Environmental Engineering

Laboratory Page @

Southern Illinois University

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INTRODUCTION

Environmental Engineering is a profession directly involved with the identification and design solutions of environmental problems. Environmental Engineers are directly responsible for providing safe drinking water, minimizing and preventing pollution in rivers, lakes and oceans, treating and properly disposing of municipal, industrial and hazardous waste, and the remediation of contaminated soil and water, among other charges of the profession. Understanding and mastering the art of Environmental Engineering requires the integration of biology, chemistry, physics, mathematics, computer science, laboratory analyses, and communication skills.

The purpose of these experiments is to introduce you to various aspects of Environmental Engineering through laboratory analysis that integrates hands-on investigation, data reduction and interpretation. Experiments include measuring conventional water and wastewater parameters as well as exploring the natural environment. A more detailed description and professional standards for a majority of these experiments can be found in Standard Methods for the Examination of Water and Wastewater. Standard Methods, as this book is often referred to, is a joint publication of the American Public Health Association, the American Water Works Association and the Water Environment Federation.

In each experiment, you will find material that relates to both the theory and the practical application of the laboratory in engineering practice. The supplemental web site for this manual is at:

http://civil.engr.siu.edu/nsflab/NSFProject/Environmental/Environ_Frame.htm

At this site additional learning tools such as video clips, photographs, and sample data sets are continually being added to illustrate key concepts of the laboratory.

At this time, we are in the developmental stage of the site and the lab manual. We welcome and encourage the use of this material in your courses. We only request that you acknowledge us and let us know that you are using it. Feedback from you is both appreciated and invaluable to the development of this project. Please contact us if you have any comments, suggestions or questions.

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LAB SAFETY

A more thorough review of laboratory safety is presented under General Topic from the web site. The purpose of this laboratory is to identify the location and use of the following items in the laboratory. Review these items with your lab instructor prior to conducting any labs.

- Safety glasses
- Eye wash station
- Shower
- Latex gloves for BOD, Solids, Solid Waste and Coliform Labs
- Insulated gloves and tongs for muffle furnace
- Aprons
- Spill kit
- Fire extinguisher
- Material Safety Data Sheet (MSDS)
- Campus unit responsible for the pickup and disposal of waste; Explain use of request forms for pickup and the need for proper labeling.

In this lab, all chemicals must be in labeled containers. The label on purchased chemicals generally identifies the content adequately. However, when you prepare a reagent for use, it must be labeled as follows: The name of the chemical or reagent, the concentration, the date and your name. You are required to label every bottle used longer than one laboratory period.
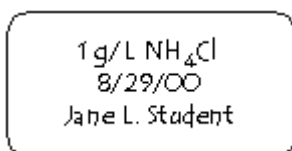

Figure 1: Example of proper labeling.

Biochemical Oxygen Demand

BIOCHEMICAL OXYGEN DEMAND

Introduction

In characterizing wastewater and surface water, the amount of biodegradable organics in the water is an important parameter. When these organics degrade in the aquatic environment, dissolved oxygen is consumed. Since oxygen is not very soluble in water (Table 1), a heavy loading of organics may deplete oxygen levels, which in turn may lead to fish kills and anaerobic conditions. Although most substances can also be degraded under anaerobic conditions, the process is slow and results in foul odors.

