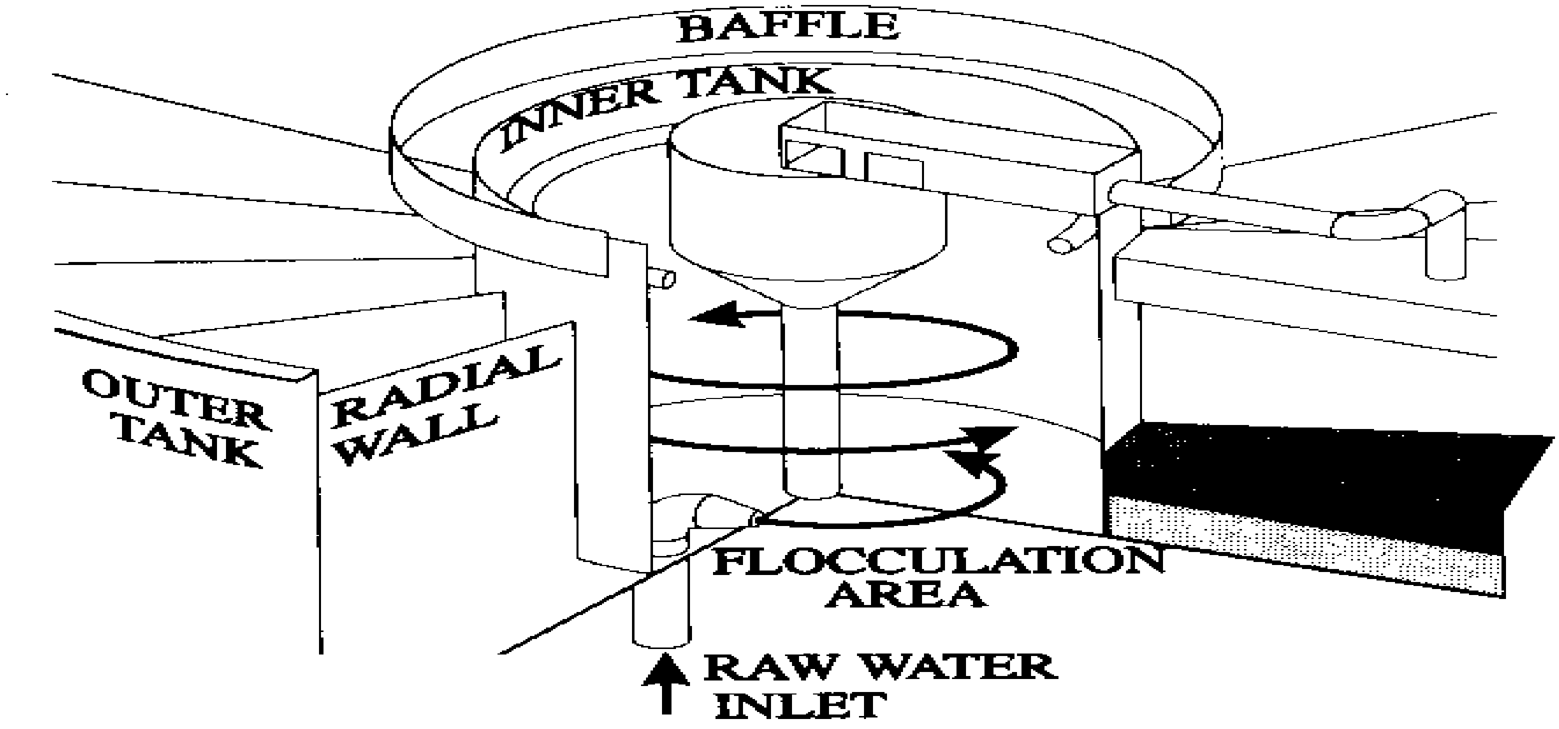


- A — RAW WATER INLET
- B — HYDRAULIC JOINT
- C — INLET DISTRIBUTOR
- D — RAPID MIXING
- E — MOVING SECTION
- F — STATIC HYDRAULIC FLOCCULATOR
- G — AIR DISSOLVING TUBE
- H — BACKWASH PUMPS
- I — SPIRAL SCOOP
- J — FLOTATION TANK
- K — DISSOLVED AIR ADDITION
- L — BOTTOM CARRIAGE
- M — PRESSURE PUMP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

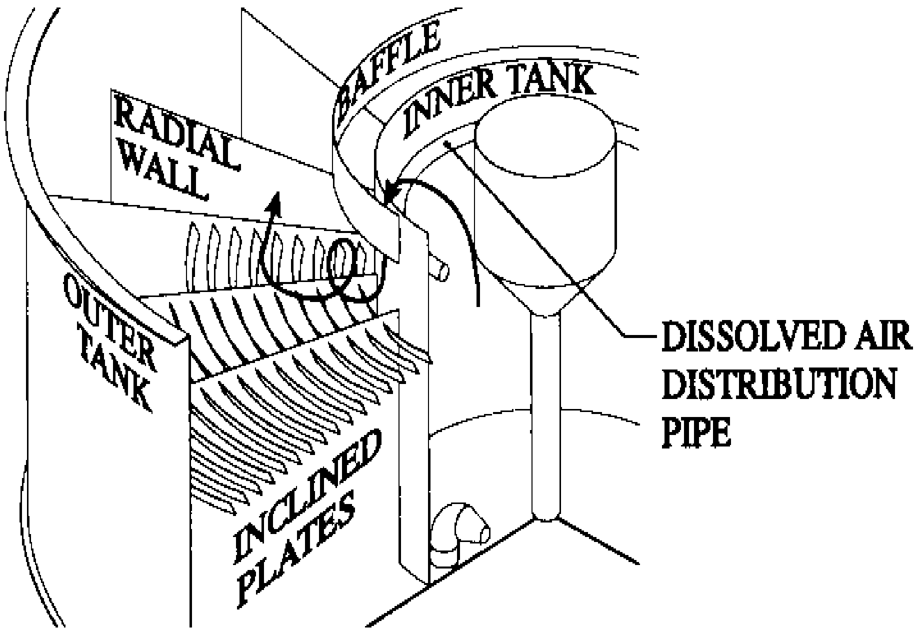
A close look of Lee-MA potable water DAF-filtration plant, USA; It includes chemical mixing, coagulation-flocculation, inclined plates DAF, automatic backwash multimedia filtration and clearwell disinfection [4]

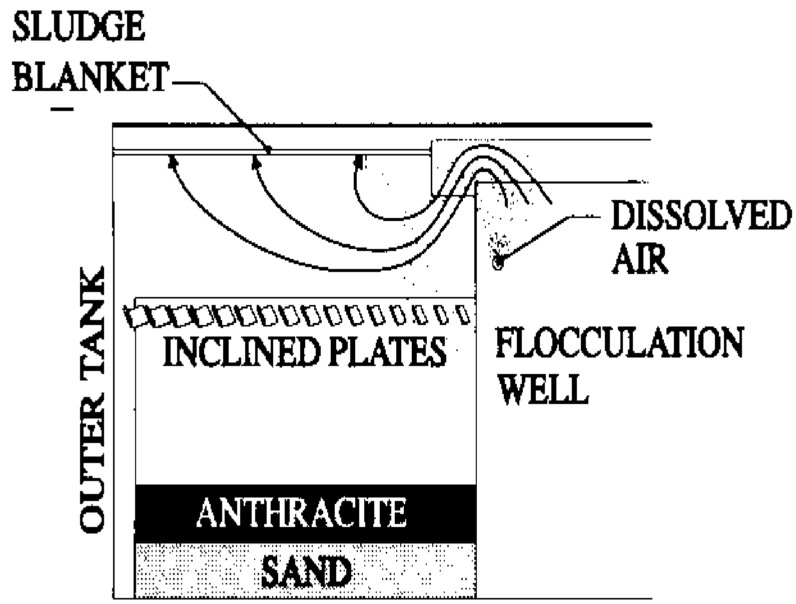


Step-by-step operations of circular potable water DAF-filtration plant: (1) chemical mixing, coagulation & flocculation [4]

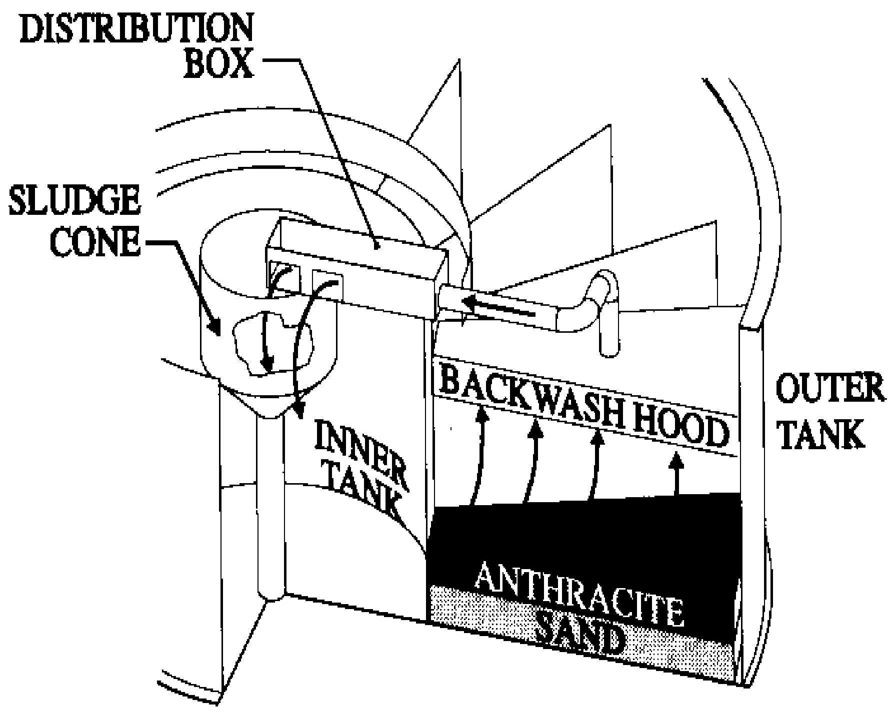


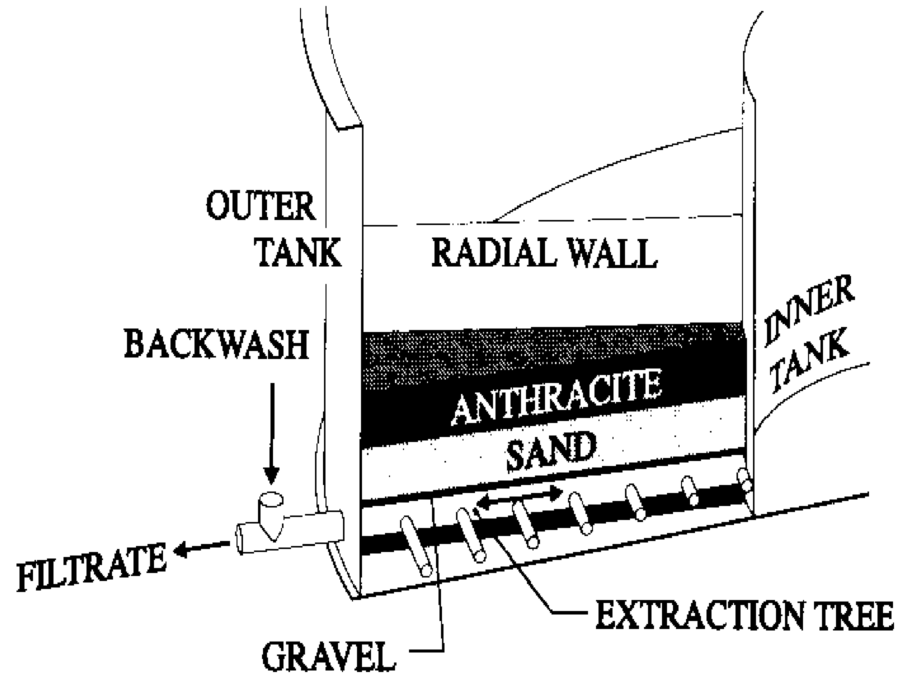
Step-by-step operations of circular potable water DAF-filtration plant: (2) dissolved air flotation with inclined plates [4]



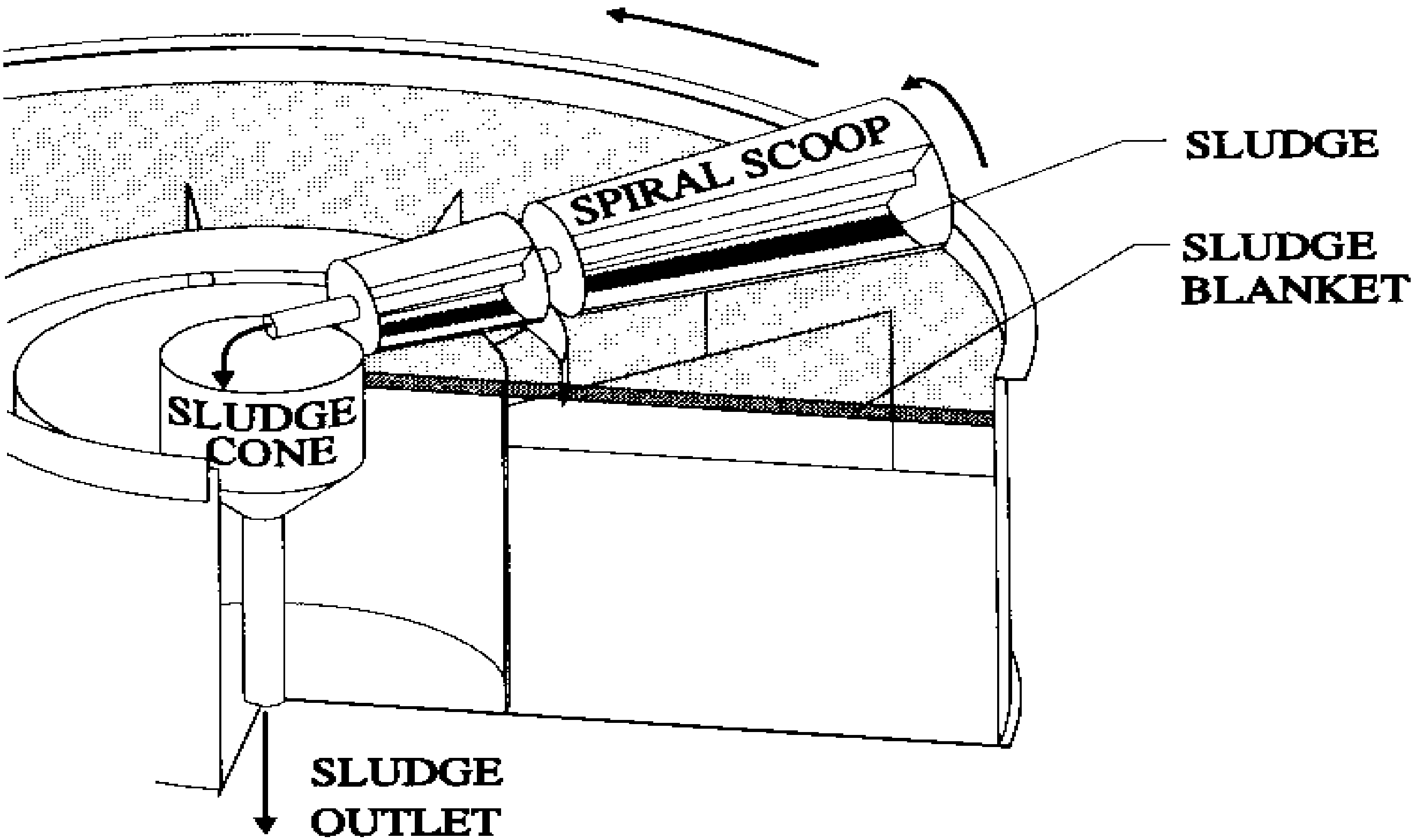


Step-by-step operations of circular potable water DAF-filtration plant: (3) automatic backwash filtration (ABF) with multimedia [4]

