

## LENOX INSTITUTE PRESS

Auburndale, Massachusetts 02466, USA

"ENVIRONMENTAL SCIENCE, TECHNOLOGY,  
ENGINEERING AND MATHEMATICS (STEM)" Series

# LABORATORY PROCEDURES AND APPARATUS FOR CHEMICAL COAGULATION/PRECIPITATION, SEDIMENTATION, DISSOLVED AIR FLOTATION, DISPERSED AIR FLOTATION, AND FILTRATION

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Wang, LK, Wang, MHS (2022). Laboratory Procedures and Apparatus for Chemical Coagulation/Precipitation, Sedimentation, Dissolved Air Flotation, Dispersed Air Flotation, and Filtration. In: "*Environmental Science, Technology, Engineering, and Mathematics (STEM)*", Wang, LK, Wang, MHS, and Pankivskiy, YI (editors). Volume 2022, Number 1, January 2022; 51 pages.. Lenox Institute Press, MA, USA. 2022(1), ISBN 978-0-9890870-3-2.

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## CHAPTER 1

## PROCEDURES AND APPARATUS FOR CHEMICAL COAGULATION SIMULATION

Chemical coagulation and flocculation are an important part of water and wastewater clarification. Coagulation or destabilization of a colloidal suspension results in joining of minute particles by physical and chemical processes. Flocculation results in formation of a larger, settleable flocs by bridging. These are commonly the first processes in a water or wastewater treatment sequence to remove either suspended matter or color. Adsorption of ionic forms also occurs to varying degrees depending on the type ion involved and the presence and amounts of other chemical constituents in the water or wastewater.

Inorganic coagulants (aluminum, iron, magnesium salts, etc.) may be used to coagulate particles and to form settleable flocs composed of the hydrous metal oxide precipitates and impurities. Alkalinity and pH controls are extremely important whenever the inorganic coagulants are used. EXPERIMENT I introduces several recommended laboratory experimental procedures involving the use of inorganic coagulants.

Polyelectrolytes are high molecular weight polymeric substances used in water purification and waste treatment to aid in the clarification of turbid suspensions or the dewatering of sludges. These compounds consist of a long chain organic "backbone" with various types of ionic (cationic or anionic) or non-ionic solubilizing groups. Because of the extremely long chain lengths one end or segment of the polymer molecule is capable of reacting independently of the other end or segments. The individual segments are adsorbed onto the surfaces of the dispersed particles and bridging between the normally stable (unsettleable) sol particles results. Under proper conditions of time, temperature, concentration and mixing, this bridging leads to a settleable or filterable floc. This mechanism of destabilization by polymers is commonly known as chemical coagulation. Although electrostatic interactions between polyelectrolyte and particle are important it has been observed that anionic (negative) polymers will destabilize negative sols. Polyelectrolytes may be obtained that vary significantly in molecular weight and composition, as well as charge. These may be natural products, such as some starches and gums, or synthetically produced. Not all of these substances are

acceptable for use with drinking waters. At the present time there is no analytical way to predict the behavior or applicability of a given polymer with a particular water or waste. Polymers are less sensitive to pH variations than metal coagulants, however, the dose required for optimum clarification varies over much wider ranges. Alkalinity control is not important when an organic polymer is used alone as the sole coagulant for floc formation or enhancement. EXPERIMENT II introduces a recommended laboratory experiment involving the evaluation of a polymer as a coagulant.

When both inorganic salt (such as alum) and organic polymer are used as coagulants and coagulant aid, respectively, in a treatment system, alkalinity and pH controls become important. In this case, the laboratory experiments listed in EXPERIMENT I must be followed for process optimization.

In general, chemical coagulation (or flocculation) experiments can be conducted in a Standard Jar Test Apparatus (Figure 1) for determining the optimum chemical dosage. The apparatus has six motorized stirrers which can be turned at same speed. Jar tests are conducted with various coagulants and coagulant aids at different dosages and pH conditions. Usually, one liter of test sample and necessary chemicals are placed in a beaker and rapidly mixed by the stirrer at 100 rpm for one minute, then slowly flocculated at 15-30 rpm for 10 minutes or longer, and finally settled at 0 rpm for 30 minutes. The settled supernatant liquid in the beaker is sampled for water quality analysis. Both the supernatant and the settled sludge are also visually observed and recorded.

The chemical coagulation and flocculation tests serve to indicate the optimum chemical dosages for removal of turbidity and color, including such auxiliary facets as pH adjustment and the necessity for the supplemental use of activated carbon. Jar tests, furthermore, yield a wealth of qualitative information on the rate of agglomeration as a function of energy input (paddle speed), the settleability of the floc formed, the floatability of the floc formed, the clarity of the treated water (which might be related to the subsequent length of filter run).

Assembly Instructions

1. Insert front leg (Item 3F) in opening shown and screw up tight.
2. Insert 2 back legs (Item 3R) in holes in projecting arms in rear of stirrer and turn cap nuts (Item 3N) down tight.
3. Insert paddle (Item 7) in opening in bottom of stirrer and push through. Slip height adjustment bushing (Item 47) over end of shaft with thumbscrew (Item 48) screwed out enough to allow entry. Place bakelite knob (Item 11) on end of shaft, push down tight and screw in set screw (Item 11A) until tight.

Instructions for Maintenance

1. Lubricate paddle shafts occasionally with vaseline and wipe off surplus.
2. Put a few drops of machine oil in the ten oil holes provided on top of stirrer.

SPECIFICATIONS:

LENGTH - 34"  
 HEIGHT - 16" (OVERALL)  
 DEPTH - 10 3/4"  
 WEIGHT - 24 LBS.

VOLTAGE

MODEL 300: 120 VAC, 50/60 Hz.  
 MODEL 302: 220 VAC, 50/60 Hz.

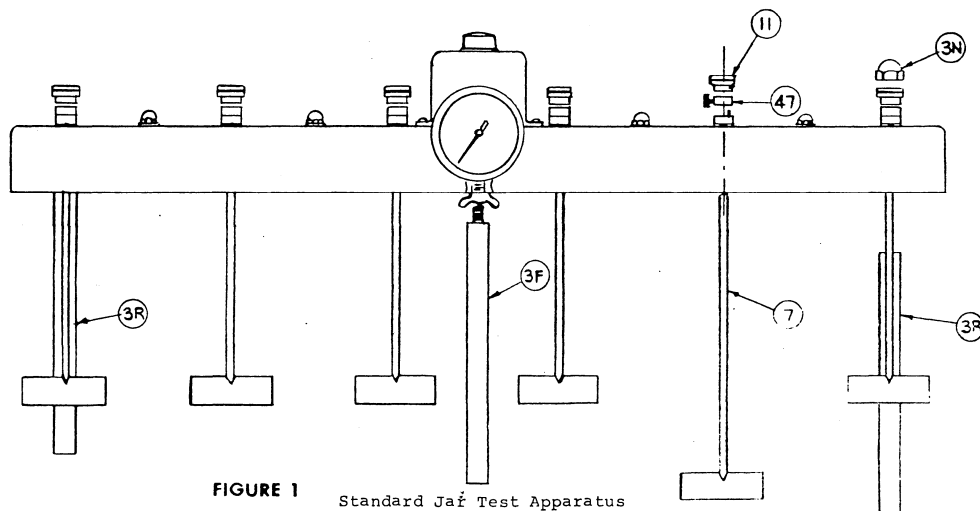


FIGURE 1

Standard Jar Test Apparatus

## CHAPTER 2

PROCEDURES AND APPARATUS FOR DISSOLVED  
AIR FLOTATION SIMULATION  
(FULL FLOW PRESSURIZATION SYSTEM)

A compressed air tank available from Sears, Roebuck and Company, Chicago, Illinois (e.g. Sears 2-gallon Open Top Sprayer, Model 786.15371) is modified by removing the nozzle on its hose extension and fitting a pressure gauge into the tank. An 1000-ml plastic graduated cylinder is fitted with a valve on the bottom to draw off supernatants. Both the modified compressed air tank and cylinder are shown in Figure 2.

The dissolved air flotation (DAF) unit can be operated under the following three conditions: (a) full flow pressurization (Figure 3-1), (b) partial flow pressurization (Figure 3-2), and (c) recycle flow pressurization (Figure 3-3).

To start a DAF full flow pressurization experiment, the compressed air tank, shown in Figure 2, is filled half full with raw or pretreated liquid sample (i.e. influent) that has been adjusted to process temperature. The compressed air tank is then pumped to 45-65 psig and shaken for 2 minutes to allow the air to dissolve in the sample. The first portion of pressurized sample (approximately 100 ml) is released into the sink to allow any bound air to escape and to clear the outlet.