Biochemical oxygen demand, or BOD, is a test to measure the consumption of dissolved oxygen due to biological degradation of organic materials and chemical oxidation of inorganic materials. In fact, BOD is used as an indicator to determine compliance with wastewater discharge permits, in the design of wastewater facilities, to monitor plant performance, and to determine the approximate quantity of oxygen required to biologically stabilize or oxidize organic matter. BOD is also an important parameter in models that estimate the assimilative capacity of the receiving body of water.
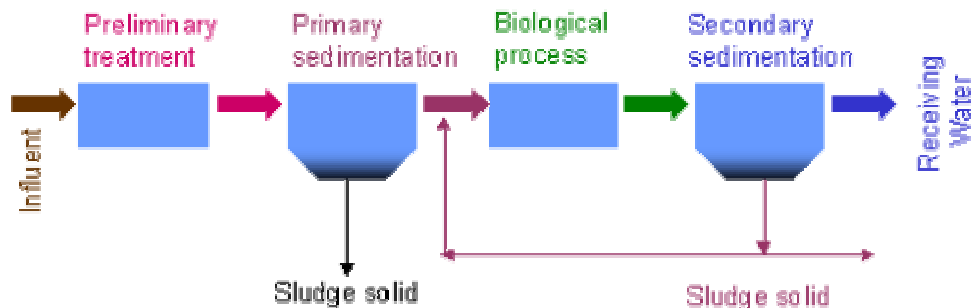
The standard measurement is the BOD after five days (BOD_5), although BOD_7 is also used to correspond with work schedules, especially at smaller plants. In this procedure, dissolved oxygen is measured initially and after a 5 (or 7) day incubation period. The BOD measured during this period is the carbonaceous BOD, since the bacteria that oxidize nitrogen are not in sufficient numbers to influence oxygen consumption until approximately seven days. However, it is common practice to use a nitrogen inhibitor. Seeding and dilution of samples are commonly used to ensure an acceptable change of dissolved oxygen occurs. Bacterial growth requires nutrients, including nitrogen, phosphorus and trace metals. These nutrients are added to dilution water, which is also buffered to ensure that the pH of the sample remains suitable for the bacteria. Oxygen consumed after 60-90 days of incubation is used to determine the ultimate BOD. Continuous oxygen uptake can be used to determine the kinetics of degradation, utilizing analysis tools such as the Thomas Method.

Table 1: Saturation of Dissolved Oxygen in Distilled Water

Temperature ℃	Solubility (mg/L)	Temperature ℃	Solubility (mg/L)
0	14.6	16	9.9
1	14.2	17	9.7
2	13.9	18	9.5
3	13.5	19	9.3
4	13.1	20	9.1
5	12.8	21	8.9
6	12.5	22	8.7
7	12.1	23	8.6
8	11.8	24	8.4
9	11.6	25	8.3
10	11.3	26	8.1
11	11.0	27	8.0
12	10.8	28	7.8
13	10.5	29	7.7
14	10.3	30	7.6
15	10.1		

Application

The following figure shows a basic treatment train found at municipal wastewater treatment facilities. In this laboratory, you will be measuring the BOD of the influent and the effluent. One of the primary objectives of municipal wastewater treatment is the reduction of BOD in the effluent, which is released into a receiving body of water.

Figure 1: Generalized schematic of a wastewater treatment facility.

Materials and Equipment

- Standard BOD bottles with ground glass stoppers (300 mL).
- Paraffin wrap.
- Dissolved oxygen meter with appropriate DO probe.
- Wide tipped volumetric pipet.
- Magnetic stirrer if DO probe does not have a stirrer built in.
- Incubator: thermostatically controlled with a temperature of 20°C ± 1°C. All light must be excluded form the samples during incubation.
- Dilution water prepared by instructor.
- Glucose-glutamic acid solution prepared by instructor.
- Influent and effluent sample of wastewater from a local municipal wastewater treatment facility. Obtain the effluent sample prior to disinfection so that dechlorination and seeding will not be required in this laboratory.

Procedure

Samples should be used within 48 hours of collection. Samples should be stored at approximately 4°C to ensure that oxygen concentrations remain constant. In addition, samples should be incubated in the dark to prevent oxygen replenishment from photosynthesis. Prior to use, the sample must be brought to room temperature. The pH of samples must be between 6.5 and 7.5 to ensure biological growth. The pH of samples can be adjusted with a solution of sulfuric acid (H_2SO_4) or sodium hydroxide (NaOH). To increase the pH of a sample, you need to add a base. In Standard Methods, the pH of a BOD sample is increased by adding sodium hydroxide (NaOH). Dissolve 40 g sodium hydroxide in distilled water. Dilute to 1 L.

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Since the actual BOD_5 is not known, several dilutions must be prepared and tested. Typical municipal influent wastewater has a BOD5 of 150-350 mg/L, whereas the effluent ranges between 10-40 mg/L. For this laboratory, prepare three dilutions of each sample. Use Table 2 to determine the required dilutions. Prepare one dilution in the appropriate range, then one below and above.