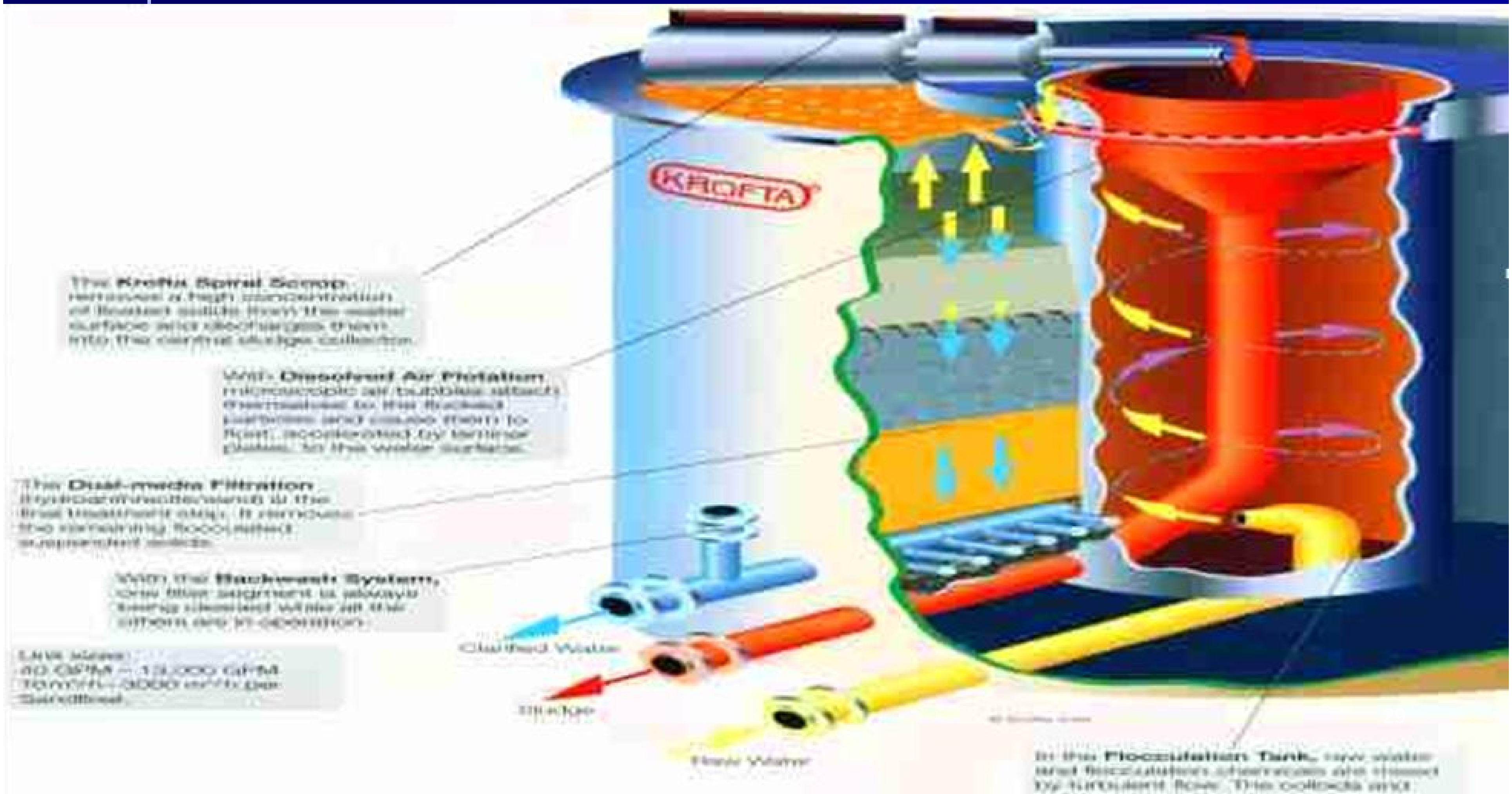




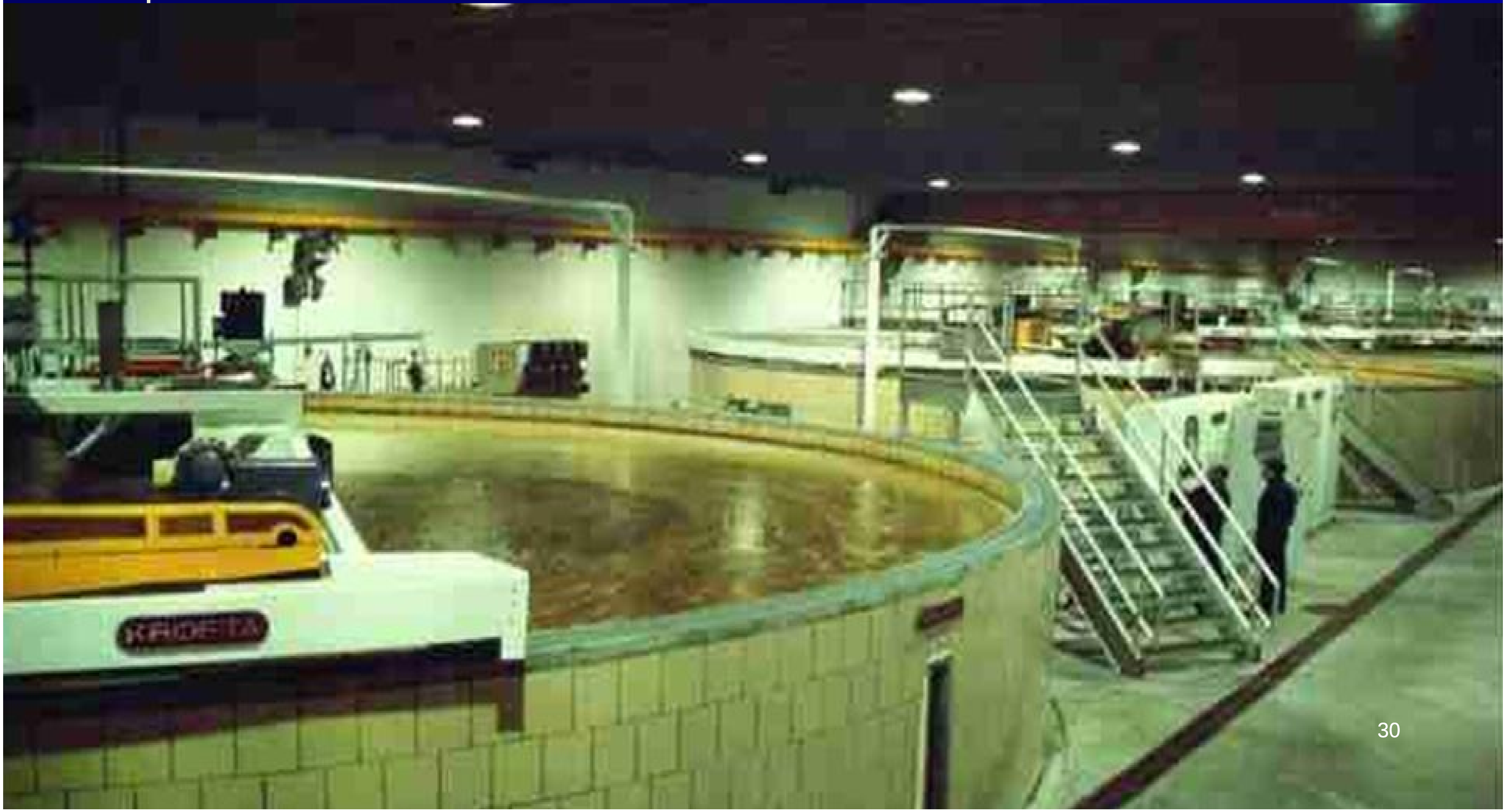
Step-by-step operations of circular potable water DAF-filtration plant: (4) sludge collection from water surface, and sludge discharge [4]



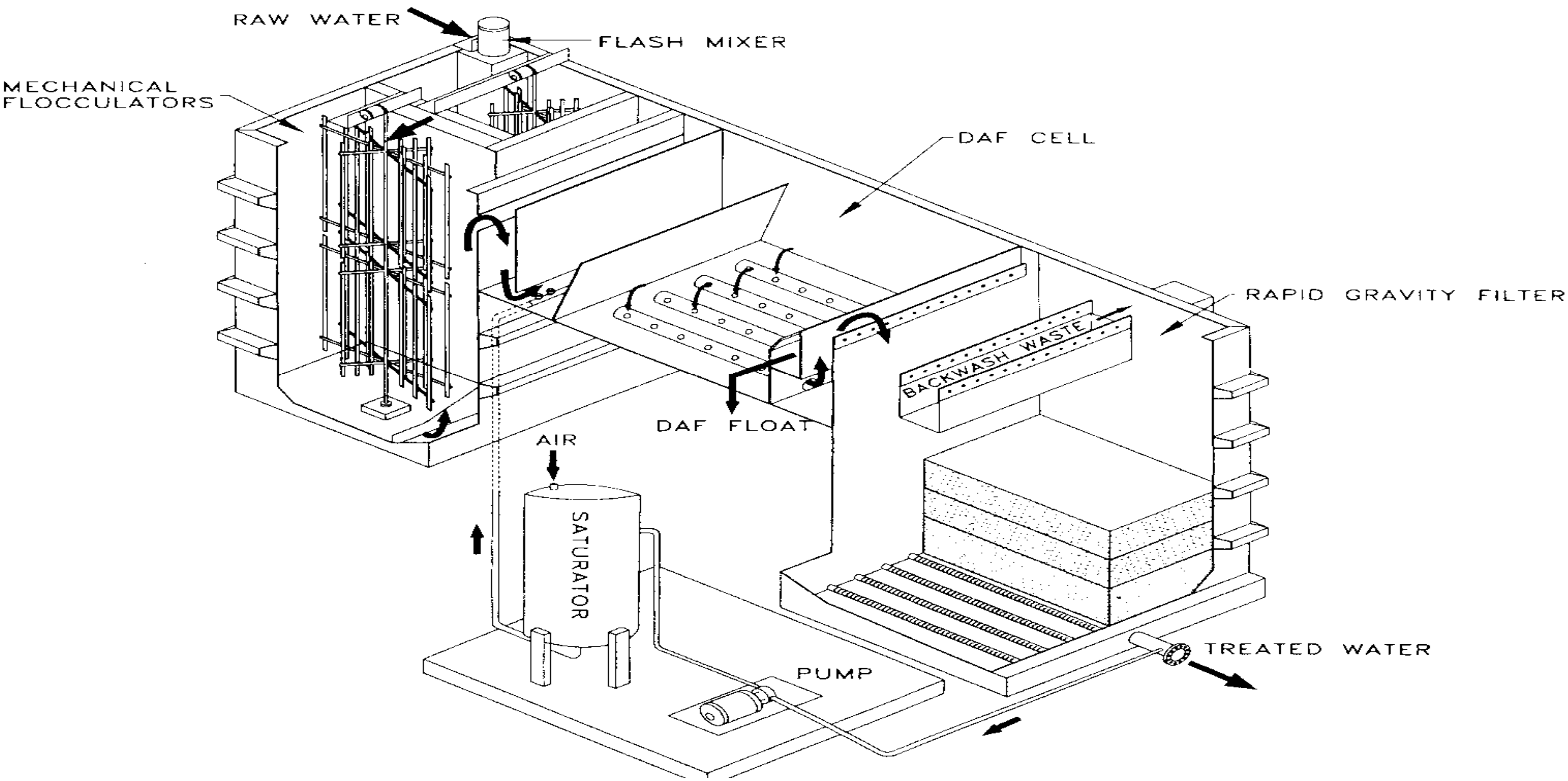
Step-by-step operations of circular potable water DAF-filtration plant: (5) discharge of treated flotation-filtration effluent from bottom



Once largest potable water flotation-filtration plant in the world: Pittsfield, MA, USA; 37.5 MGD, 142 MLD design capacity; built in 1986 [4]