The remaining pressurized sample (1000 ml) is then carefully and slowly released into the modified 1000 ml graduated cylinder (see Figure 2) by putting the outlet shaft all the way to the bottom of the cylinder and moving the shaft upward with the upward flow of the filled sample. (If proper dose of chemical is added at the same time when 1000 ml of pressurized sample is released into the 1000 ml cylinder, it is suggested that the filled cylinder be capped and inverted once to insure proper mixing of chemical). Note when a line of demarcation first appears between the clarified liquid at the bottom and the solids layer at the top, it is time to estimate the rising velocity of the sludge blanket by noting the level of the interface at regular time intervals. The rising velocity (in/min) of the sludge-water interface should be estimated accurately with the aid of a stop watch. A light source behind the cylinder may enhance the visibility of the particles. After two to three minutes, the ml of floating sludge, ml of settled sludge if any, and physical characteristics of supernatant are recorded. Finally,

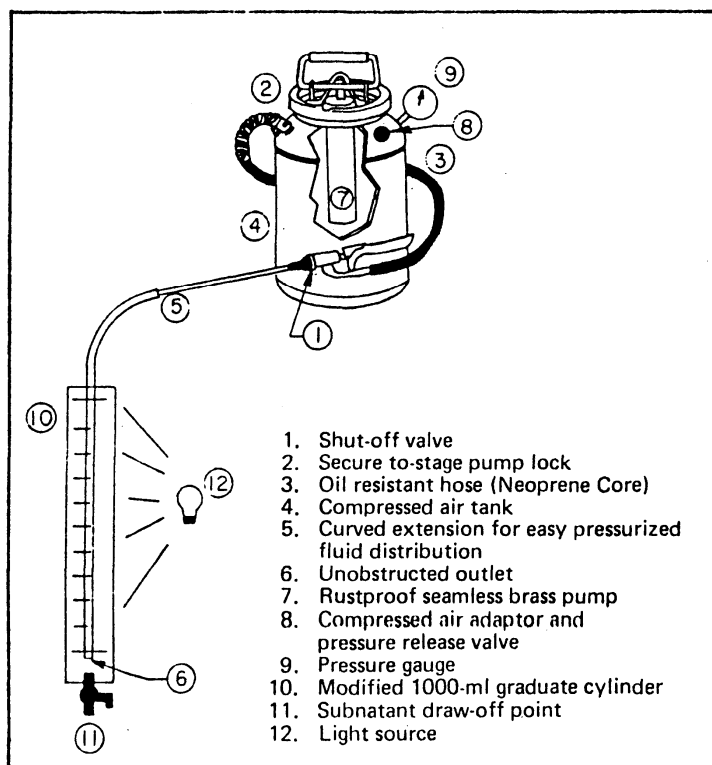


Fig. 2 Laboratory Dissolved Air Flotation Apparatus



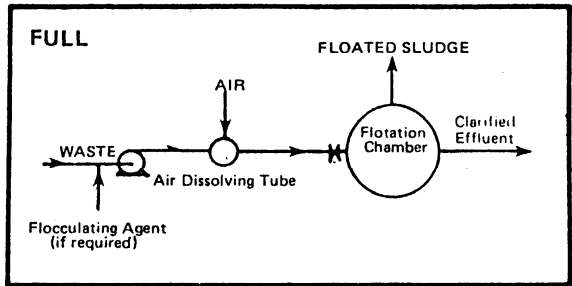


Fig. 3-1 FULL FLOW PRESSURIZATION SYSTEM

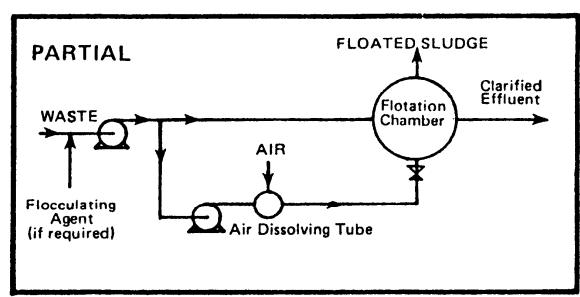


Fig. 3-2 PARTIAL FLOW PRESSURIZATION SYSTEM

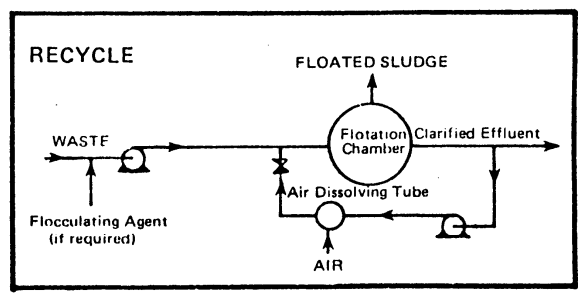


Fig. 3-3 RECYCLED FLOW PRESSURIZATION SYSTEM

at least 200 ml of subnatant (i.e. effluent) are drawn off from the cylinder bottom for testing suspended solids and other water quality parameters.

Equation 1 can be used to calculate the air to solids ratio for the full flow pressurization system based on the laboratory experimental results.

$$A/S = 1.3a(FP-1)/X \quad (1)$$

where

- A = Mass flow rate of air released for flotation of suspended solids, mg/sec
- a = Air solubility, ml/l
- 1.3 = Weight in milligrams of 1 milliliter of air
- 1 = One atmosphere of air remaining in solution after depressurization

The flotation efficiency in terms of suspended solids removal can be calculated by the following formula:

$$E = 100 (1 - X_e/X) \quad (2)$$

where

- E = Percentage of suspended solids removal
- X = Suspended solids of influent, mg/l
- X<sub>e</sub> = Suspended solids of effluent, mg/l

## CHAPTER 3

PROCEDURES AND APPARATUS FOR DISSOLVED  
AIR FLOTATION SIMULATION  
(PARTIAL FLOW PRESSURIZATION)

The experimental apparatus for partial flow pressurization of DAF (Figure 3-2) is identical to that for full flow pressurization, shown in Figure 2.

To start a DAF partial flow pressurization experiment, the 1000 ml graduated cylinder (Figure 2) is initially filled with desired volume ( $V_i$ ) of raw or pretreated liquid sample (i.e. influent not to be pressurized) which is adjusted to the process temperature. The value of  $V_i$  is decided based on the desired percentage of partial flow as follows:

Percentage of Partial Flow	Unpressurized Influent Volume ( $V_i$ )	Pressurized Influent Volume ( $V_p$ )
10%	900 ml	100 ml
20%	800 ml	200 ml
30%	700 ml	300 ml
40%	600 ml	400 ml
50%	500 ml	500 ml

The compressed air tank (Figure 2) is then filled approximately half full with influent (with or without chemical addition) and adjusted to the process temperature. The compressed air tank is subsequently pumped to 45-65 psig and shaken for 2 minutes to allow air to dissolve in the pressurized influent. The first portion of pressurized water (approximately 100 ml) is released into the sink to allow any bound air to escape and to clear the outlet. The remaining pressurized water ( $V_p$ ) is then released into the 1000-ml graduated cylinder (which is initially filled with  $V_i$  ml of the influent) by putting the outlet shaft all the way to the cylinder bottom and moving the shaft upward with the upward flow of the sample ( $V_i + V_p$ ).

The rising velocity (in/min) of floating sludges or flocs is timed with a stop watch by observation. After two to three

minutes, important physical characteristics of floating sludge, settled sludge and supernatant are recorded. At least 200 ml of supernatant are drawn off from the cylinder bottom for testing suspended solid and other water quality parameters.

Equation 2' can be used for calculation of flotation efficiency.

## CHAPTER 4

PROCEDURES AND APPARATUS FOR DISSOLVED  
AIR FLOTATION SIMULATION  
(RECYCLE FLOW PRESSURIZATION SYSTEM)

The recycle flow pressurization system and the experimental apparatus for the system are shown in Figure 3-2 and Figure 2, respectively.

To start a DAF recycle flow pressurization experiment, the 1000-ml graduated cylinder (Figure 2) is initially filled with desired volume ( $V_i$ ) of raw or pretreated liquid sample (i.e. influent) which is adjusted to the process temperature. The value of  $V_i$  is decided based on the desired percentage of recycle flow as follows.