Using the effluent sample, prepare two BOD bottles at each of the three dilutions. To prepare the dilution, place the required amount of sample in the bottle. Completely fill the remainder of the bottle with dilution water, taking care not to entrap air bubbles. Place the glass stopper on the bottle, allowing for a small amount of water to spill off the bottle. There should be a water seal remaining in the lip area. This water seal will prevent oxygen from entering the bottle. As an additional precaution, wrap a piece of paraffin wrap over the top of the bottle. Repeat this procedure for the influent sample. Use one set of each dilution to measure the initial DO, and incubate the other set. Place the remaining six bottles (three influent and three effluent dilutions) in the incubator. Record the time and date. As with the samples collected from the treatment facility, these prepared samples must be kept in the dark to prevent oxygen replenishment from photosynthesis and at a constant temperature of 4°C to ensure that oxygen concentrations remain constant.

Table 2: Dilution ranges for pipetting into 300 mL BOD bottles.

Sample Volume (mL)	Minimum BOD (mg/L)	Maximum BOD (mg/L)
1	600	2400
3	200	800
5	120	480
10	60	240
30	20	80
50	12	48
100	6	24
200	3	12
300	2	8

After the required incubation period (5 or 7 days), remove the BOD bottles from the incubator and measure the final dissolved oxygen levels.

Check the dilution water blank to be certain that the DO uptake ($DO_{initial} - DO_{final}$) was not more than 0.2 mg/L. If the value is above 0.2 mg/L, the results are suspect. A valid dilution is one that has a final DO greater than or equal to 1 mg/L and a DO uptake of at least 2 mg/L.

Place 6 ml of the glucose-glutamic acid standard in two BOD bottles. Then add 15 mL of wastewater effluent for seed. Fill the remainder of the bottle with dilution water. Use one bottle to determine the initial DO. Incubate the second bottle with the other samples and measure the final BOD after 5 days.

Also prepare two blank samples of dilution water. Use one bottle to determine the initial DO. Incubate the second bottle with the other samples and measure the final BOD after 5 (or 7) days.

Make sure to properly label all bottles. The label should state what is in the bottle, the concentration, the date, and your name.

Analysis

As stated earlier, a valid dilution is one that has a final DO of at least 1 mg/L, and a DO uptake of at least 2 mg/L. The BOD of the sample is determined from the DO uptake and the fractional dilution (*F*):

$$BOD = \frac{DO_{initial} - DO_{final}}{F}$$

The fractional dilution of the sample is the volume of sample divided by the BOD bottle volume.

Because the BOD test is a bioassay, the results can be influenced greatly by the presence of toxic substances. Distilled waters, which is used to prepare the dilution water, are frequently contaminated with copper. Use the bottles with the glucose-glutamic acid to check for water quality as well as seed effectiveness and the quality of your analytical technique. The BOD_5 for this 300 mg/L mixed primary standard should be 198 ± 30.5 mg/L if a nitrogen inhibitor was used.

Elements of Report

Within your report, you should include the following items specific to your experiment:

- Name, location and general description of wastewater facility
- Specific equipment (manufacturer and model) used and accuracy
- Which dilution provided the best estimate of BOD_5 for the influent and the effluent?
- Identify any BOD samples that should be eliminated based on the final DO or the minimum DO depletion.

- What is BOD_5 of the influent and effluent, and how does this value compare to typical values reported in the literature?

- What are the different compounds added to the dilution water? What purpose does each serve?

- If you conducted a 7 day BOD test, calculate BOD_5 and the ultimate BOD (L_o) of the sample assuming k=0.35/day (base e). Generate a graph showing the change in BOD over time. Extend this graph to at least $0.9L_o$.

- If you conducted a 5 day BOD test, calculate BOD_7 and the ultimate BOD (L_o)of the sample assuming k=0.35/day (base e). Generate a graph showing the change in BOD over time. Extend this graph to at least $0.9L_o$.

References

Standard Methods for the Examination of Water and Wastewater, 20th Ed. Published jointly by APHA, AWWA and WPCF, 1998.

Laboratory Manual for CE 310: Introduction to Environmental Engineering, Spring 2000, Ray, B.T., Southern Illinois University Carbondale.