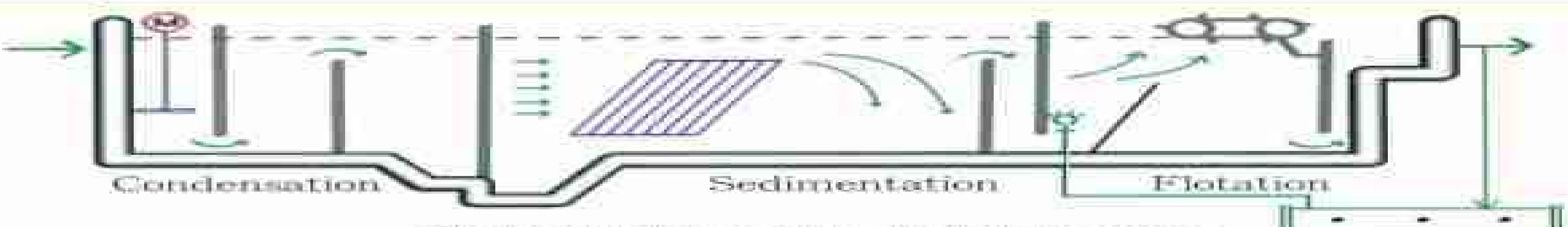


Rectangular flotation-filtration package plant (DAFF) – Clearwater Group, Black Diamond, Washington, USA (Identical unit operations: chemical mixing, flocculation, DAF, and filtration)

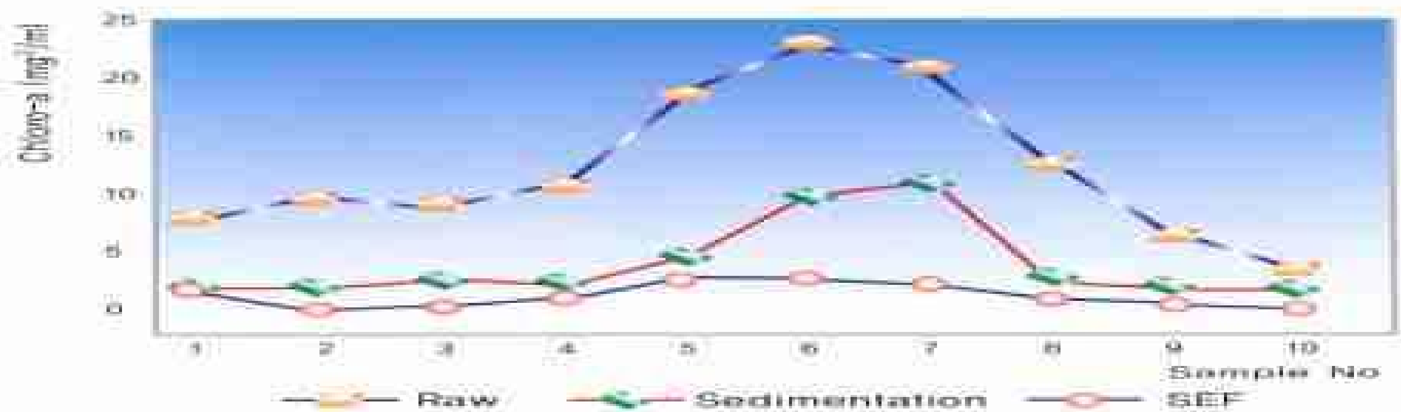


An existing sedimentation clarifier is upgraded to a DAF-sedimentation clarifier; Algae separation efficiency is significantly improved by the upgrade [5]

Rectangular Sedimentation & Flotation, Seoul, Korea; Algae Separation

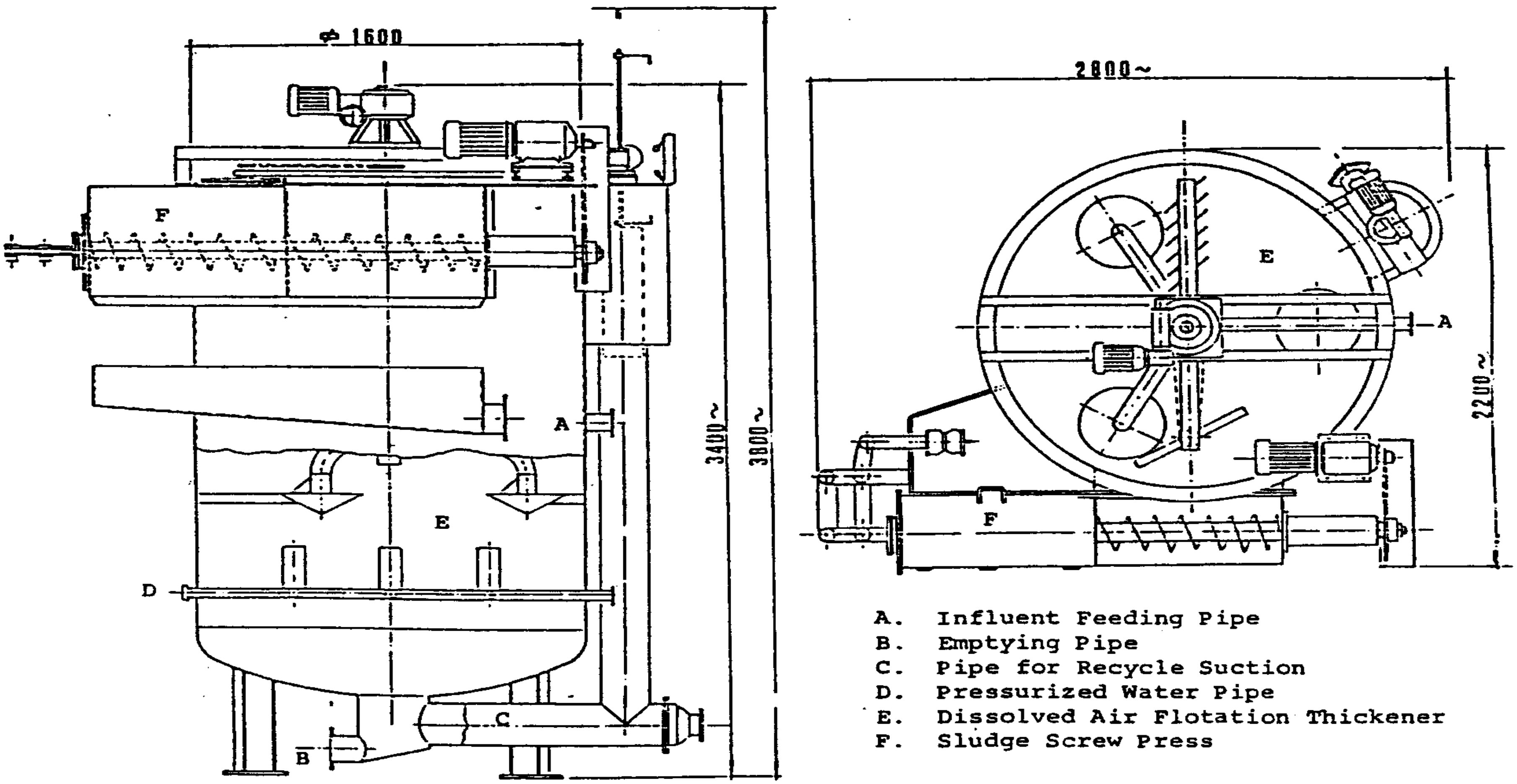


Schematic diagram of Sedimentation-flotion process



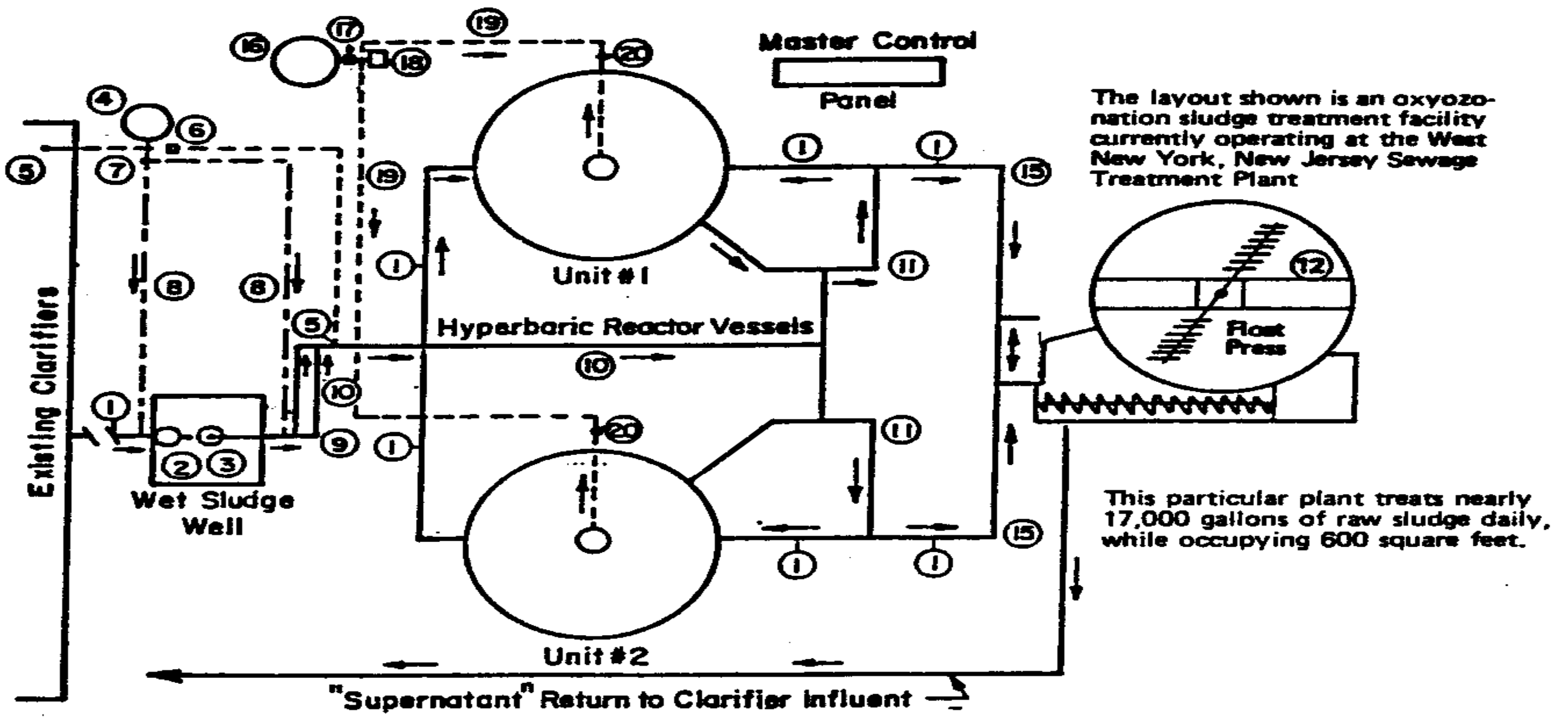
Chlorophyll-a removal by Sedimentation – SEF process

Flotation sludge thickening and screwpress sludge dewatering is combined together as a FloatPress [4,8]



A. Influent Feeding Pipe
B. Emptying Pipe
C. Pipe for Recycle Suction
D. Pressurized Water Pipe
E. Dissolved Air Flotation Thickener
F. Sludge Screw Press

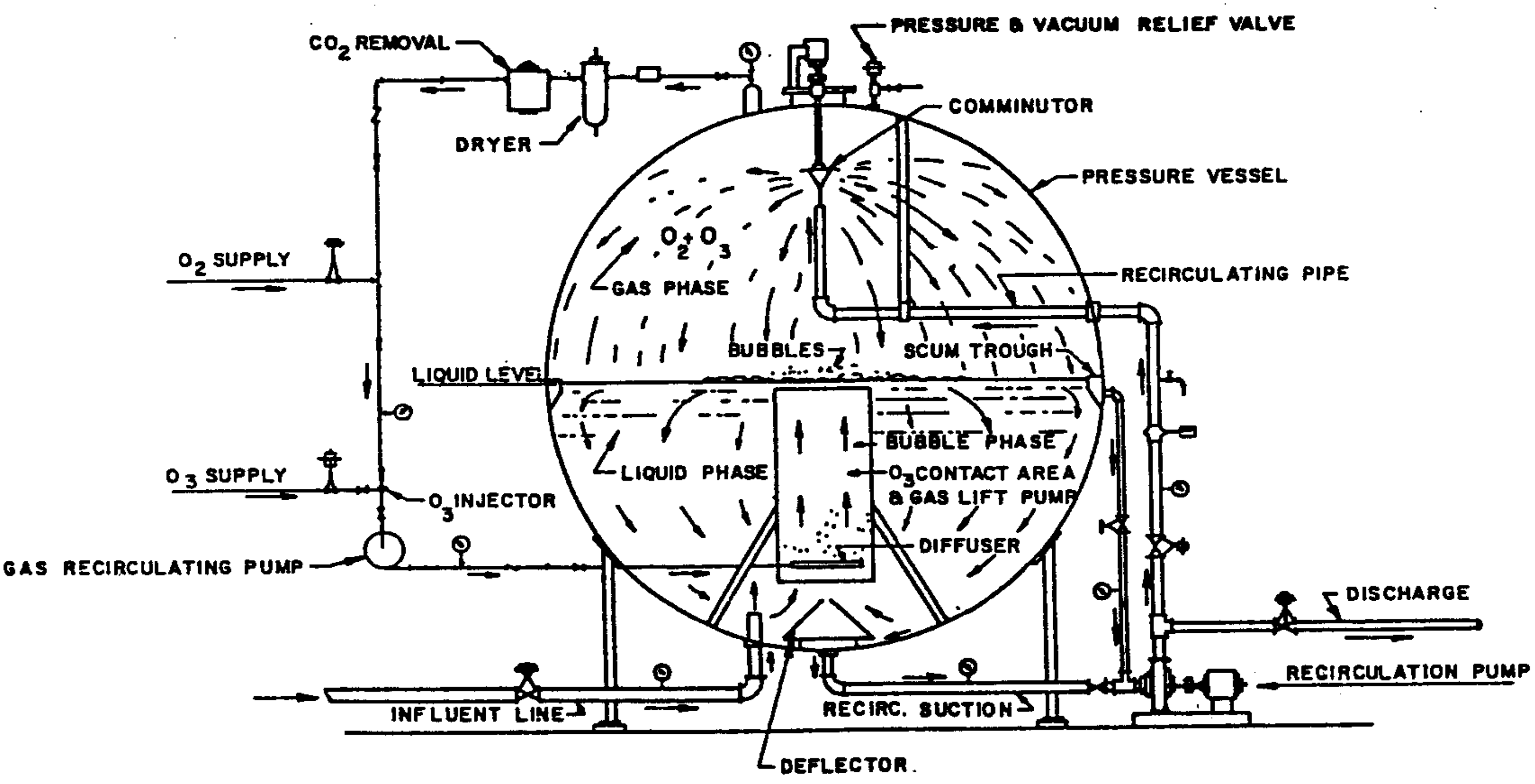
Oxyozosynthesis system is a combined Ozonation-Oxygenation Flotation for chemical sludge digestion and FloatPress sludge dewatering [9]