Percentage of Recycle Flow	Influent Volume ( $V_i$ )	Recycle Volume ( $V_r$ )
10%	900 ml	100 ml
20%	800 ml	200 ml
30%	700 ml	300 ml
40%	600 ml	400 ml
50%	500 ml	500 ml

The compressed air tank (Figure 2) is then filled approximately half full with the recycle water (e.g. clarified effluent or other sources of clean water) adjusted to the process temperature. Suspended solids value on the recycle water ( $X_r$ ) are tested to provide a correction factor in the final calculation. The compressed air tank is subsequently pumped to 45-65 psig and shaken for 2 minutes to allow air to dissolve in the clean water. The first portion of pressurized water (approximately 100 ml) is released into the sink to allow any bound air to escape and to clear the recycle outlet. The remaining pressurized water ( $V_r$ ) is then released into the 1000-ml graduated cylinder (which is initially filled with  $V_i$  ml of the influent) by putting the outlet shaft all the way to the cylinder bottom and moving the shaft upward with the upward flow of the sample ( $V_i + V_r$ ).

The rising velocity (in/min) of floating sludges or flocs is timed with a stop watch by observation. After two to three

minutes, important physical characteristics of floating sludge, settled sludge, and subnatant are recorded. At least 200 ml of subnatant are drawn off from the cylinder bottom for testing suspended solids and other water quality parameters.

The following material balance equation (Equation 3) should be used for recycle flow correction:

$$X_e (V_i) + X_r (V_r) = X_c (1000) \quad (3)$$

where

- $X_e$  = Theoretical effluent suspended solids, mg/l
- $V_i$  = Volume of influent used, ml
- $X_r$  = Suspended solids of recycle water, mg/l
- $V_r$  = Volume of recycle water used, ml
- $X_c$  = Suspended solids of the clarified subnatant, mg/l

The value of  $X_e$  calculated in Equation 3 is then used in Equation 2 for determination of flotation efficiency in terms of suspended solids.  $X_r = X_c$

Equation 4 should be used for calculation of the air to solids ratio based on the laboratory experimental results:

$$A/S = 1.3 a V_r (FP-1)/V_i X \quad (4)$$

The quantity of air which will theoretically be released from solution following pressure reduction can be computed from:

$$a_r = a \cdot (FP_r - P_e)/14.7 \quad (5)$$

where:

- $a_r$  = Air released at atmospheric pressure at 100% saturation, ml/liter liquid. (Air volume at standard conditions, e.g., 0°C + atm. absolute)
- $a$  = Air saturation at one atmosphere pressure, cm<sup>3</sup>/liter (std. conditions)
- $P_r$  = Pressure before release, lb/in<sup>2</sup> absolute
- $P_e$  = Pressure after release, lb/in<sup>2</sup> absolute

Equation 5 is valid for all dissolved air flotation systems (Figures 3-1, 3-2 and 3-3). The actual quantity of air released will depend on how close the equilibrium solubility at  $P_r$  is attained and on the turbulent mixing conditions at the point of pressure reduction. The closeness to equilibrium solubility will depend on the time of retention. The closeness to equilibrium solubility will depend on the time of retention under pressure, on the mass transfer contact surface between air and water and on the degree of mixing. Conventional static holding tanks can usually yield up to 50 percent saturation in the normal retention times.

The use of packing or mixing can produce 90 percent saturation in conventional retention times. This can be taken care of in the calculations by multiplying  $P_r$  by a factor,  $F$ , where  $F$  is the fraction of saturation attained in the retention tank, and is equal to one for water saturated with air.

It should be noted that the operation of the pressure cell closely simulate the recirculation of effluent as used in the full scale flotation system. The returned effluent (recycle water) may be developed by repeated flotation of several different portions of raw waste. After the recycle water has been developed and used in the flotation tests, samples may then be withdrawn for chemical analysis.

EXPERIMENT III introduces a recommended laboratory experimental procedure for the recycle flow pressurization system.

## CHAPTER 5

PROCEDURES AND APPARATUS FOR DISPERSED  
AIR FLOTATION SIMULATION  
(BATCH SYSTEM)

Figures 4 and 5 show the tester dimensions and piping arrangements, respectively of a bench-scale foam separation unit for use in these type of experiments.

To start the batch foam separation (or dispersed air flotation) experiments, sufficient volume of raw water is adjusted to the desired pH with 1.0 N sodium hydroxide or 1.0 N sulfuric acid, an appropriate amount of surfactant is added to the raw water, and the mixture is poured into the Foamer Tester (Figure 4). Compressed air is then diffused through the liquid mixture by means of a plastic cloth grid (Figure 5). Foam is withdrawn from the top and collected in a container. The run is allowed to proceed until no additional foam is formed. A sample of the bulk liquid near the reactor bottom is analyzed for pH, color, turbidity and other water quality parameters. The foam is collapsed in a beaker and its volume measured.

From batch foam separation experiments, one may be able to determine the feasibility of the process and the approximate optimum chemical dosages.