Wastewater Engineering: Treatment, Disposal and Reuse, 3rd Ed., Metcalf and Eddy, McGraw-Hill, 1991.

Standard Handbook of Environmental Engineering, Corbitt, R.A., McGraw-Hill, 1990.

Biochemical Oxygen Demand Lab Data Sheet

Name _____

Date _____

Laboratory Section _____

Treatment Facility _____

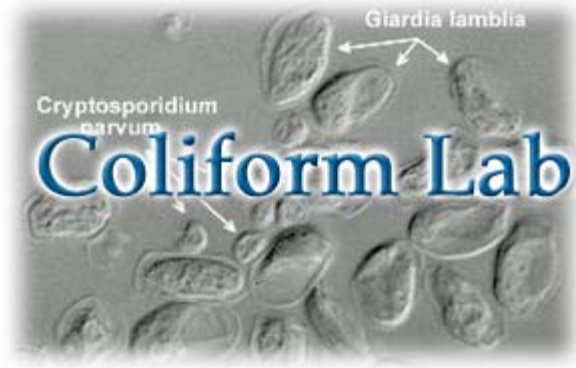Initial Date and Time _____

Final Date and Time _____

Sample	Volume WW mL	Initial DO mg/L	Final DO mg/L	DO uptake mg/L	F	BOD mg/L
1						
2						
3						
4						
5						
6						
Dilution Water Blank						
G-GA Standard						

EQUIPMENT USED (include model numbers):

NOTES:

COLIFORM LAB

Introduction

Pathogenic organisms present in water and wastewater are difficult to test for, and are often in small numbers. Therefore, the typical approach is to test for the presence of indicator organisms such as the coliform group. The coliform bacteria are present in the intestinal tract of mammals. Although not pathogenic themselves, the presence of coliform bacteria in large numbers may indicate the possibility of contamination of the water supply by fecal matter or insufficient treatment of a wastewater. One analytical method commonly used by regulatory agencies and water utilities to test for coliform is the membrane filter technique. The objective of this laboratory is to conduct this experiment, using different sources of water and wastewater.

Materials and Equipment

- Vacuum System
- 0.45 m membrane filter
- Filtration apparatus
- Pipets
- Graduated cylinder
- Petri dishes (pre-sterilized plastic dishes are available commercially)
- Absorbent pads
- Tweezers
- Incubator (35±0.5°C with a relative humidity of at least 60%)
- M-Endo medium (prepared by lab instructor)
- Sterilized buffered dilution water (prepared by lab instructor)
- Water and/or wastewater sample collected in sterilized glass or plastic bottles

Note: Anything contacting the sample must be sterilized to prevent contamination. This includes, but is not limited to, glassware, filters, pipets and the filtration apparatus.

Procedure

Collect two different water samples from different sources. If collecting from a treatment facility, collect the sample prior to chlorination if possible. Otherwise, the chlorine must be neutralized with sodium thiosulfate immediately after collecting. Drinking water samples should also be dechlorinated. Some manufacturers of sample bottles place sodium thiosulfate in the sample bottles prior to distribution.

Using sterile forceps, place a sterile membrane filter (grid side up) over the porous plate of the flask of the filter device. Place the funnel unit over the flask and lock it in place. Shake your sample 25 times to assure that it is well mixed. Pipet the required volume of sample into the top of the filter apparatus. For drinking water, 100 mL is the standard sample size. Filter the sample under a partial vacuum. A satisfactory filtration time is within five minutes. If this cannot be obtained, the required volume may be distributed among numerous membranes (i.e. 100 mL may be filtered in two 50 mL or four 25 mL portions).

For analyzing samples other than drinking water, the required volume may be estimated using Table 1. Because the range of sample volume is large, it is best to analyze other waters by filtering three different sample volumes. When less than 10 mL of sample is to be filtered, add approximately 10 mL of sterile dilution water to the funnel before filtration. Alternately, you may pipet the sample into a sterile bottle and mix with approximately 10 mL of sterile dilution water first, and then filter the entire amount. This increase in water volume aids in the uniform dispersion of the bacteria over the effective filtering surface.