LEGEND

1 Pinch Type Flow Control Valve
2 Sludge Grinder
3 Mixer
4 Chemical Solution Storage Tank
5 PH Probe
6 PH Control Device
7 Chemical Solution Feed Pump
8 Chemical Feed Lines
9 Variable Speed Progressive Cavity Pump
10 Influent Pump
11 Progressive Cavity Recirculation Pump
12 Float Press
15 Auxiliary Sludge Removal
16 Oxygen Storage Tank
17 Oxygen Supply Control Device
18 Ozone Generator
19 O_2 and O_3 Feed Line
20 Gas Recirculation and Gas Feed Line

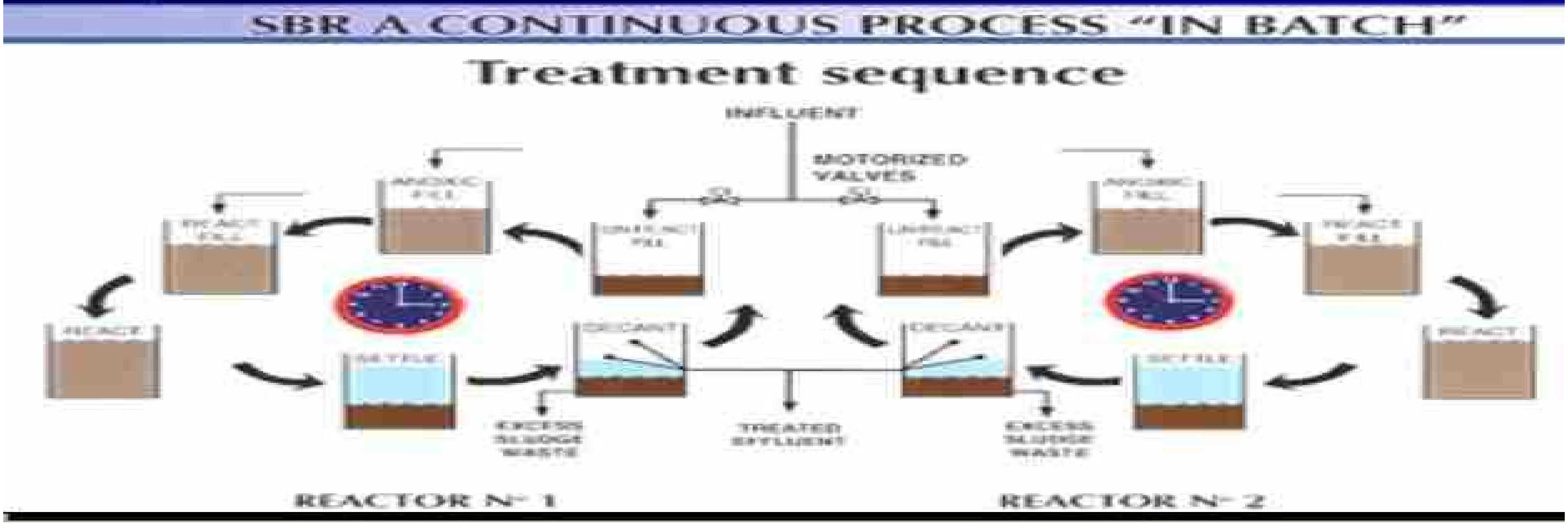
Design of an ozonation-oxygenation (Hyperbaric) reactor [9]



HYPERBARIC REACTOR VESSEL

Biological SBR: One single reactor performs the unit processes of filling, anaerobic mixing, aerobic mixing, clarification, withdraw and idle for carbonaceous oxidation, nitrification and denitrification; Physicochemical SBR: One single reactor performs the unit processes of filling, mixing-coagulation, flocculation, and clarification [5]

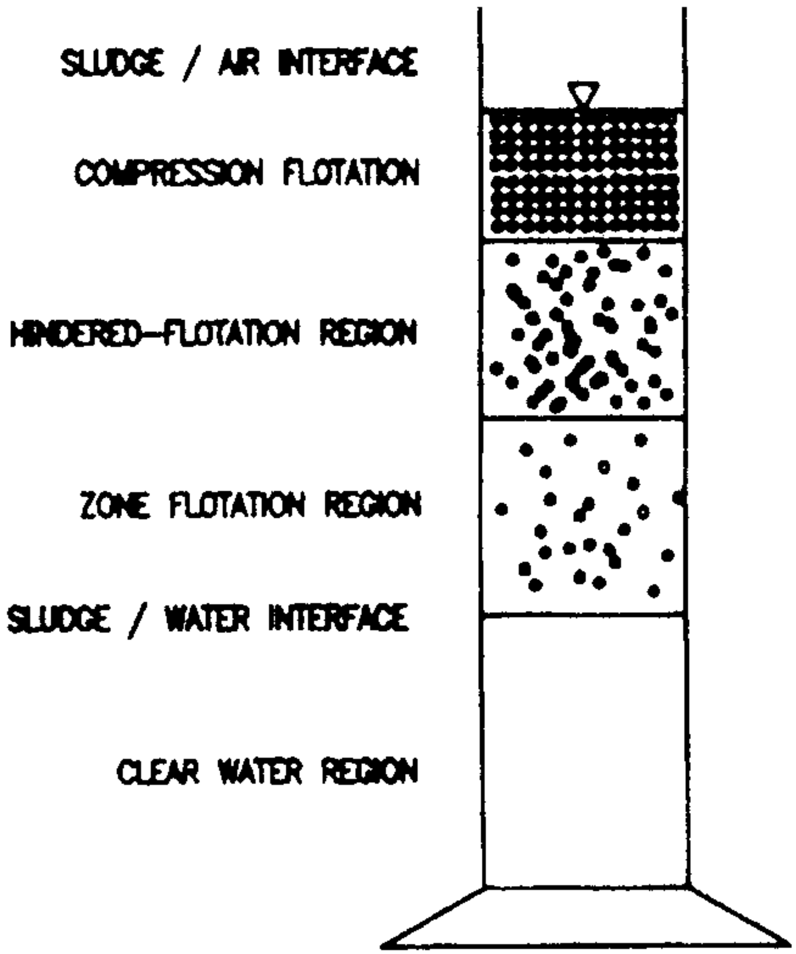
Sequencing Batch Reactor (SBR)-Flotation or Sedimentation Biological or Physicochemical

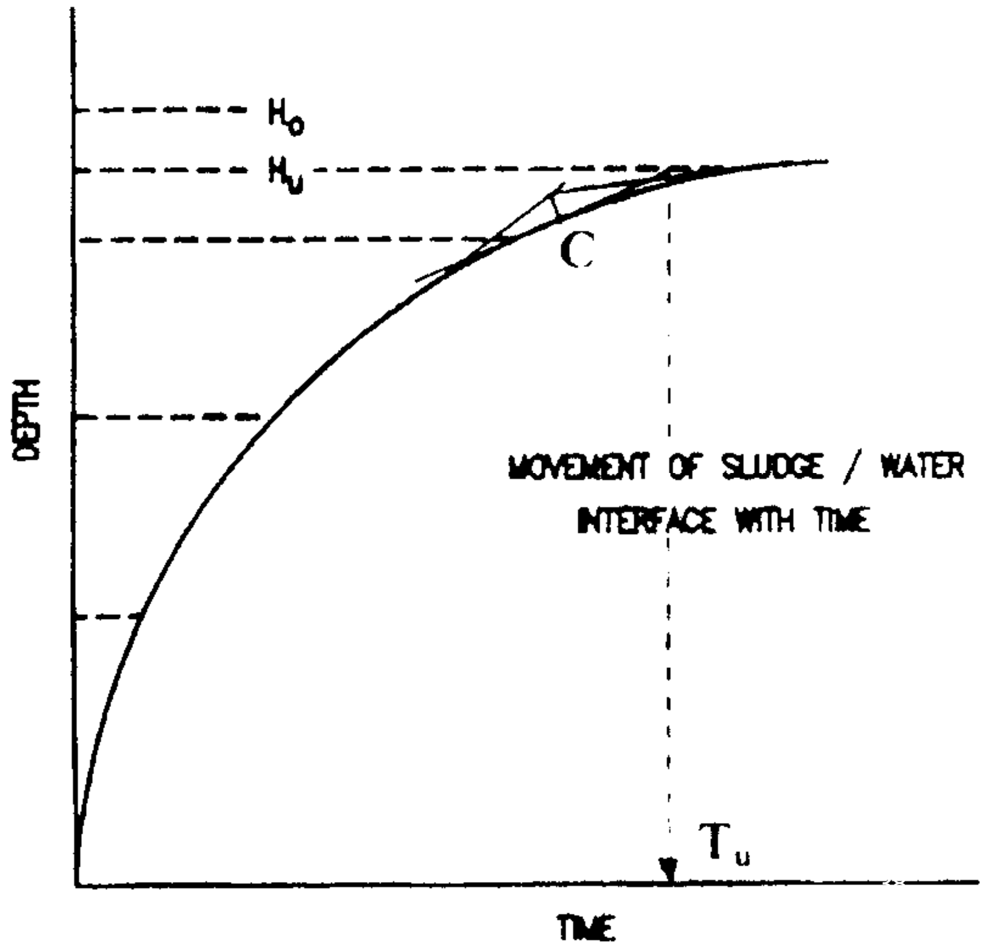


Recent advances in dissolved gas flotation (DGF) systems [1-9]

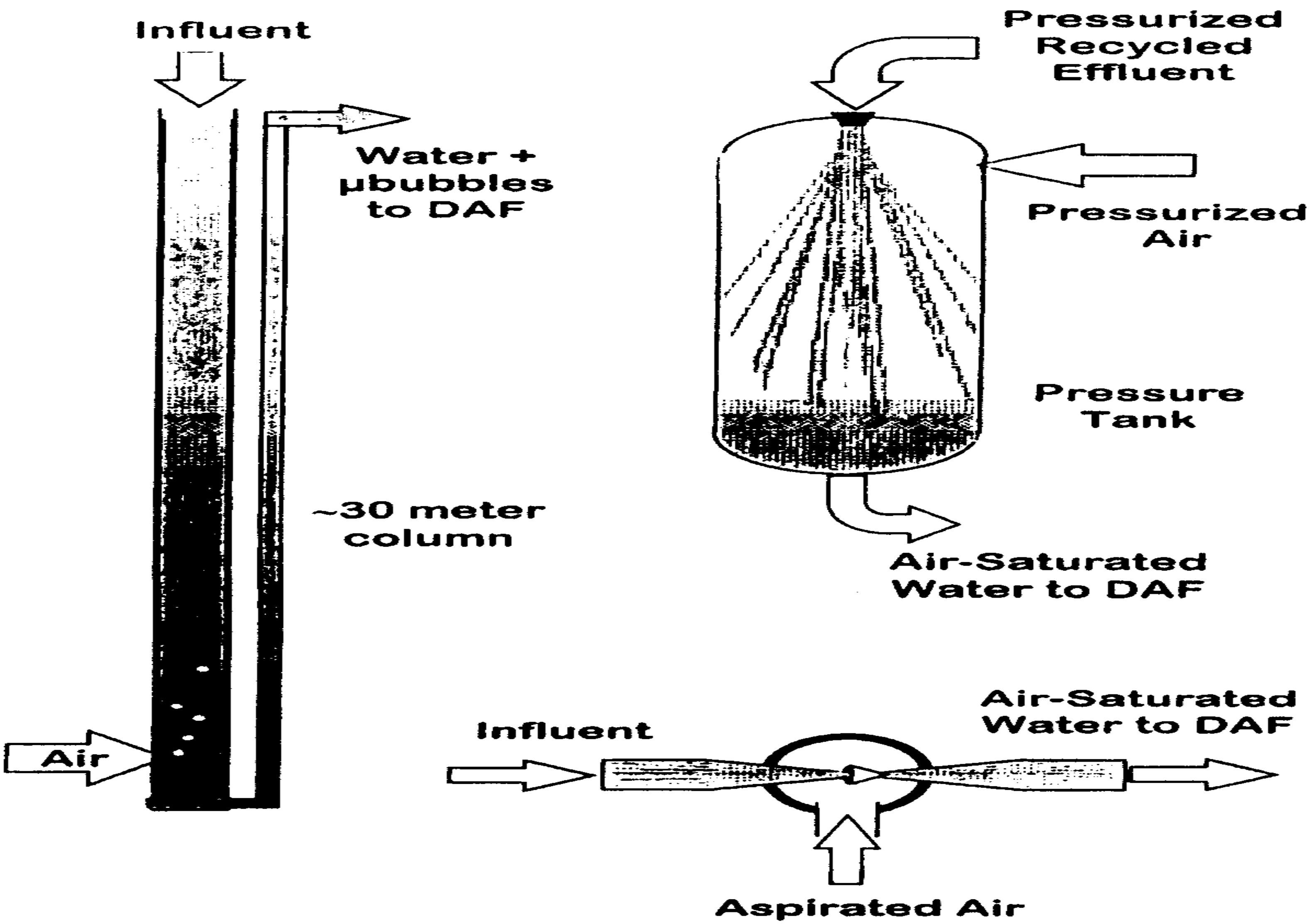
- Flotation Reactor Improvement
- Improved Sludge Thickening
- Using various gases for DGF: DAF, DNF, DCDF, DOF, etc.
- Improved Secondary DAF Clarification
- Improved Primary DAF Clarification
- Both Primary and Secondary Clarification
- Primary, Secondary and Tertiary Clarification
- Combined Chemical and Biological Treatment