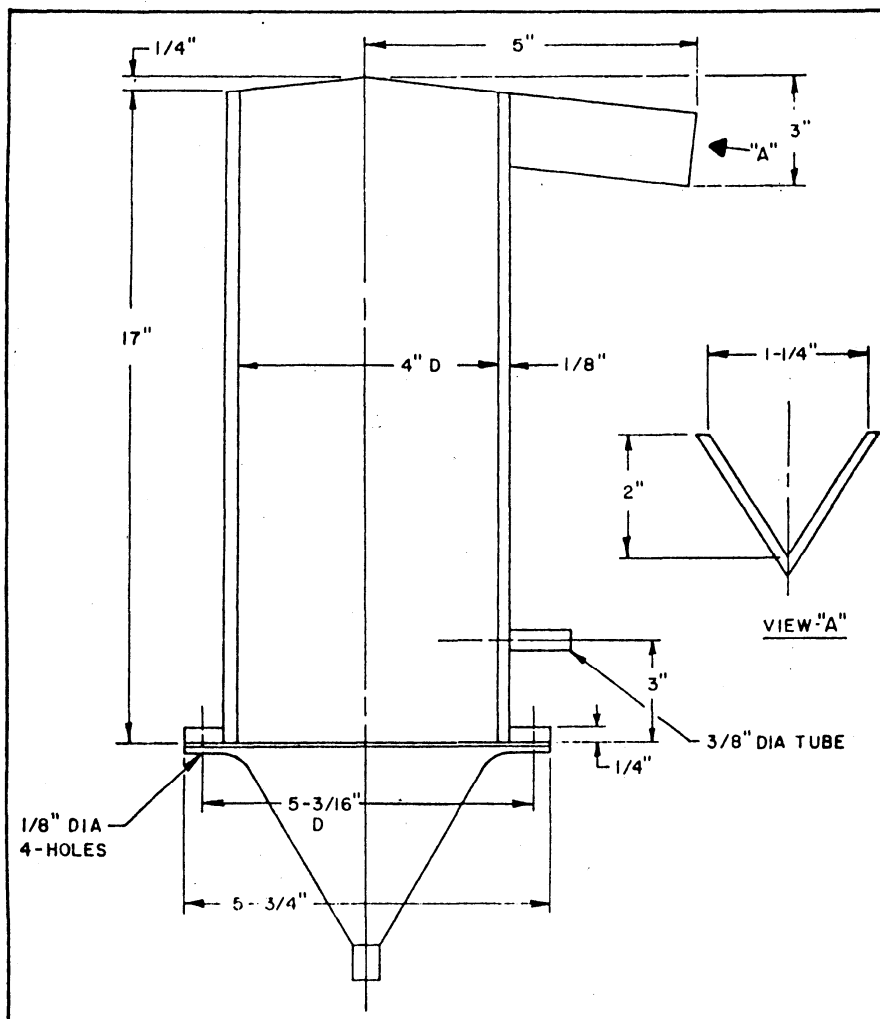


Fig. 4 Dimensions of Bench-Scale Dispersed Air Flotation Cell

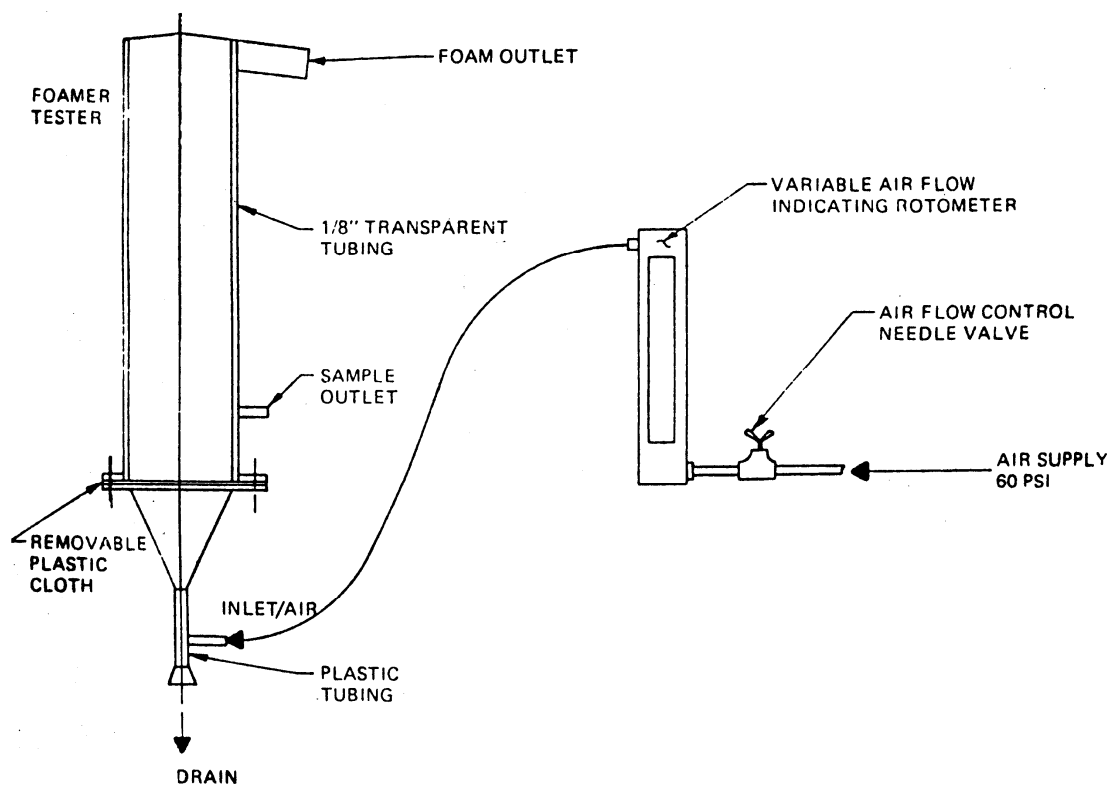


Fig. 5 Piping Arrangement of A Bench-Scale Dispersed Air Flotation Cell

## CHAPTER 6

PROCEDURES AND APPARATUS FOR DISPERSED  
AIR FLOTATION SIMULATION  
(CONTINUOUS SYSTEM)

Figure 6 shows an experimental set-up for continuous foam separation experiment. Continuous pilot plant operations allow the engineers to determine not only the optimum chemical dosages but also the optimum operational conditions in terms of flows, feed locations, chemical dosages, etc.

For the continuous foam separation study, sample solution is prepared, mixed well, and placed in the large feed tank. Four liters of initial sample are taken with the desired amount of collector added, the initial color, turbidity, optical density, surfactant concentration, streaming current reading, conductivity and pH are determined. The collector is also uniformly prepared and placed in a smaller feed tank. The solutions of influent feed and collector are pumped into the foam separation cell at specified rates for each run. The concentrations in the feed tanks are adjusted to provide the desired concentrations of target solute and of collector. Compressed air is diffused through the solution by means of the coarse gas diffuser. After start-up, the bulk liquid is pumped through the system, and the optical density is continuously recorded. The run is continued until a steady state is reached (i.e. there is no change in the optical density). During the steady state, the bubble velocity, and bubble size are measured. Samples of bottom effluent and collapsed foam are taken throughout the entire experiment. Samples are analyzed for color, optical density, residual solute concentration, residual surfactant concentration, turbidity, streaming current reading, conductivity and pH.

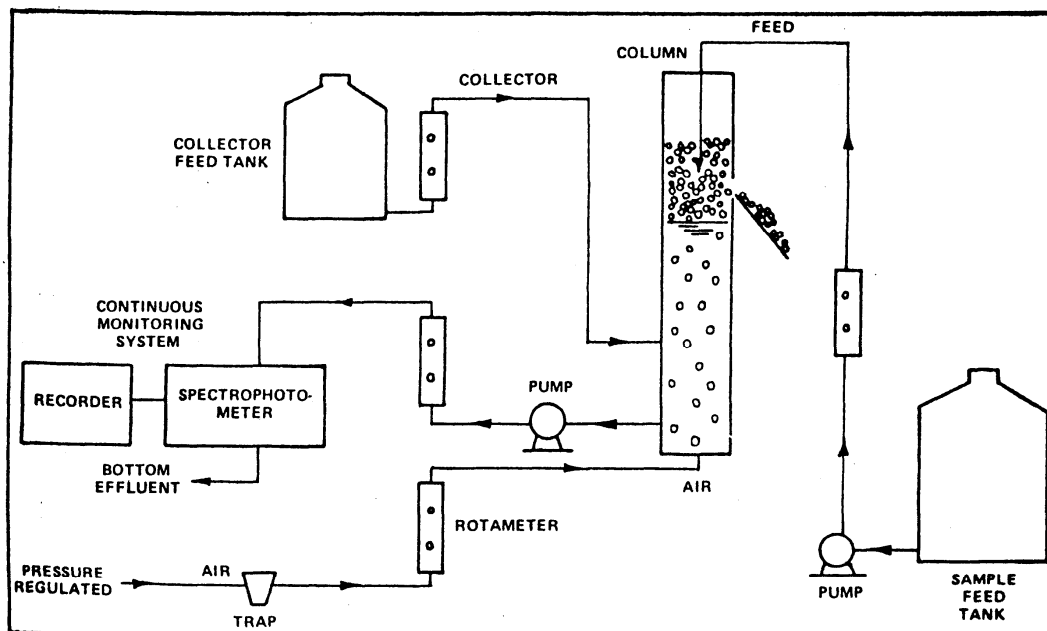


Fig. 6 RECOMMENDED APPARATUS FOR CONTINUOUS FOAM SEPARATION EXPERIMENTS

## CHAPTER 7

PROCEDURES AND APPARATUS FOR  
SIMULATION OF CHEMICAL COAGULATION,  
SEDIMENTATION AND FILTRATION

A conventional physical-chemical treatment system consisting of rapid mechanical mixing, slow mechanical flocculation and filtration (Note: Filtration also includes granular activated carbon) can be used for both water purification and wastewater treatment.

The procedures and apparatus for simulation of the conventional physical-chemical treatment system are partially covered by Chapter 1 (Procedures and Apparatus for Chemical Coagulation Simulation), Experiment I (Coagulation and Flocculation with Hydrolyzine Metallic Salts) and Experiment II (Coagulation and Flocculation with Organic Polymers), with a few modifications and additions.

Since the conventional physical-chemical treatment system relies upon production of heavy and dense flocs for subsequent separation by sedimentation, the rapid mixing speed and detention time as well as flocculation mixing speed and detention time must be either optimized in laboratory or controlled in accordance with the design criteria recommended by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers. (1, 2). For instance, for water purification (a) rapid mixing chamber should be equipped with mechanical devices and its detention time should be not more than 30 seconds; (b) slow mechanical flocculators shall have a detention time of 30 minutes or longer and shall be driven by variable speed drives with the peripheral speed of paddles ranging from 0.5 to 3.0 feet per second (Note: The rotation speed, in the unit of rpm, of a Standard Jar Test Apparatus' paddle can then be determined accordingly); (c) sedimentation generally shall have a minimum of four hours of settling time. Reduced sedimentation time may be approved only when equivalent effective settling can be demonstrated.

For simulation of filtration step, the supernatant of settled water from a Standard Jar Test Apparatus shall pass through either a Whatman filter paper No. 40 (or equivalent) or a simulated bench-scale filtration column. For quick chemical dosage determination and the conventional treatment system simulation, the Whatman filter paper is recommended. For further confirmation testing, the bench-scale filtration column shall be

constructed and operated according to the design criteria recommended by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers. The filtration rate generally should not exceed 3 gpm/ft<sup>2</sup> of filter area except where testing as approved by the reviewing authority has demonstrated. During filter backwash, a minimum rate of 15 gpm/ft<sup>2</sup>, consistent with water temperatures and specific gravity of the filter media, shall be maintained. A backwash rate of 20 gpm/ft<sup>2</sup> or a rate necessary to provide for a 50 percent expansion of the filter bed is recommended. A reduced backwash rate of 10 gpm/ft<sup>2</sup> may be acceptable for full depth anthracite or granular activated carbon filters.

Figure 7 shows a typical filter bed diagram for construction of a bench-scale or pilot filter.