Table 1: Approximate filtration volume

Source	Approximate Volume
Drinking water	100
Lakes	10-100 mL
Bathing beaches	0.01-10 mL
Streams, rivers	0.01-10 mL
Unchlorinated wastewater	0.0001-0.1 mL

After filtering the sample, and with the filter still in place, rinse the interior surface of the funnel with 20 to 30 mL of sterile dilution water three times (this may be applied from a squeeze bottle).

Place an adsorbent pad in the bottom of a sterilized petri dish. Saturate the pad with 1.8-2.2 mL of M-Endo medium. Decant any excess medium. Remove the filter from the filtration device using sterile forceps. Place in on the saturated pad

using a rolling motion to avoid the entrapment of air. The contact with the medium is important, since the colonies will not grow without this contact.

Place the prepared cultures in waterproof bags and incubate in a submerged water bath for 22-24 hr at 35±0.5°C. Do not incubate beyond 24 hr. After incubating, remove the cultures. Count any colonies that develop a red color with a metallic sheen. These are colonies of coliform bacteria. Report the results as # of colonies/100 mL. Other bacteria may be present, but will not exhibit the characteristic color and sheen. These colonies may be pink, blue, or white lacking sheen.

In addition to the samples, test the dilution water. Evidence of contamination in this sample indicates unsterile conditions and invalid data. A number of improper procedures can result in less than desirable cultures.

Analysis

A suitable quantity of the sample water results in an ideal colony count of 20 to 80 coliform colonies and not more than 200 colonies. Less than 20 colonies are considered unreliable statistically. More than 200 colonies makes counting individual colonies on the filter difficult.

Compute the concentration of coliform colonies, or coliform density, using the following equation:

$$(Total)\, coliform\, /100\, mL = \frac{coliform\ colonies\ counted \times 100}{mL\ sample\ filtered}$$

If no coliform colonies are observed, report the coliform colonies counted as "<1 coliform/100 mL". If the total number of bacterial colonies, coliforms plus noncoliforms, exceed 200 per membrane, or if the colonies are not distinct enough for accurate counting, report results as "too numerous to count" (TNTC) or "confluent", respectfully.

If you distributed your sample over multiple membranes, you should calculate the coliform density by using the total number of colonies counted and the total volume filtered.

Elements of Report

In addition to the general requirements of your report, you should include the following information:

- Sample site
- Specific model of equipment
- Explain why we measure for the total number of coliform bacteria in a water sample, particularly since coliforms are not normally considered a pathogen

- What is the desirable range of total coliforms on a membrane filter? What is the maximum number of total colonies present?

- Why do you need to have a smaller sample volume for river water and raw sewage compared to drinking water?

- Is there evidence of contamination in your dilution water sample? Discuss sources of contamination and the need for sterilized equipment

References

Standard Methods for the Examination of Water and Wastewater, 20th Ed. Published jointly by APHA, AWWA and WPCF, 1998.

Laboratory Manual for CE 310: Introduction to Environmental Engineering, Spring 2000, Ray, B.T., Southern Illinois University Carbondale.

Introduction to Environmental Engineering, 3rd Edition, M.L. Davis, D.A. Cornwell, WCB McGraw-Hill, 1998.

Field Manual for Water Quality Monitoring: An Environmental Education Program for Schools, 12th Edition, M.K. Mitchel and W.B. Stapp, Kendall/Hall Publishing Co., 2000.

Coliform Lab Data Sheet

Name _____

Date _____

Laboratory Section _____

Site 1 _____

Site 2 _____

Site 1		
Sample	Volume (mL)	Number of Colonies
1		
2		
3		
Site 2		
Sample	Volume (mL)	Number of Colonies
1		
2		
3		

NOTES:

JAR TEST

Introduction

Untreated water contains dissolved, suspended and colloidal size particles. The solids lab focused on the procedure for quantifying the amount of dissolved and suspended solids. In those experiments, the suspended solids were filtered out of the water using a 1.2 mm pore size glass fiber filter. Colloids range in size from 0.001-1 μm. As a consequence, colloidal size particles were included as dissolved particles. In water treatment, the initial gravity settling will not remove colloids. Instead, they remain suspended due to their electrical charge and subsequent slow settling velocity (< 0.1 mm/s). In addition, colloidal size particles are difficult to remove during filtration.