Improved flotation reactor design [5,6]

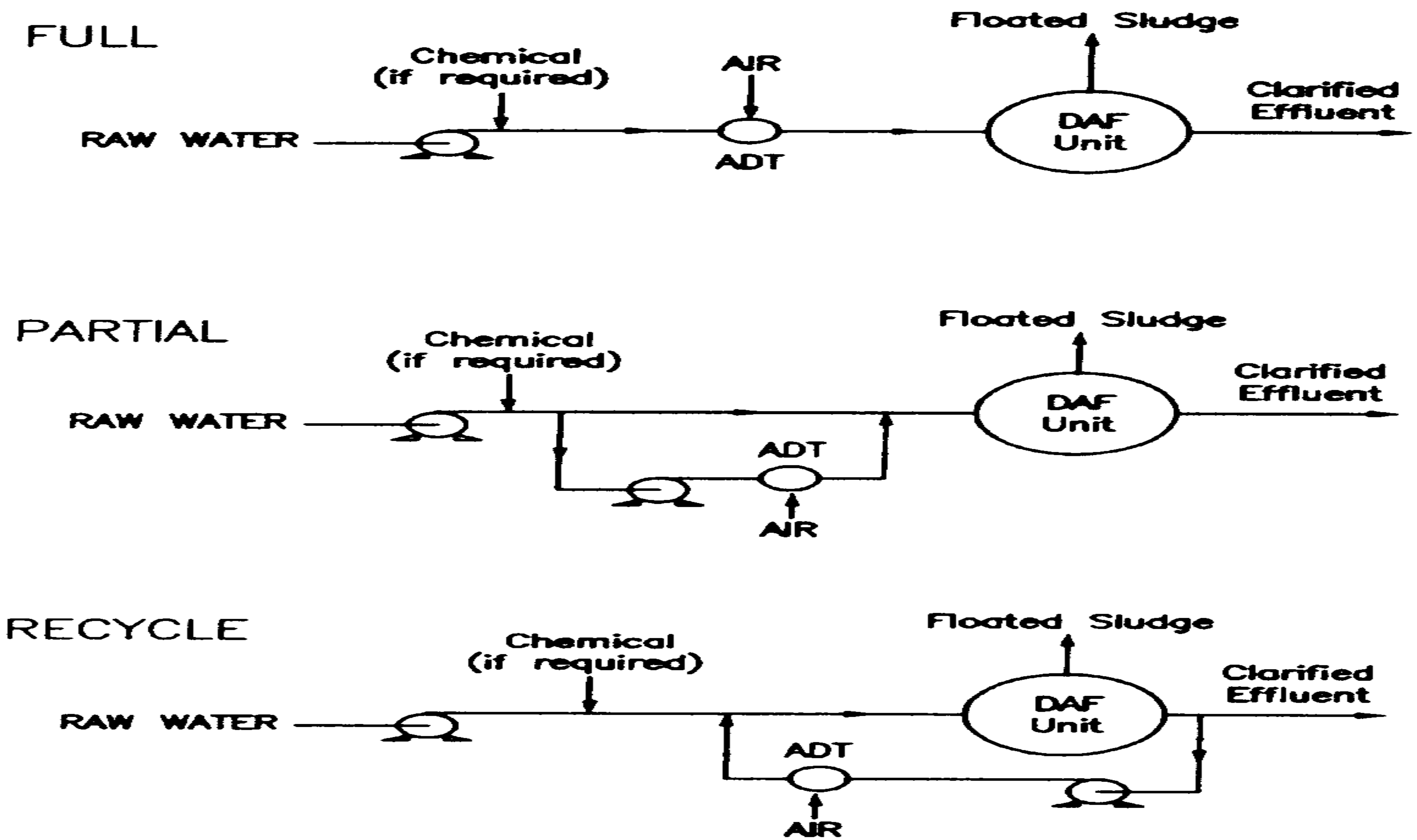




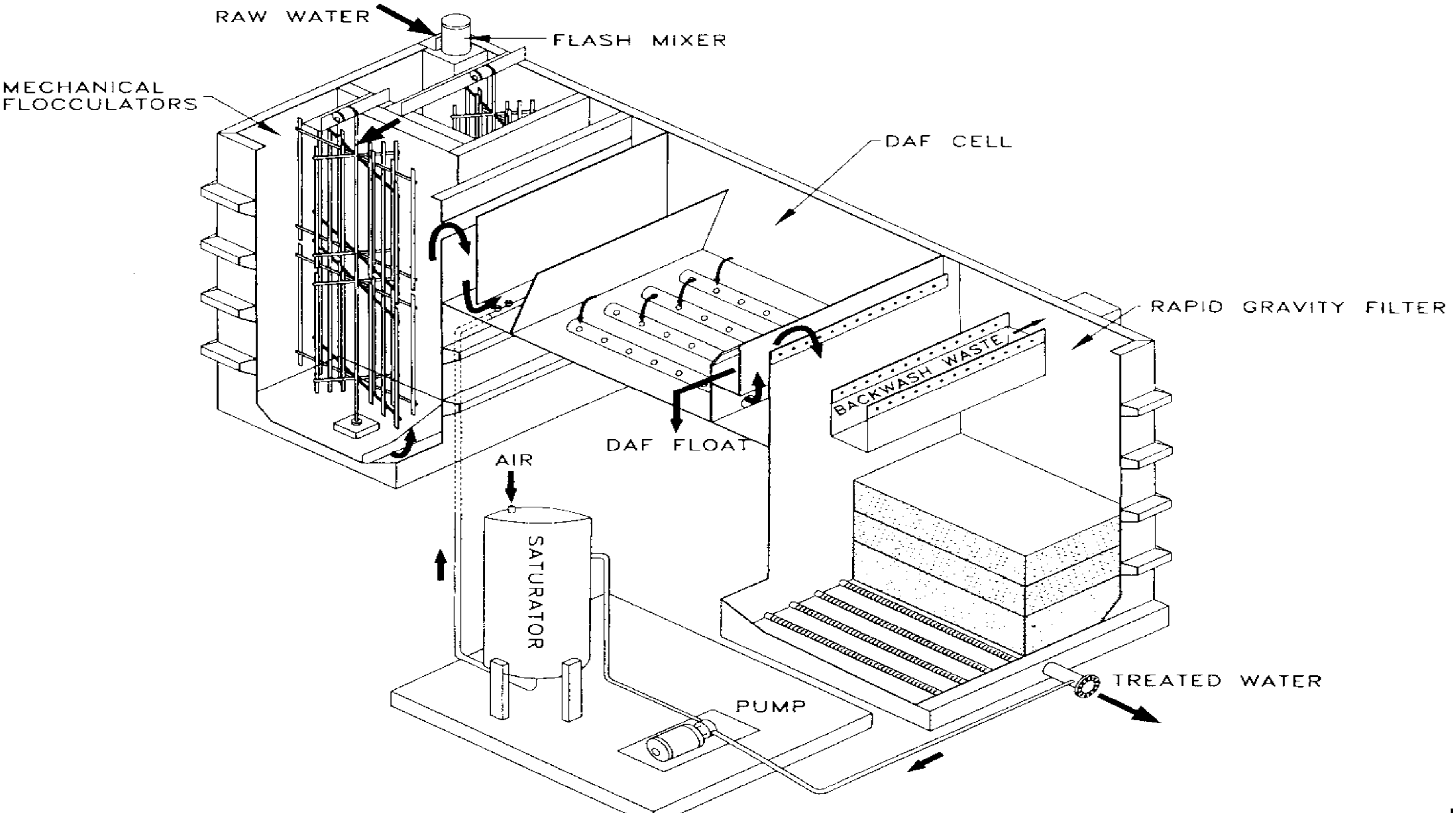
Improved gas dissolving technologies



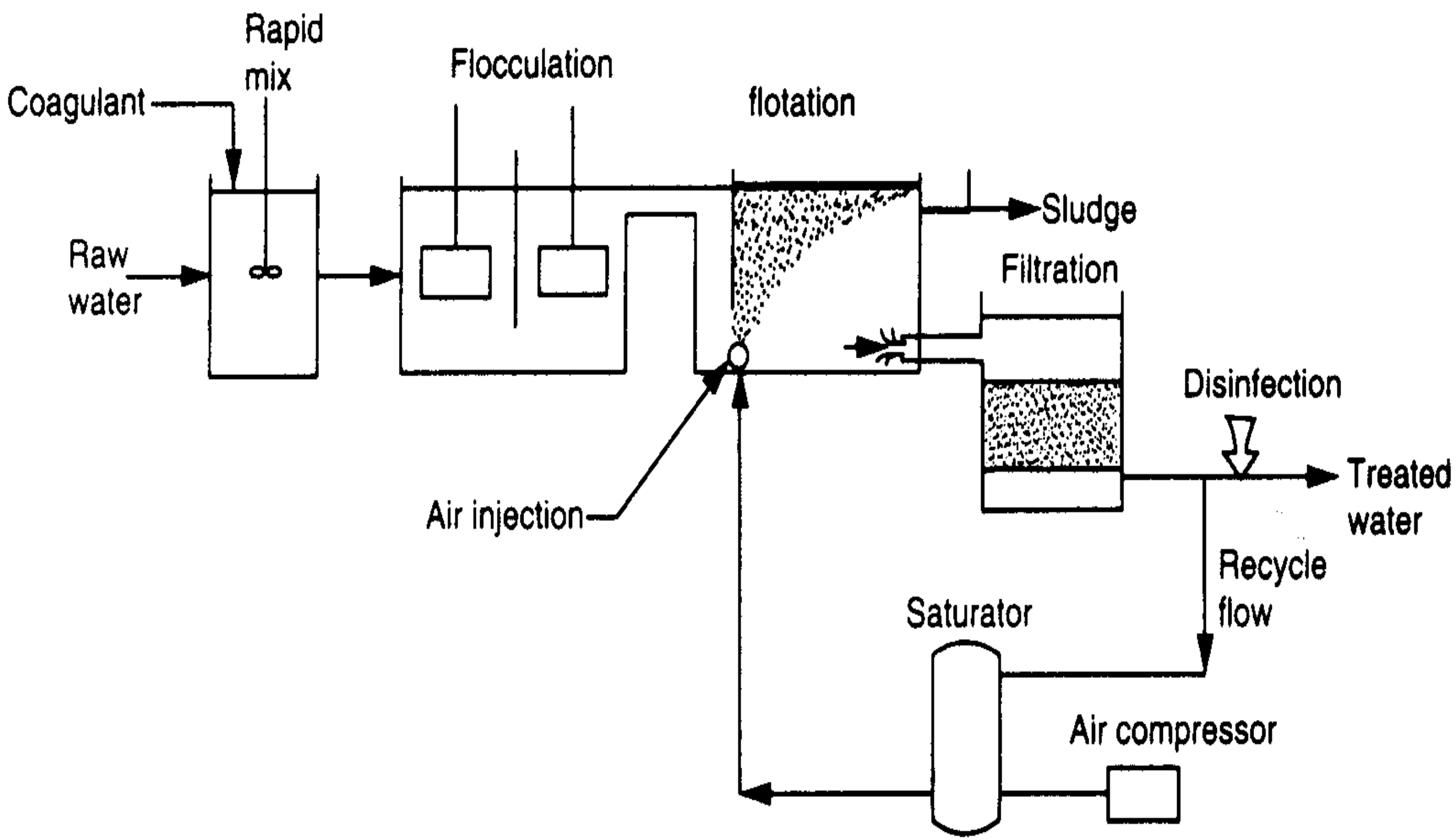
Improved operational modes: (1) full flow pressurization mode; (2) partial flow pressurization mode; and (3) recycle flow pressurization mode. [4]



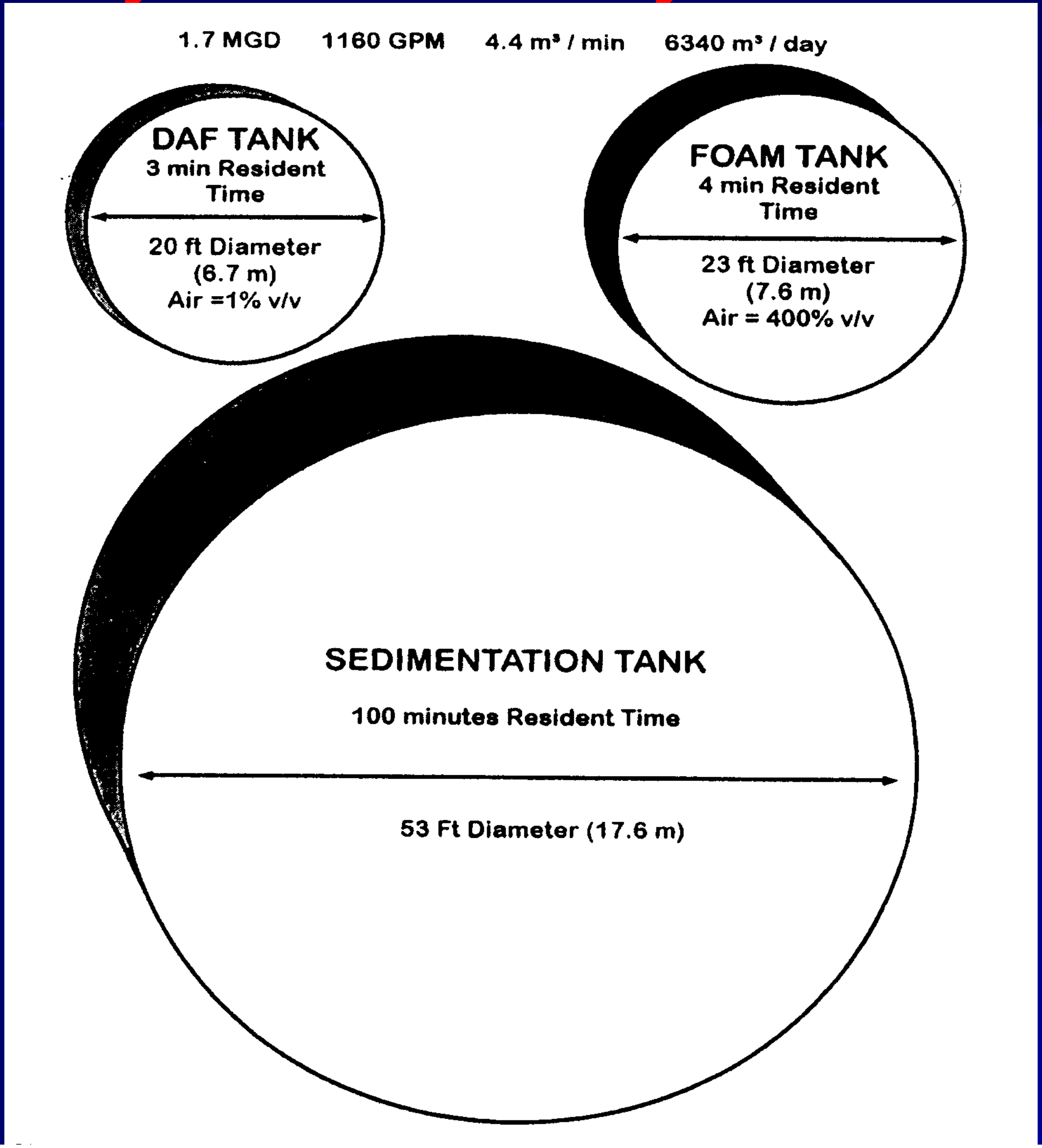
Flotation package plant for small and medium-size water or wastewater treatment including all unit processes in one unit