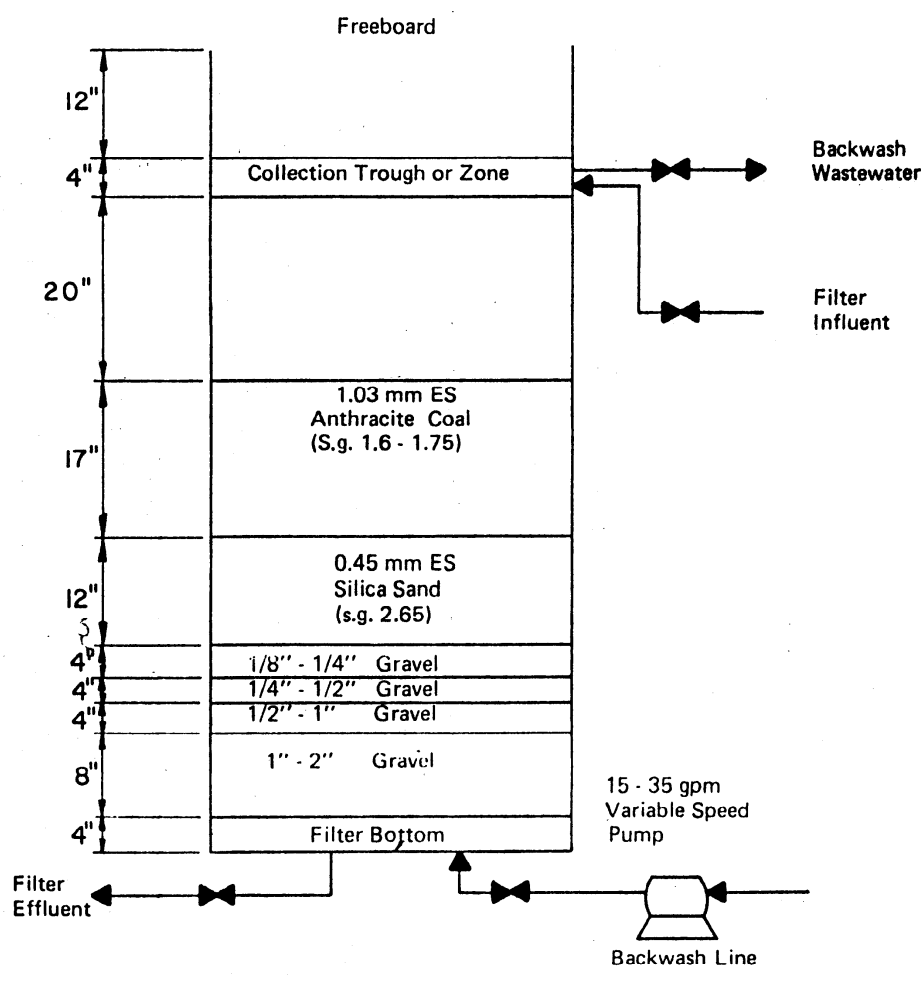


FIGURE 7 FILTER BED DIAGRAM

## CHAPTER 8

PROCEDURES AND APPARATUS FOR  
SIMULATION OF CHEMICAL COAGULATION,  
FLOTATION AND FILTRATION

An innovative physical-chemical treatment system consisting of static rapid mixing, static flocculation, flotation and filtration (Note: Filtration also includes granular activated carbon) can be used for both water purification and wastewater treatment.

The procedures and apparatus for simulation of the innovative physical-chemical treatment system are partially covered by Chapter 1 (Procedures and Apparatus for Chemical Coagulation Simulation), Experiment I (Coagulation and Flocculation with Hydrolyzine Metallic Salts) and Experiment II (Coagulation and Flocculation with Organic Polymers), with a few modifications and additions.

The innovative physical-chemical treatment system requires production of light and small pin flocs for subsequent separation by flotation. Accordingly the rapid mixing at 100 rpm shall not have detention time of over 30 seconds, and the flocculation at 15-30 rpm shall not have a detention time of over 15 minutes. The settling time of a Standard Jar Test shall be zero.

The flocculated water should be immediately filtered by either a Whatman No. 40 filter paper (or equivalent) or a simulated bench-scale filtration column. For quick chemical dosage determination and the innovative treatment system simulation, the Whatman filter paper is recommended. For further confirmation testing the bench-scale filtration column shall be constructed and operated according to the design criteria recommended by the Great Lakes-Upper Mississippi River Board of State Sanitary Engineers.

Alternatively, the flocculated water can be filtered by a filtration bed consisting of only 11 inches of fine quartz sand (effective size = 0.35 mm; uniformity coefficient = 1.6 or less). The fine quartz sand can be supported by fine plastic screen (250 micron size) with either expanded metal support or porous plate support. This filtration apparatus is a simulation of Automatic Backwash Filter (ABF).



## EXPERIMENT NO. I

## COAGULATION AND FLOCCULATION WITH HYDROLYZINE METALLIC SALTS

BACKGROUND

Coagulation and flocculation processes are an important part of water and wastewater treatment. Coagulation or destabilization of a colloidal suspension results in joining of minute particles by physical and chemical processes. Flocculation results in formation of a larger, settleable structure by bridging. These are commonly the first processes in a water treatment sequence to remove either suspended matter or color. Adsorption of ionic forms also occurs to varying degrees depending on the type ion involved and the presence and amounts of other chemical constituents in the water or wastewater.

Analysis of a water or waste preparatory to design of a treatment sequence often involves coagulation and flocculation experiments in the laboratory. Aluminum or iron salts may be used to coagulate particles and to form settleable flocs composed of the hydrous metal oxide precipitates and impurities. These tests, called jar tests, are widely used for control of plant operations and are routinely performed by treatment plant operators. The coagulation and flocculation tests serve to indicate the optimum chemical dosages for removal of turbidity and color, including such auxiliary facets as pH adjustment, and the necessity for the supplemental use of activated carbon. Jar tests, furthermore, yield a wealth of qualitative information on the rate of agglomeration as a function of energy input (paddle speed), the settleability of the floc formed, the clarity of the supernatant water (which might be related to the subsequent length of filter run).

Coagulation and flocculation experiments may also be used, in conjunction with other tests, to study basic processes including, for example, the kinetics of reaction, and the removal of colloidal and trace constituents from aqueous solution.

OBJECTIVES

To conduct jar tests on a synthetic or natural surface water in order to estimate an optimum dosage of aluminum sulfate or ferric sulfate for the removal of suspended matter or color.

PROCEDUREA. Determination of Optimum Coagulant Dosage

1. Collect 20 to 50 liters of a natural surface water. Analyze the water for pH, turbidity, color after filtration, and alkalinity. Alternately, make up a clay suspension with tap water. Record both the water temperature at time of test and ambient air temperature. If the raw water is clear and colorless, it may be desirable to augment the suspended matter with kaolin, montmorillonite, illite, or bentonite clay and the color with the extract from boiled leaves or with instant coffee. Turbidity might be increased to about 50 turbidity units and color to about 100 color units.
2. Calculate the amount of alkalinity required to react with the maximum dosage of aluminum or ferric sulfate. If necessary, augment the natural alkalinity of the water by the addition of 0.1N  $\text{Na}_2\text{CO}_3$  so that the alkalinity will be at least 25 mg/l as  $\text{CaCO}_3$  equivalent if the reaction is complete. Measure the pH.
3. Place 1 liter aliquots in 1 liter beakers on the six-jar laboratory stirrer and check stirrer operation. A light table will facilitate viewing of the contents of the beakers. Prepare portions of the aluminum or ferric sulfate solution which will yield 10 to 100 mg/l when added to the sample aliquots.
4. At the start of a one minute rapid mix at 100 rpm, add the coagulant solutions to the five beakers keeping one beaker as a control.
5. Flocculate at 30 rpm for 20 minutes or longer, if necessary. Record the elapsed time before a visible floc is formed. If large flocs are formed, it may be desirable to reduce the paddle speed. Note the size and appearance of the floc formed.
6. After flocculation, remove the paddles and settle for 30 minutes.
7. Measure the turbidity or color of the supernatant in each jar, taking care not to disturb the sediment in sampling. Measure the pH of the supernatant and the

depth of sludge. If possible, estimate the volume of sludge which might be produced by treating 1 million gallons of the test water. Select the optimum dosage on the basis of supernatant clarity and settleability of floc.

8. If satisfactory results are not obtained, repeat the jar test experiment with another range of coagulant doses. The test also may be repeated, if appropriate, to further narrow the range of dosages near the optimum. Estimate the range of dosages over which this coagulant would be effective.