Colloidal particles cause color in water, as well as taste problems. Since much of the colloidal matter comes from natural organic matter, they contribute to the formation of undesirable chlorine disinfection by-products. Other material, such as toxic metals, synthetic organic molecules, iron and manganese may also be sorbed to these fine particles.

To remove colloids as well as bacteria, coagulation and flocculation are typically combined in a two-stage process during water treatment. This chemical-physical treatment causes small particles to combine into larger aggregates that are more readily separated from water by sedimentation and filtration. In the coagulation stage of the process, aluminum sulfate (alum) or ferric sulfate are rapidly mixed with the water. The chemical neutralizes the charged particles, which causes them to adhere to each other and form flocs. When properly formed, the flocs are larger and more dense than the colloids, and will settle quickly. Flocculation is the slow mixing of the water in order to encourage the formation of the floc.

The coagulant dose required to produce a floc varies with the concentration, size and types of particles in the raw water as well as the alkalinity or pH. To determine the most economical amount of chemical to add, a jar test can be conducted. During this test, the optimum dose, pH, flocculator mixing rate or detention time can be chosen. The basic procedure involves a series of batch experiments that simulate the full-scale process.

Equipment and Material

- Aluminum sulfate
- Ferric sulfate (optional)
- 1 liter beakers
- Laboratory stirrer with illuminated base
- Timer
- Scale for weighing coagulant

- Pipets
- 1000 mL volumetric flask
- Turbidimeter (optional)
- pH meter (optional)

For this lab, you should prepare a stock solution of the coagulant. The stock solution of alum is prepared by dissolving 10 grams of alum into 1000 mL of distilled water. Each 1.0 mL of this stock solution will equal 10 mg/L when added to 1000 mL of water to be tested. Prepare this solution in using the volumetric flask. Fill the flask approximately half full with distilled water. Then add the dry ingredient. Mix well. Fill the flask to the line on the neck of the flask.

Procedure

Typically, a lab stirrer for jar tests has six paddles. For each paddle, fill a 1 liter beaker with 1 liter of raw water. Using the stock solution, dose each beaker with increasing amounts of alum. Different sources of raw water will require different doses. A reasonable starting point for this experiment is 0.5 mL-3.0 mL in increments of 0.5 mL. After adding the alum, stir the beakers at a high rpm for approximately 1 minute. Then reduce the rpm and stir for an additional 30 minutes while observing the floc formation. Allow the floc to settle for one hour. For this lab, you can determine the optimum dose visually by selecting which beaker has the clearest water. Alternately, you can test the turbidity of the water in each beaker.

Experimental parameters such as paddle speed, rapid mixing time, flocculation time and settling time can be adjusted to simulate a wide range of full scale operating conditions. Further testing can be conducted over a narrower range of alum doses based on the results of the preliminary test.

Additional tests can also be conducted to optimize the alum dose over a range of pH values. In this case, choose the optimum dose from the previous experiment. Adjust the raw water in each beaker to provide a range of pH values. The pH may be adjusted by either addition sulfuric acid (to lower the pH) or lime (CaO) or soda ash (Na_2CO_3) (to raise pH). Add the alum, mix and settle using the same procedure as before.

Analysis

If the sample appears cloudy, with little or no floc and almost no settling, too little coagulant was used, a condition referred to as a coagulant underfeed. A coagulant overfeed on the other hand will form a dense floc. It will appear fragile and fluffy when the stirrer is turned off, and as a result, will not settle well. A floc formed by an overfeed is called a false floc, and will carry to the filter. This is one of the most common treatment problems. A good floc will appear heavy and

tight, not too dense, with spaces of bright, clear water between the particles and will begin to settle as soon as the stirrer is turned off.

If the turbidity of the water is tested, develop a graph of turbidity (NTU) versus alum dose (mg/L).   If the pH of the water was also adjusted, develop a graph of turbidity (NTU) versus pH. From these graphs, the conditions that produce the lowest residual turbidity are the optimal conditions.