Medium to large-size municipal plants (with sufficient land space and budget) adopt independent unit processes and unit operations

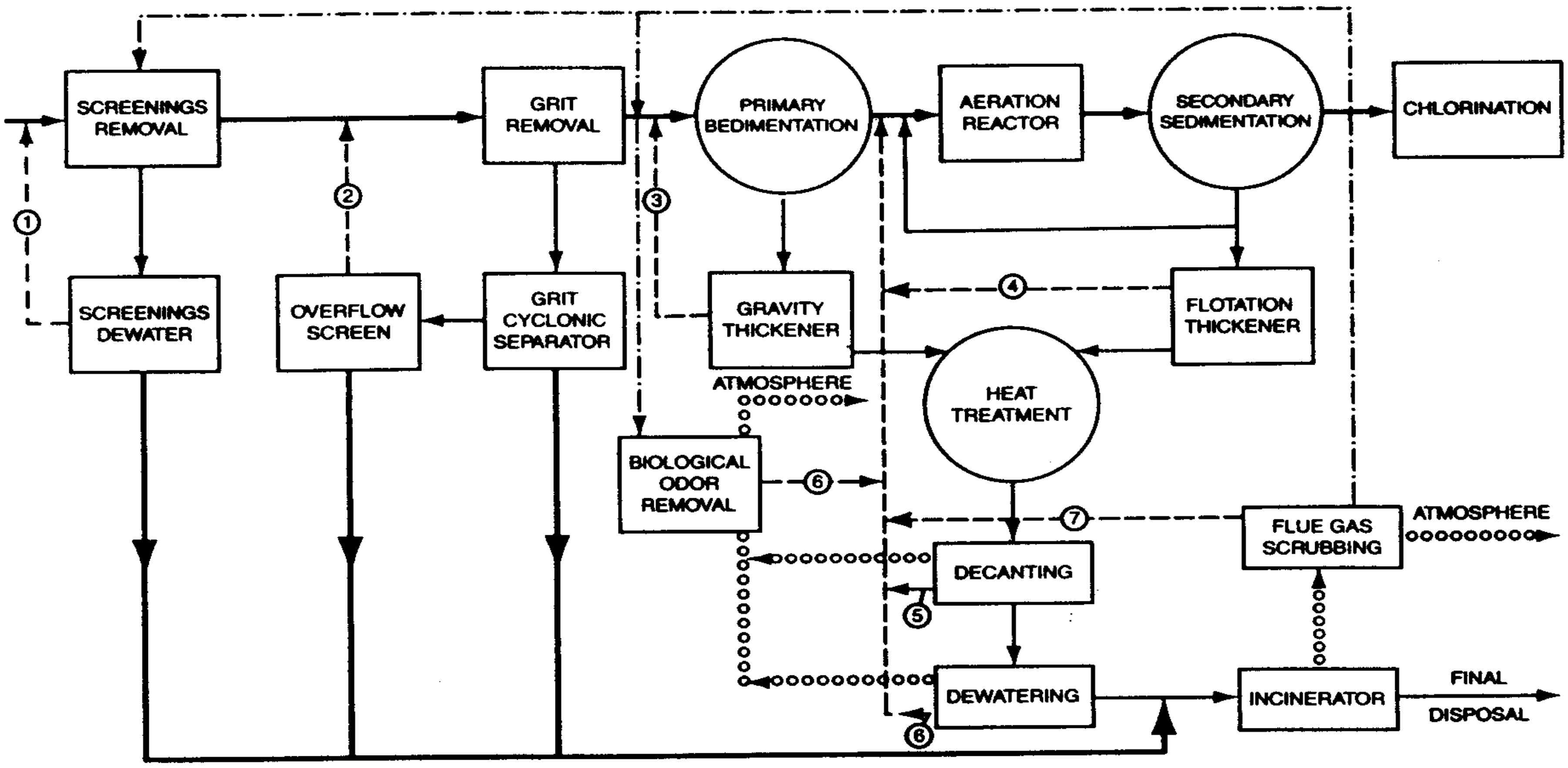


Process improvement: replacement of bulky sedimentation with much smaller and shallower DAF for primary and secondary clarifications [3]

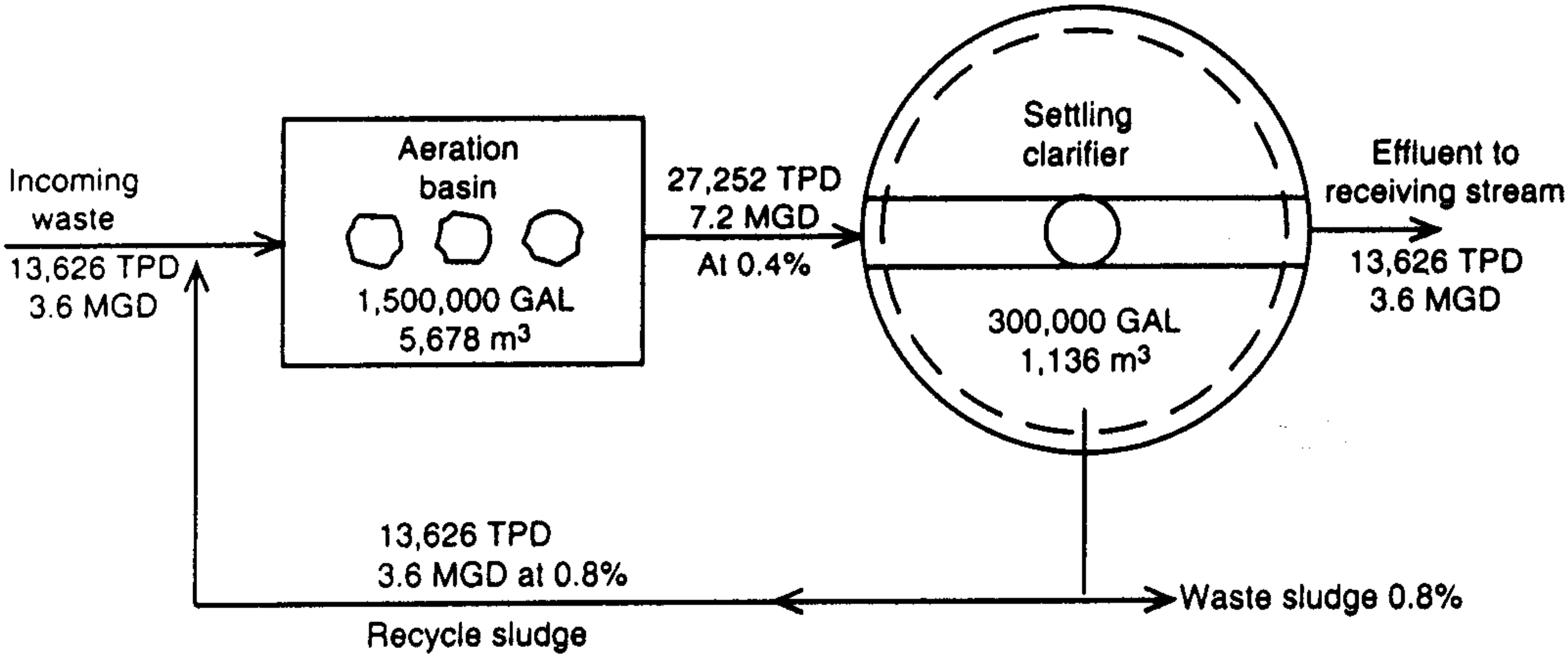


Improvement of industrial applications (with limited land space and low budget): adoption of small and shallow DAF with almost zero foot print [3]

Traditional DAF application was for thickening of secondary sludge; Now improved DAF is also for primary and secondary clarification

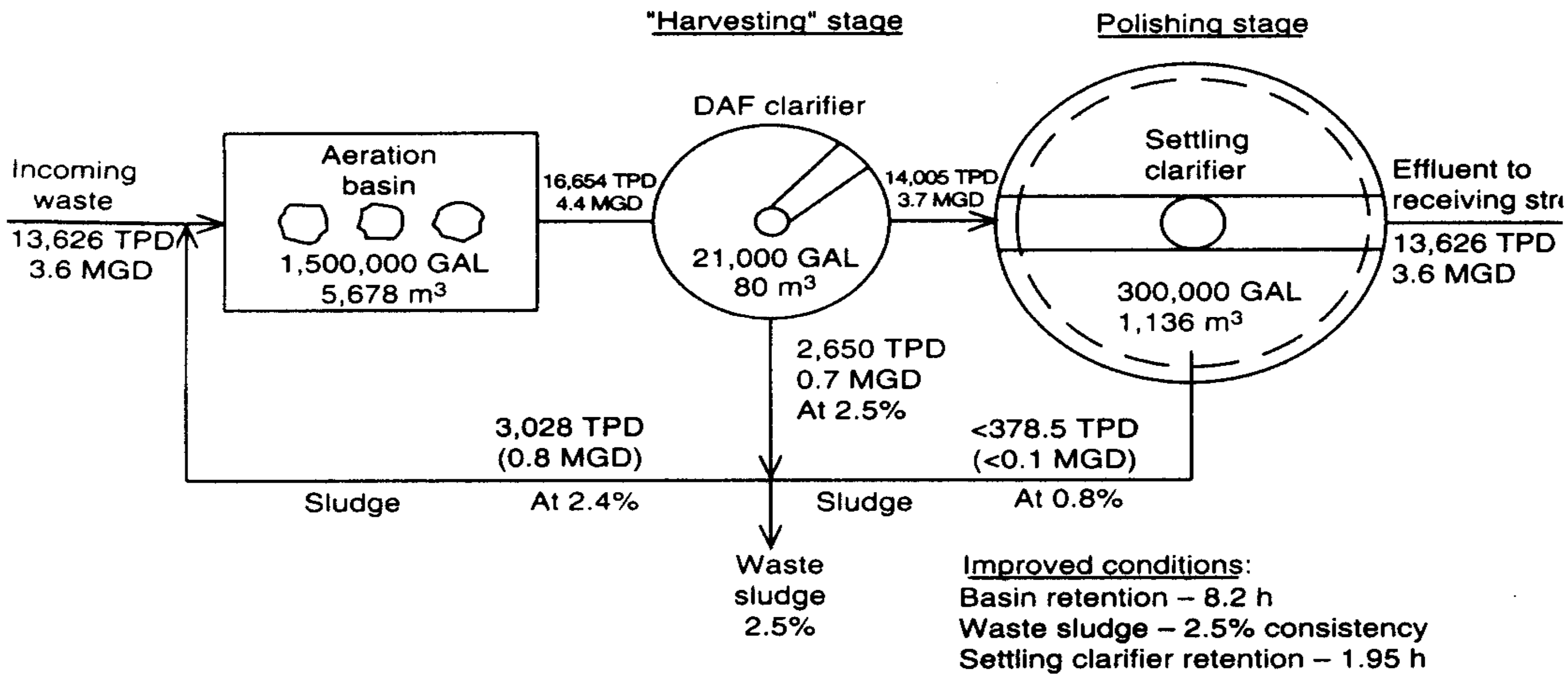


Case study: an existing biological WWTP needed improvements: Aeration retention = 5 hr; waste sludge = 0.8 %; sedimentation retention = 1 hr; Effluent limitations could not be met.