B. Determination of Optimum pH

1. Repeat the jar test of Part A using the observed optimum dosage of ferric sulfate but adjusting sample pH to 6, 7, 8 and 9 with sodium hydroxide or sulfuric acid prior to adding coagulant.
2. Measure final pH, turbidity and color of the supernatant of each sample. Measure the depth of sludge in the beaker.
3. Plot turbidity and color versus initial pH and against final pH. Select optimum initial pH based on use of the optimum coagulant dosage determined in Part A.

C. Microscopic Examination

1. If a microscope is available, examine samples of the colored and turbid waters and the supernatant. Describe the nature of the material observed. Using a calibrated grid in the ocular, estimate the size of the particles present.

D. Coagulation in Conjunction With Activated Carbon For Reduction of Color

1. If the color of the water is not reduced sufficiently using the coagulant alone, investigate removal efficiency using activated carbon in varying dosages. Develop a procedure such that the color is successfully reduced to an acceptable level for a public water supply.

E. Effect of Mixing Time and Intensity (Aggregation Kinetics)

1. If a different size or configuration of paddles is available, investigate the effect on coagulation and flocculation of varying paddle size and varying mixing intensities. Tapered flocculation may be simulated by reducing paddle speeds (power input) during the course of mixing.
2. Prepare identical (optimum) coagulant dosages for all six beakers.
3. Use the same rapid mix as before but vary the time of slow mix at 30 rpm. Use 5, 10, 15, 20, 30 and 45 minutes for the six jars respectively. Terminate mixing by carefully lifting the paddle from the beaker at the appropriate time.
4. Allow 30 minutes for settling.
5. Measure the color, turbidity and pH of the supernatant in each beaker.

F. Removal of Microorganisms

1. With a prepared microbiological culture, such as E. coli, examine the efficiency of removal of viable organisms using a coagulation procedure similar to the preceding.

ANALYSIS

1. Prepare tables with facilitate comparisons of coagulant dosages with alkalinity, pH, color, turbidity and other changes observed. Plot the inverse of turbidity and color versus coagulant dosage as part of the analysis.
2. Comment on the differences between coagulation with iron and aluminum salts. Define the pH ranges over which each salt should result in effective coagulation.

## EXPERIMENT NO. II

## COAGULATION AND FLOCCULATION WITH ORGANIC POLYMERS

BACKGROUND

Polyelectrolytes are high molecular weight polymeric substances used in water purification and waste treatment to aid in the clarification of turbid suspensions or the dewatering of sludges. These compounds consist of a long chain organic "backbone" with various types of ionic (cationic or anionic) or non-ionic solubilizing groups. Because of the extremely long chain lengths one end or segment of the polymer molecule is capable of reacting independently of the other end or segments. The individual segments are adsorbed onto the surfaces of the dispersed particles and bridging between the normally stable (unsettable) sol particles results. Under proper conditions of time, temperature, concentration and mixing, this bridging leads to a settleable or filterable floc. This mechanism of destabilization by polymers is known as flocculation. Although electrostatic interactions between polyelectrolyte and particle are important it has been observed that anionic (negative) polymers will destabilize negative sols.

Polyelectrolytes may be obtained that vary significantly in molecular weight and composition, as well as charge. These may be natural products, such as some starches and gums, or synthetically produced. Not all of these substances are acceptable for use with drinking waters. At the present time there is no analytical way to predict the behavior or applicability of a given polymer with a particular water or waste. Performance and optimum dose are usually judged using the jar test procedure commonly used for evaluating metal coagulants. Although polymers are less sensitive to pH variations than metal coagulants, the dose required for optimum clarification varies over much wider ranges.

OBJECTIVES

To evaluate various polymers for the clarification of turbid suspensions and to determine the optimum dose of a given polyelectrolyte.

PROCEDURE

1. A natural water is collected or suspensions of clay are

prepared as described in Experiment No. I.

2. Two or more different cationic polymers are selected for evaluation. Suitable portions of each are carefully weighed and dissolved by slowly adding to water using a magnetic stirrer. These stock solutions should be freshly prepared every two weeks.
3. Six well-mixed 500-ml volumes of the turbid suspension are transferred to one-liter beakers which are then placed under the paddles of the jar test apparatus. The current is turned on and the speed of the paddles set to about 85 rpm.
4. Just prior to experimentation aliquots of a polymer solution are diluted in small beakers to 100 ml total volume. These are prepared so that the final 600-ml experimental solution contains concentrations of polymer of 0, 0.5, 5.0, 10.0, and 30 mg/l.
5. These polymer solutions are added rapidly but carefully to each of the beakers and allowed to rapid mix for ten seconds. After this time the paddle speeds are reduced to 25 rpm. Qualitative observations of floc formation and the clarity of the suspensions for each sample are made and recorded.
6. After 20 minutes of slow mixing the stirring is stopped and similar observations are made and recorded. A further 30 minutes of quiescent settling is permitted after which samples of the top 200 ml of each suspension are withdrawn for absorbance or turbidity measurements. Qualitative observations are also recorded.
7. This procedure is repeated for one or more of the polymers to be evaluated. The results with two or more of the polymers are compared. Usually the polymer requiring the smallest dose for good clarification is selected for further testing. The actual selection should be made on least cost per dose if these data are available.
8. For the next set of experiments a similar series of polymer solutions are prepared such that the minimum optimum dose is bracketed. For example, if 10 mg/l were the smallest concentration giving good results, then the next series would consist of 2, 4, 6, 8, 10 and 12 mg/l. Note that the control sample is no longer required but that one sample is repeated to check on the reproducibility of the results.

The procedure is repeated. Another series over a smaller range of concentrations may also be run if necessary.

#### ANALYSIS

The general procedures outlined above do not guarantee meaningful or even reproducible results. Good techniques and attention to details by the students are required. Occasionally the mixing speeds and time periods specified are inadequate for good results with specific polymers or turbid suspensions. The student is being asked to make judgments on the experimental procedure. For example, frequently only a very few parts per billion of polymer will result in the most effective clarification although the minimum dose for the first series of experiments calls for 0.5 mg/l.

There is no substitute for planning and preparation before experimentation. Determination of the concentrations and weights of polymer to prepare the stock solutions should be based on the experimental convenience of delivering a series of volumes for the dilutions. These decisions, as well as a clear understanding of what is to be accomplished, should be obtained before setting foot in the laboratory.

Procedures for handling of the samples taken for the absorbance or turbidity measurements should also be worked out beforehand. For spectrophotometric measurements any wavelength in the visible range is suitable. The most sensitive wavelength to use can be determined from an absorption spectrum of the suspension.

## EXPERIMENT NO. III

## BATCH LABORATORY FLOTATION TEST

BACKGROUNDFlotation Principles

Flotation is the separation of suspended solid particles, and sometimes dispersed liquids, from a liquid phase. This is done by the addition of a gas phase, usually air, in fine bubbles to the liquid phase. The rising bubbles either adhere to or are trapped in the particle structure, resulting in an increase in the buoyancy and a rise of the bubble-particle complex. Particles having a density even greater than the liquid can be separated by this means. Separation by flotation does not depend so much on the size and the relative density of the particles as it does on their surface properties. This determines essentially which particles will adhere to bubbles.

Flotation was first developed about 1900 in the mining industry as a means of separating an ore into a concentrate. In the past 30 years, it has been applied to waste treatment to remove suspended solids, grease and oil from wastewater. In the paper industry it has been used in treatment of "white water", i.e., finely suspended fibers in water from the paper machines or digesters. Favorable results have been obtained with oil and also with algae.

Two methods are in use which differ in the way the bubbles are produced. In dispersed air flotation they are generated by passing the gas through some kind of disperser: porous media, perforated tubes (spargers), revolving impellers, etc. Bubble size is of the order of 1000 microns diameter. In dissolved air flotation bubbles are produced because they come out from a supersaturated solution. This is done by saturating the liquid at high pressure and releasing the pressure. In either case the air-particle complex rises to the surface where it is skimmed off, and the clarified liquid is withdrawn from the bottom of the container. Dissolved-air particle sizes are smaller, ranging from 30 to 120 microns. Sometimes the clarified liquid or rather a part of it is charged with gas under pressure, then the pressure is released and mixed with new waste, supplying the bubbles for the latter's particles flotation. This is known as flow pressurization.