Report

For this report, explain how each step of the experimental process relates to unit processes in a water treatment facility. In addition, list the brand and model number of the stirrer unit used.

References

Nazaroff, W.W. and Alvarez-Cohen, L., 2001, Environmental Engineering Science, Wiley.

Phipps and Bird, The Jar Test. http://www.phippsbird.com/jartest.htm (July 2001).

Data Sheet

Name _____

Section Number _____

Raw water source _____

Make and Model of Jar Test Apparatus _____

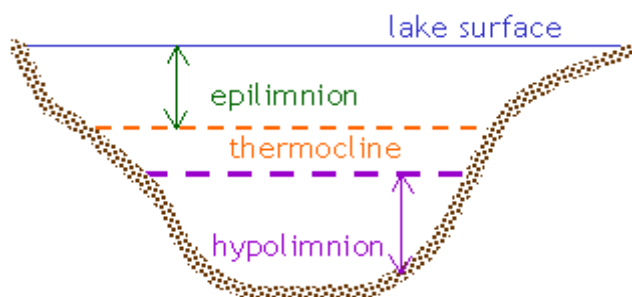| Jar	Dose (mg/L)	Comments	pH (optional)	Turbidity (optional)
1				
2				
3				
4				
5				
6				

LAKE PROFILE

Introduction

Lakes exhibit stratification due to density differences in the water as the temperature increases or decreases at different depths. During the summer, warm surface air and longer days with direct sunlight on the surface of the water causes the surface of the lake to be much warmer than the water at different depths. If you have gone swimming in a lake during the summer, you have probably noticed a distinct change in water temperature at a certain point beneath the surface. The point where the temperature has a distinct temperature change is known as the thermocline. The warm region above the thermocline is the epilimnion. Below the thermocline is the hypolimnion.

The density of water changes with temperature (Table 1). In addition, the amount of dissolved oxygen changes with temperature (Table 2). Since field probes are commercially available to measure temperature and dissolved oxygen concentrations in water, the profile of a lake can be measured. From this data, you can also show the stratification of the lake due to density differences, and identify the epilimnion, thermocline and hypolimnion. The temperature and dissolved oxygen concentrations in these regions will support different aquatic and biological life. For example, as organic sediments build up at the bottom of the lake, they exert a significant oxygen demand on the hypolimnion. Since the dissolved oxygen in this region is low, and replenished at a slow rate, this region may become anaerobic.

Figure 1: Generalized schematic of lake stratification.

Table 1: Density of Water at 1 atm

Temperature (°C)	Density, ρ, (kg/m^3)
0	999.842
3.98	1,000.000
5	999.967
10	999.703
12	999.500
15	999.103
17	998.778
18	998.599
19	998.408
20	998.207
21	997.996
22	997.774
23	997.542
24	997.300
25	997.048
26	996.787
27	996.516
28	996.236
29	995.948
30	995.650
35	994.035
40	992.219
45	990.216
50	988.039
60	983.202
70	977.773

The profile of the lake will change as the seasons change. Throughout the summer, the depth of the epilimnion region will increase. However, as winter approaches, shorter days and cooler temperatures cause the density of the upper layer to increase to the point of being more dense than the lower level, causing the lake to "turn over". In colder climates, a second overturn can occur in the spring as the surface ice melts, becomes dense and sinks to the bottom of the lake.

Turbidity in surface water is caused by colloidal or suspended particles. The composition of these particles varies. In general, they are from the erosion of soil particles, organic material, bacteria or plankton. The turbidity in the water limits the depth at which sunlight can penetrate the water, consequently controlling the life forms that thrive at different depths.

Table 2: Saturation of Dissolved Oxygen in Distilled Water

Temperature ºC	Solubility (mg/L)	Temperature ºC	Solubility (mg/L)
0	14.6	16	9.9
1	14.2	17	9.7
2	13.9	18	9.5
3	13.5	19	9.3
4	13.1	20	9.1
5	12.8	21	8.9
6	12.5	22	8.7
7	12.1	23	8.6
8	11.8	24	8.4
9	11.6	25	8.3
10	11.3	26	8.1
11	11.0	27	8.0
12	10.8	28	7.8
13	10.5	29	7.7
14	10.3	30	7.6
15	10.1		

The overall objective of this lab is to measure the dissolved oxygen, temperature and pH profile of a lake, as well as measure the turbidity of the water. The secondary objective is to introduce students to on-site measurement techniques that may involve remote site visits.