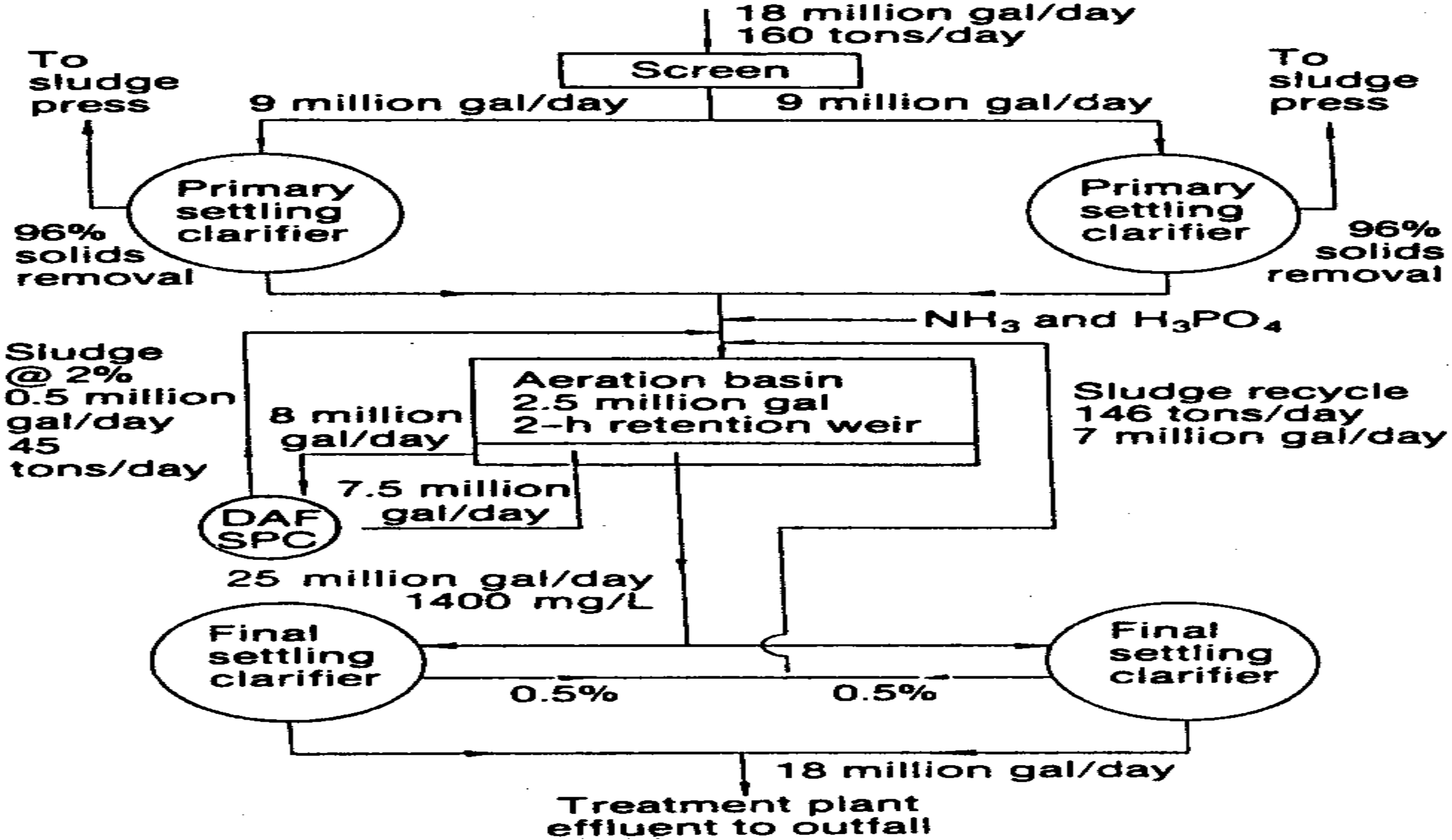


Original conditions:
Basin retention – 5 h
Waste sludge – 0.8% consistency
Settling clarifier retention – 1 h

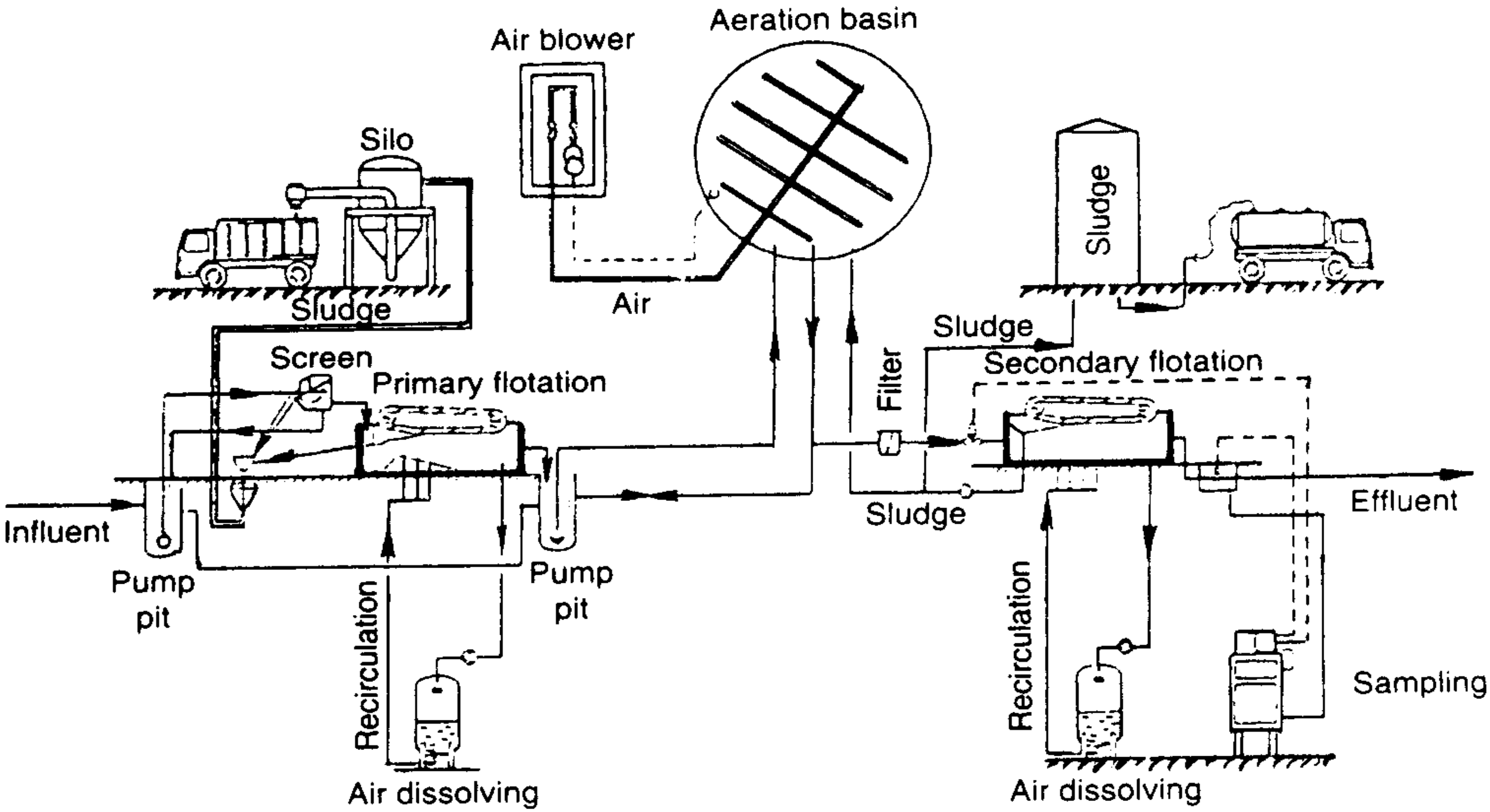
Case study solution: installation of a small DAF between aeration basin and sedimentation for significant improvements: Aeration retention = 8.2 hr; waste sludge = 2.5 %; sedimentation retention = 1.95 hr; Effluent limitations can now be met.



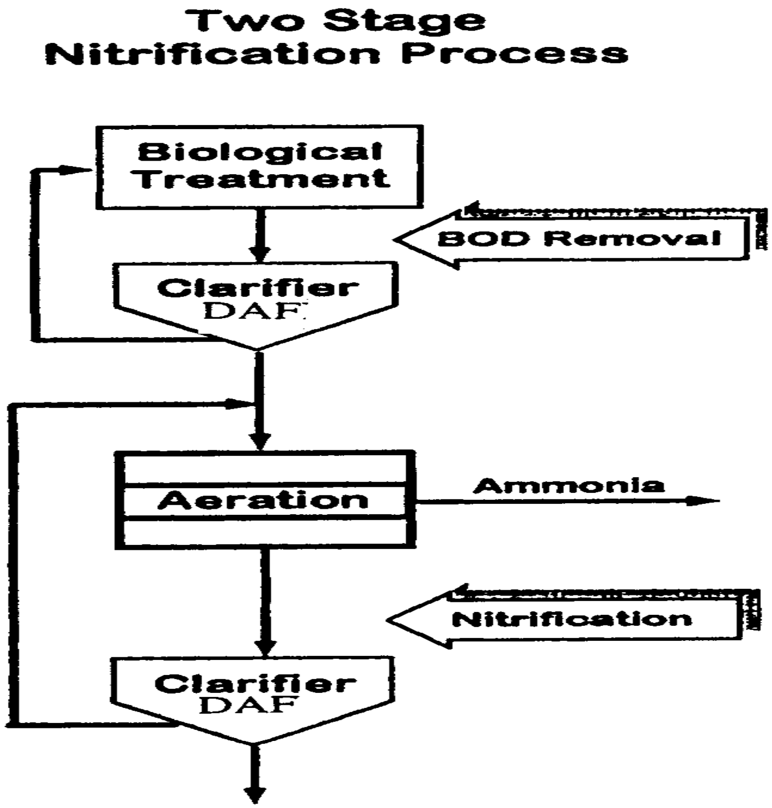
Champion International Corp (Paper Mill) 18-MGD WWTP Improvements: installation of a Supracell DAF between the existing aeration basin and two final settling clarifiers; all problems are solved [4]

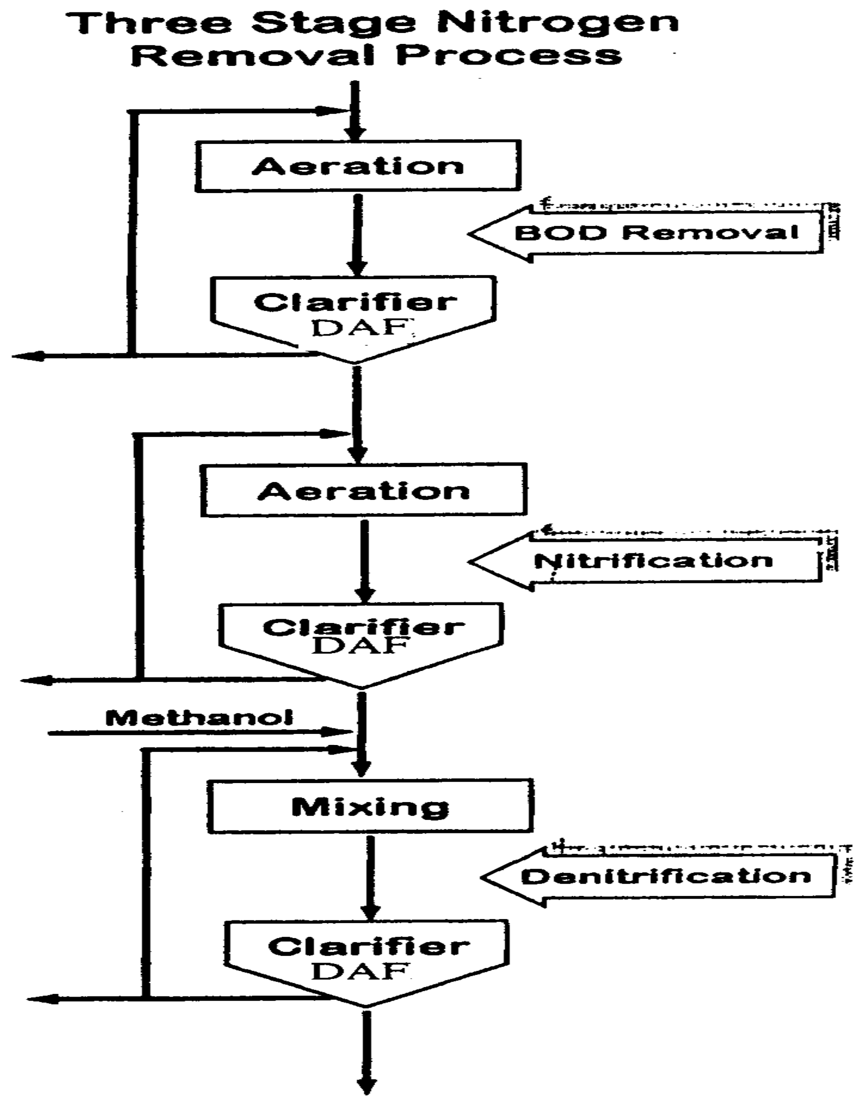


Dairy biological WWT process system improvements: adoption of DAF for both primary and secondary Flotation [4]

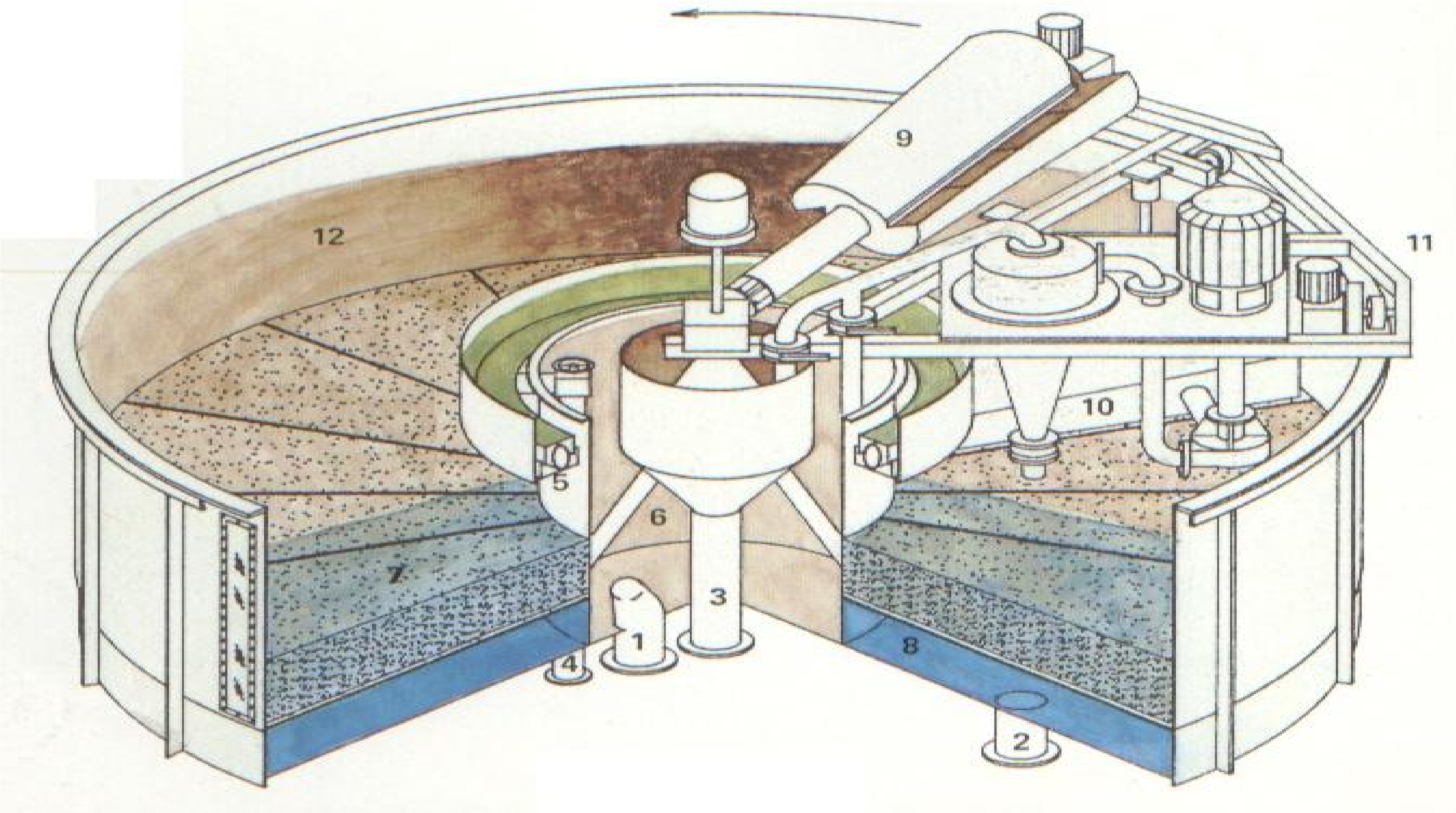


Biological nitrification & denitrification process improvements: adoption of DAF for tertiary clarification