### Performance and Design Features

The performance of a flotation system depends on having sufficient air bubbles to float substantially all the suspended solids. An insufficient quantity of air will result in only partial flotation of the solids, and excessive air will yield no improvement. The performance of a flotation unit in terms of effluent quality and solids concentration in the float can be related to an air/solids ratio, which is usually defined as pounds of air released per pound of solids in the influent waste. In general the air/solids ratio will increase with the percent solids in the waste. Also, to get higher solids removal, i.e., lower solids content in the effluent, requires a higher air/solids ratio. In both cases the results will vary with the nature of the solids in the feed. Addition agents can also modify the results.

The rise velocity closely follows Stokes' Law. The rise velocity of a solids-air mixture will vary from 1 to 5 in. per min. and will increase with increasing air-solids ratio. It is related to the hydraulic loading, expressed in gpm per square foot of surface area or overflow velocity. The primary variables for flotation design are pressure, recycle ratio, feed solids concentration, retention period, and addition agents.

The principal components of a dissolved-air flotation system are a pressurizing pump, air injection facilities, a pressure retention tank, a back pressure regulating valve, and a flotation basin. The pressure in the pressure retention tank used to dissolve air is created by the mechanical action of the impeller of the pressurizing pump.

The flotation tank can be designed in accordance with procedures similar to those established by the American Petroleum Institute:

(a) the depth to width ratio ( $D/W$ ) = 0.3 to 0.5; (b) the maximum horizontal velocity ( $V_H$ ) shall not exceed 3.0 fpm. Flow ( $Q$ ) in determining cross-sectional area and horizontal velocity must include that portion added as recycle; (c) the rate-of-rise in fpm  $V_T$ , determined by the laboratory bench scale test procedure outlined in the following "procedure"; (d) the factor for short circuiting and turbulence  $F_S$ , is assumed as 1.4; and (e) the effective flotation basin length  $L$ , =  $(V_H F_S / V_T) D$ .

Mechanical flight type skimmers may be used on the top of the flotation basin to remove floated solids. A bottom collector may also be incorporated to remove any heavy settleable solids not amenable to flotation.

#### PROCEDURE

It is possible to estimate the flotation performance of a waste in a cell by means of a batch laboratory test. Rate of separation data may be conveniently obtained in the laboratory from treatment tests performed on the raw water or waste in question. Generally, the procedure used in obtaining rate of separation data is to observe the solids-liquid interface and to record its travel with time.

In the tests using dissolved-air flotation the rate of rise of the major portion of the solids is recorded. At times, the solids-liquid interface may be vague and good judgement may have to be exercised in following this interface. Care should be taken to avoid following the interface formed by the air bubbles alone. In general, this interface lags behind the solids-liquid interface.

A suggested procedure for the performance of laboratory flotation tests and the equipment needed is as follows:

Assume that a recirculation ratio of 0.33 is to be tried.

1. Place 750 ml of a representative sample of the raw water or waste in a one liter graduated glass cylinder.
2. Fill the pressure cell approximately three-fourths full with recycle water. It is desirable that the operation of the pressure cell closely simulate the recirculation of effluent as used in the full scale flotation system. The returned effluent (recycle water) may be developed by repeated flotation of several different portions of raw waste. After the recycle water has been developed and used in the flotation tests, samples may then be withdrawn for chemical analysis.
3. Secure the cover gasket and cover of the pressure cell, making certain all the valves are closed.
4. Inject air into the cell until a pressure of 45 to 70 psig is attained and maintained during testing. Record the pressure.
5. Shake the cell vigorously for 30 to 120 seconds. Record the shaking time.

6. Release 250 ml of the liquid which has been pressurized into the graduated cylinder. The volume of liquid in the graduated cylinder then totals 1000 ml (750 ml raw and 250 ml pressurized). The ratio of volumes of recycle water to the raw waste is termed the recycle rate. Thus, the recycle rate used in this test is 33%. The most suitable recycle rate can be determined by repeated tests at varying rates of recycle and usually is not less than 20% and no more than 50%. To facilitate the introduction of the air-charged recycle water to the graduated cylinder, a rubber tube may be connected to the petcock on the pressure cell. After clearing the rubber tube of air, (allow some liquid to escape through the tube by opening petcock. Sufficient liquid should be removed until it has a milky appearance) the air-charged recycle water is introduced through the rubber tube into the graduated cylinder. The end of the tube should be placed near bottom of the cylinder.
7. Obtain the following information:
- Record waste temperature, pH, operating pressure, recycle rate, and flotation detention time.
  - Record rate of separation data. A detention time of three to ten minutes is usually used. Record the detention time. If flotation is not complete in ten minutes, longer detention times may be used. The following form is suggested in obtaining the rate of separation data.

<u>Time</u> <u>(min)</u>	<u>Volume</u> <u>ml</u>	<u>POI (Position of Interface)</u> <u>-----(feet)-----</u>
0	0	0
1	100	0.115
2	350	0.411
3	500	0.589
4	650	0.766
5	800	0.946
6	950	1.122
7	950	1.122
8	950	1.122

The ultimate data desired is the position of the interface at various intervals throughout the test. The column above labeled "Volume" is used as a convenient means of obtaining the position of the interface at any given time. For example, in the

hypothetical case shown above, a liter graduate cylinder was used in the test. At the beginning of the test the solids-liquid interface is at the bottom of the graduate or at zero volume. As flotation progresses, the solids-liquid interface moves progressively up the height of the graduate cylinder. The position of the interface at any given time may be conveniently obtained using the appropriate graduate mark on the liter cylinder as a reference. After the flotation test, the graduation marks may be converted to feet of height by actual measurement.

The data obtained are plotted using time as the abscissa and POI in feet as the ordinate.

The slope of the straight line portion of the curve represents the rate of particle rise.

During flotation it should be noted whether settling of solids took place. Note observation.

- c. Record the floated scum volume obtained after three to ten minutes of flotation.
- d. After the flotation is completed, a sample of the raw water or waste and treated effluent should be taken for analysis. The treated effluent should be carefully withdrawn from the graduated cylinder either through the use of a petcock installed in the side and near the bottom of the cylinder or through the use of a siphon inserted in the cylinder. Sufficient liquid should be withdrawn to complete the desired analysis, however, care should be taken to avoid the break up of the scum blanket.

Determine suspended solids and pH. The pH of the effluent is the same as that of the raw waste itself if no chemical treatment is used. If possible, a small portion of the floated scum should be analyzed for total solids content.

8. Relate the effluent suspended solids and the float solids to the calculated air/solids ratio. When the recycle flow pressurization system is used, the air/solids ratio can be computed by

$$A/S = 1.3 a V_r (FP-1)/VX$$

where

- a = air saturation, cm<sup>3</sup>/liter, (at 0°C + 1 atm)  
 V<sub>r</sub> = pressurized volume, liters  
 P = absolute pressure, atm.  
 V = waste volume, liters  
 X = influent suspended solids concentration, mg/l  
 A = mass of air required  
 S = mass of solids present  
 F = correction for non-saturation. (In the laboratory it may be assumed that shaking is thorough and sufficiently long so that equilibrium is attained and F = 1.)

When pressurized recycle is not used (i.e., full flow pressurization system):

$$A/S = 1.3 (FP-1)/X$$

9. Should chemical flocculation with flotation be desired, the chemical may be added into the raw waste after step "1" is completed, flocculation may be carried out, for convenience, in another vessel. Care should be taken not to break up the floc when transferring the waste to the cylinder. Enough time for flocculation should be allowed before introducing the air-charged recycle water. Under appropriate conditions, a floc may be formed by gentle agitation of the waste after the chemical is added. The procedure described above also applies when chemical flocculation is used. When using chemical flocculation, care should be exercised not to break up the floc particles in handling the flocculated waste.

Because of the peculiarities of some floc formations, they will break up readily upon any excessive agitation after being formed. This is most readily noticed when a liquid with a performed floc is transferred from the cylinder used in the jar mixing test to the cylinder

used in the flocculation test. If the floc does break up and does not reform immediately, it is suggested that the transfer to the flotation cell not be made and that flotation be accomplished in the vessel where the floc was formed. The procedures for running this test are the same. However, withdrawing of the clarified liquid, as described in step "7" of the procedure will probably be through a siphon.

In flotation of a particular waste, it is quite possible that the test using the recirculation ratio of 0.33/1 may not yield the best results. It may be that some other recirculation ratio would yield the results needed to work in with the economy of design and effluent requirements. Therefore, the tests described above may be repeated with other recirculation ratios until the optimum ratio is obtained.

#### PROBLEMS AND QUESTIONS

1. Use the data obtained in the experiment to make a preliminary specification of a continuous dissolved air flotation unit to treat 100 gpm of the waste continuously to bring the suspended solids concentration down to an acceptable level. The specification should include: the pressure, the recycle ratio, the depth and horizontal area of the flotation tank, the addition agents per 1000 gallons of waste, and the means of removing and disposing of the floated froth.
2. What must be the nature of the solids-air-water interface for successful flotation? What must the density of an air-solids-oil complex, related to water?

EXPERIMENT NO. IV  
DISPERSED AIR FLOTATION AND FOAM SEPARATION

BACKGROUND

Two common methods of flotation are currently in use: dissolved air flotation and dispersed air flotation. In dispersed air flotation, gas bubbles are generated by introducing the gas phase through a revolving impeller, through porous media, or through a jet eductor mixer. Bubble size is of the order of 1000 microns in diameter.

A dispersed air flotation cell usually is operated as a foam separation process unit which involves the selective adsorption of surface-active substances at the gas-liquid interfaces of rising air bubbles, and the subsequent separation of the surface-active substances from the cell top as condensed foam. The process has been used to a wide extent in the metallurgical industry and paper and pulp industry. The air addition of a typical dispersed air flotation cell is about 400 percent of influent flow by volume. In drinking water treatment by foam separation, about 90 percent of turbidity can be successfully removed.

Among the methods of foam separation, foam fractionation usually implies the removal of dissolved (or sometimes colloidal) solute. The overflowing foam, after collapse, is called the foamate. On the other hand, froth flotation usually implies the removal of solids and solutes in the foam phase.

The attached figure shows a full scale dispersed air flotation cell (KROFTA FOAMER). The foamer is composed of a shallow tank with a feed well where raw water, recycled water and chemicals enter. A recycle pump feeds an ejector that discharges tangentially into the tank, creating a circular movement of bulk liquid in the tank. With a blower, air is added into the ejector at low pressure. This air is dispersed in the ejector and enters into the tank, producing a large amount of foam that travels on the top of the circulating bulk liquid. The foam is continuously collected by the foam collector and extracted into the foam suction tank, where a suction blower holds a light vacuum. The foam collapses in the foam suction tank and is extracted continuously by a water lock and discharged into a collection tank. The purified water is discharged in the center of the tank at the bottom opening and overflows the telescopic adjustable weir.

### OBJECTIVES

To operate a commercial dispersed air flotation cell (KROFTA FOAMER) for separating dissolved surface-active agents from an industrial process water in order to understand the hydraulic structure, and operational procedures of the flotation cell. Also to conduct surfactant concentration tests on the influent, effluent and foamate for estimating the water quality and treatment efficiency.

### PROCEDURE

#### A. SAMPLE PREPARATION AND PRETREATMENT

Describe the influent sample to be treated and any necessary pretreatment procedures. Collect enough influent sample for subsequent surfactant analysis.

#### B. INVESTIGATION OF A COMMERCIAL DISPERSED AIR FLOTATION CELL

Describe the commercial flotation cell to be tested. Document the operational procedures.

#### C. PILOT PLANT OPERATION AND INVESTIGATIONS

1. Operate the dispersed air flotation cell continuously for at least 10 minutes, or until the cell reaches the steady state condition.
2. Record the temperature, influent flow rate, effluent flow rate, foam flow rate, recycle flow rate (if any), pressure at the air blower inlet, size of the flotation cell, water depth, etc.
3. Take liquid samples from the effluent compartment and foam collection tank for subsequent surfactant analysis.

### ANALYSIS

1. Make material balances for flows and surfactants based on the measured flows and concentrations.
2. Calculate the treatment efficiency, detention time, and hydraulic loading rate.



3. Answer the following questions:
  - a. Can a dissolved air flotation cell be operated as a foam separation process unit?
  - b. Why does the dispersed air flotation need large volume of air for separation of impurities?
  - c. What type of substances can be separated by foam separation?
4. Draw a few meaningful conclusions.

EXPERIMENT NO. V  
PILOT PLANT OPERATION OF  
A DISSOLVED AIR FLOTATION CELL

BACKGROUND

In a Dissolved Air Flotation (DAF) system, a recycled subnatant flow is pressurized from 30 to 70 lb/in<sup>2</sup> g and then saturated with air in a pressure tank. The pressurized effluent is then mixed with the influent sludge and subsequently released into the flotation tank. The excess dissolved air then separates from solution, which is now under atmospheric pressure, and the minute (average diameter 80 microns) rising gas bubbles attach themselves to particles which form the floating sludge blanket. The thickened blanket is skimmed off and pumped to the downstream sludge handling facilities while the subnatant is returned to the plant. Polyelectrolytes are frequently used as flotation aids, to enhance performance and create a thicker sludge blanket. A description of the DAF process in general is presented in the attached sheets.

DAF is the most common form of flotation thickening in use in the United States and has been used for many years to thicken waste activated sludges, and to a lesser degree to thicken combined sludges. DAF has widespread industrial wastewater applications.

OBJECTIVES

To operate a commercial dissolved air flotation cell (KROFTA SUPRACELL) for separating the fibers (or other suspended solids) from an industrial process water, in order to understand the hydraulic structure, and operational procedures of the flotation unit. Also to conduct suspended solids tests on the influent, effluent and scum for estimating the water quality and treatment efficiency.

PROCEDURE

A. SAMPLE PREPARATION AND DETERMINATION OF OPTIMUM COAGULANT DOSAGE IF NECESSARY

Describe the sample to be treated, and any necessary coagulation procedures. Collect at least 0.5 liter of flotation influent for subsequent solid analysis.

B. INVESTIGATION OF A COMMERCIAL DISSOLVED AIR FLOTATION CELL

Describe the commercial flotation cell to be tested. Document the operational procedures.

C. PILOT PLANT OPERATION AND INVESTIGATIONS

1. Operate the flotation cell continuously for at least 15 minutes, or until the unit reaches the steady state condition.
2. Record the temperature, influent flow rate, effluent flow rate, recycle flow rate, air pressure at the pressurization retention tank, size of the flotation cell, water depth, scum thickness, rotation speeds of the air distribution and scum collection units.
3. Take liquid samples from the effluent compartment and the scum layer for subsequent solids analysis.
4. Make material balances for flows and solids.
5. Calculate the air-to-solids ratio, recirculation ratio, and treatment efficiency.
6. Draw

**LABORATORY PROCEDURES AND APPARATUS FOR CHEMICAL  
COAGULATION/PRECIPITATION, SEDIMENTATION, DISSOLVED AIR  
FLOTATION, DISPERSED AIR FLOTATION, AND FILTRATION**

ABSTRACT:

This publication has been used as one of the lecture materials at the Lenox Institute of Water Technology (LIWT) for the humanitarian environmental education of LIWT [1], for the continuing education of New England Water Works Association (NEWWA) for both the licensed professional engineers (PE) and the certified water and wastewater operators [2], and for the technology transfer program of the United Nations Industrial Development Organization (UNIDO) [3, 4, 5] in developing countries. The publication covers the subjects of: (a) chemical coagulation/precipitation simulation; (b) dissolved air flotation (DAF) simulation full flow pressurization systems; (c) DAF simulation partial flow pressurization systems; (d) DAF simulation recycle flow pressurization system; (e) dispersed air flotation simulation batch system; (f) dispersed air flotation simulation continuous systems; (g) simulation of chemical coagulation/precipitation, sedimentation and filtration system; (h) simulation of chemical coagulation/precipitation, flotation and filtration system; (i) experiment of coagulation and flocculation with hydrolyzing metallic salts; (i) experiments of coagulation and flocculation with organic polymers; (k) experiment of batch laboratory flotation test; (l) experiment of dispersed air flotation and foam separation; and (m) pilot plant operation of a dissolved air flotation cell.

**KEYWORDS:**

Laboratory Simulation, Laboratory Procedures, Apparatus, Chemical Coagulation, Chemical Precipitation, Sedimentation, Dissolved Air Flotation, Dispersed Air Flotation, Foam Separation, Filtration, Process Simulation, Laboratory Experiments, Pilot Plant Operation, Continuing Education, Lenox Institute of Water Technology (LIWT), New England Water Works Association (NEWWA)

## ACRONYM

DAF	Dissolved air flotation
LIWT	Lenox Institute of Water Technology
NEWWA	New England Water Works Association
PE	Professional engineer
STEM	Science, Technology, Engineering and Mathematics
UN	United Nations
UNIDO	United Nations Industrial Development Organization
USEPA	US Environmental Protection Agency

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**APPENDIX:****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, 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 International Foundation, a Diplomat 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 Diplomat 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).