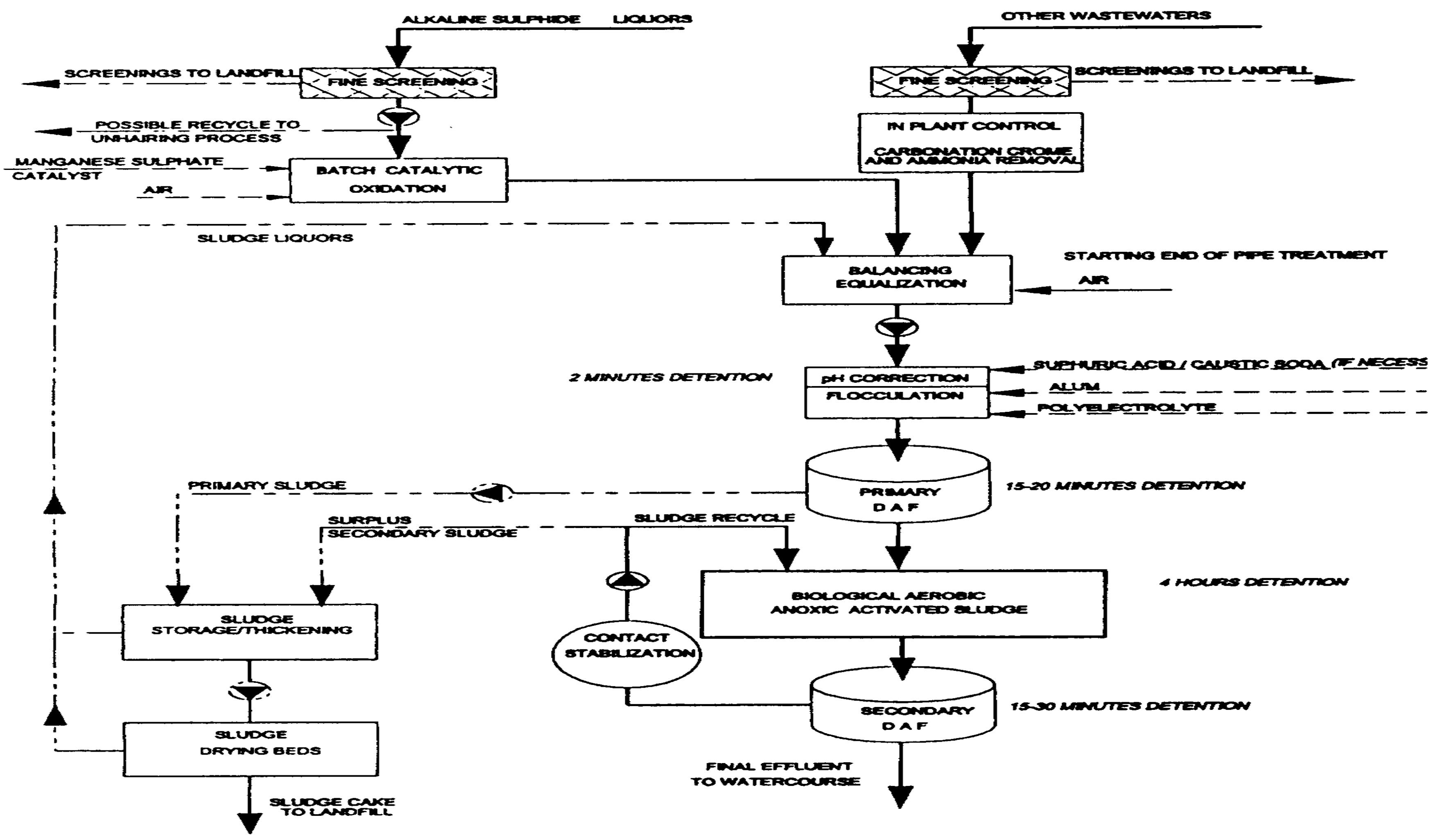




Recommended final stage tertiary WW treatment: combined DAF-filtration clarifier or equivalent (tertiary clarification + tertiary filtration).



Tannery WWTP improvements: (1) combined physicochemical and biological treatment; (2) primary DAF clarification and secondary DAF clarification [7]

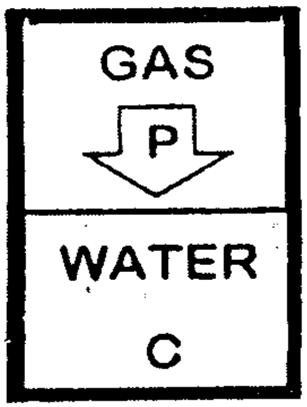


USEPA DAF performance data: DAF is highly effective for removal of classical pollutants, toxic heavy metals and toxic organics [4]

Control Technology Summary for Dissolved Air Flotation

Pollutant	Effluent concentration: Range	Effluent concentration: Median	% Removal
Classical pollutants (mg/L)			
BOD (5-d)	140–1000	250	68
COD	18–3200	1200	66
TSS	18–740	82	88
Total phosphorus	<0.05–12	0.66	98
Total phenols(a)	>0.001–23	0.66	12
Oil and grease	16–220	84	79
Toxic pollutants (μg/L)			
Antimony	ND–2300	20	76
Arsenic	ND–18	<10	45
Xylene	ND–1000	200	97
Cadmium	BDL–<72	BDL	98[a]
Chromium	2–620	200	52
Copper	5–960	180	75
Cyanide	<10–2300	54	10
Lead	ND–1000	70	98
Mercury	BDL–2	BDL	75
Nickel	ND–270	41	73
Selenium	BDL–8.5	2	NM
Silver	BDL–66	19	45
Zinc	ND–53000	200	89
Bis(2-etHylhexyl) phthalate	30–1100	100	72
Butyl benzyl phthalate	ND–42	ND	>99
Carbon tetrachloride	BDL–210	36	75
Chloroform	ND–24	9	58
Dichlorobromomethane		ND	>99
Di-*N*-butyl phthalate	ND–300	20	97
Diethyl phthalate		ND	>99
Di-*N*-octyl phthalate	ND–33	11	78
N-nitrosodiphenylamine		620	66
2,4-Dimethylphenol	ND–28	14	>99
Pentachlorophenol	5–30	13	19
Phenol	9–2400	71	57
Dichlorobenzene	18–260	140	76
Ethylbenzene	ND–970	44	65
Toluene	ND–2100	580	39
Naphthalene	ND–840	96	77
Anthracene/phenanthrene	0.2–600	10	81

Various gases (including green house gas, carbon dioxide) can be compressed for generating fine gas bubbles for flotation



P = Pressure of the the gas

Note: 1 atm = 1.01 Bar = 14.7 psi

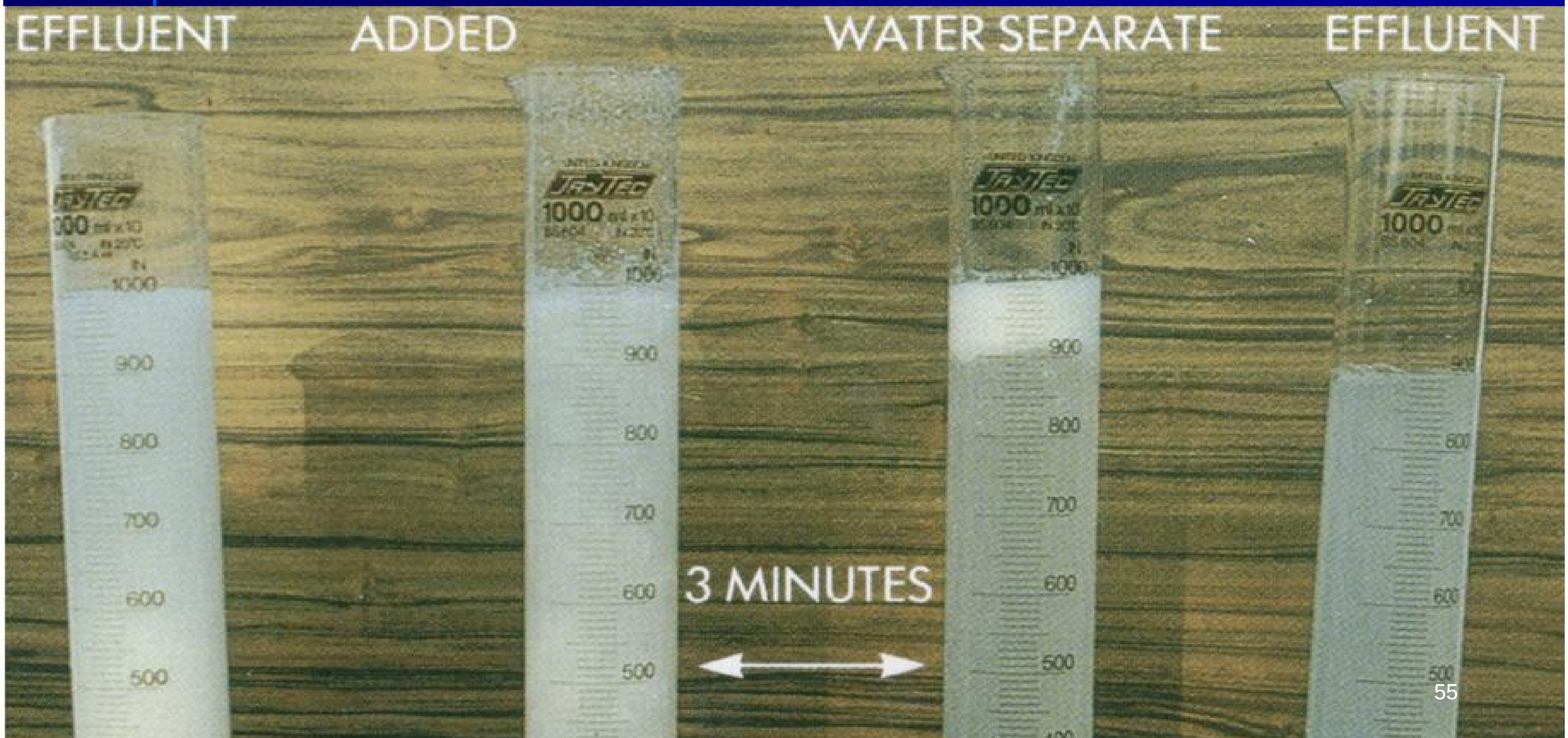
C = Concentration of the gas in a saturated solution

mL(STP) / 100 mL water = % v/v gas / water

Solubilities of some gasses, P = 1 atm

Temp °C	Air	Oxygen	Nitrogen	Hydrogen	CO_2
4	2.63	4.40	2.14	0.206	14.7
20	1.87	3.10	1.54	0.182	8.78
50	1.30	2.09	1.09	0.161	4.36

Dairy wastewater treatment by dissolved carbon dioxide flotation (DCDF): (1) starting from far left end, the dairy effluent is milky and cloudy, (2) DCDF is in action; (3) the white sludge is floated to the top; (4) the supernatant is the DCDF effluent.



Summary

- Various highly efficient flotation processes and systems are introduced for water and wastewater infrastructure sustainability. This publication covers the following subjects: (a) Flotation types , theories, principles, and “zero velocity concept”; (b) Unit processes of mixing, coagulation, precipitation, flocculation, clarification (flotation or sedimentation), filtration, disinfection, sludge thickening and sludge dewatering; (c) Flotation rising rate, surface loading rate, and detention time; (d) Dissolved air flotation (DAF), DAF-filtration (DAFF) and sedimentation comparison; (e) Various municipal and industrial applications of DAF and DAFF; (f) Full scale rectangular and circular DAF and DAFF installations for potable water treatment and industrial effluent treatment when land space and budget are limited; (g) upgrading an existing sedimentation to a DAF-sedimentation clarifier; (h) DAF sludge thickening and screwpress sludge dewatering (Float Press); (i) Oxyozosynthesis system (oxygenation, ozonation, sludge wet oxidation, and Float Press sludge dewatering); (j) Biological or physicochemical sequencing batch reactor (SBR); (k) Recent advances in and case histories of dissolved gas flotation (DGF), primary flotation, secondary flotation, tertiary flotation, nitrification, denitrification, flotation sludge thickening, dissolved carbon dioxide flotation (DCDF), dairy wastewater treatment (WWT), and tannery WWT.

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