Application

Lakes may be used as surface water source for a municipal water supply. The location of the intake pipe is critical for water quality. If the location is in the hypolimnion, and the water may become anaerobic. In this case, the water will have taste and odor problems, requiring additional chemical treatment, and generally customer complaints. If the intake is in the epilimnion, it may also have taste and odor problems during the summer, due to warmer water and algae. Optimal placement of the intake during one season may be compromised during lake turnover. Therefore, It is common practice to have two or more intakes at different depths, which can be used at different times of the year.

Turbidity is also important in water treatment since suspended solids can shelter microorganisms from the action of disinfectants. Suspended solids are readily removed by coagulation, sedimentation and filtration. If treated water is still high in turbidity, something is likely to be malfunctioning in the treatment plant.

Turbidity can be measured using a simple device called a Secchi disk, or a more precise analytical instrument called a turbidimeter. In the field, the use of the

Secchi disk allows us to determine the depth at which turbidity becomes a factor. The Secchi disk is a black and white disk attached by a chain or a rope, with a weight beneath the disk. The disk is lowered until it disappears. The depth at which it disappears is recorded. It is difficult to use this method in fast river currents, shallow rivers, or areas of low turbidity.

In treatment plants, a turbidimeter is used to determine turbidity. It is an analytical instrument that measures the scattering of light through a sample. Instruments that measure the scattering of light are called nephelometers; hence the units are reported as nephelometer turbidity units, or NTU's. Originally, turbidity was measured using a Jackson tube, which is a long glass tube suspended over a lit candle. A sample of water was slowly poured into the tube until the candle flame, as viewed from above, became diffuse. In this case, the turbidity was measured as a length, and reported as Jackson Turbidity Units (JTU's). The measurements from all three methods can be roughly equated.

In surface water filtration for treatment of drinking water, turbidity in the filtered water must be equal to or less than 0.5 NTU in at least 95% of the measurements taken each month. Turbidities in excess of 5 NTU are easily detectable in a glass of water and are usually objectionable for aesthetic reasons. Individual states may increase the 0.5 limit to 1 NTU if they determine that overall treatment achieves the disinfection requirements. Systems using slow sand filtration must achieve a turbidity level of less than 5 NTU at all times and not more than 1 NTU in more than 5 percent of samples taken each month. The 1 NTU limit may be increased by the state up to 5 NTU if it determines that there is no significant interference with disinfection.

Materials and Equipment

- Field meter capable of measuring temperature and dissolved oxygen (and possibly pH).
- Boat
- Life jacket
- Secchi disk

Make sure the line holding the Secchi disk is marked in meters (or feet) increments for easy measurement in the field. The line holding the probe for the field meter must also be marked in meter (or feet) increments. This laboratory can also be done from a pier or near the shore, depending on the depth of the water.

Procedure

Observe and record information on the site, including weather and surrounding land use. If possible, obtain hydrographic maps of the lake. From this map, locate the deepest part of the lake for your first measurements.

Select a minimum of two different sampling locations. For the Secchi disk, you will take two readings at each location (as described below), and report the average reading. Drop the Secchi disk vertically into the water. The weight below the disk should prevent it from moving away from you due to any current.

Secchi Disk Procedure

- Drop the disk until it disappears. Record this depth.

- Drop the disk slightly further into the water. Raise the disk until you can see it again. Record this depth.

- Report the average of these two readings.

Field Meter

- Drop the probe to the bottom of the lake. Read and record the depth, pH, temperature and dissolved oxygen concentration. Depending on the probe used, you can choose fewer properties or other properties to measure.

- Raise the probe to the next increment (either 1 m or 1 ft). Record this depth and the parameters to be measured.

- Continue this procedure until you reach the surface of the lake.

Analysis

Plot the data with depth as an independent variable (on the x-axis). In this case, we have two dependent variables, temperature and dissolved oxygen. These variables should be plotted on the y-axis. Because they have a different range, you should plot these as two different axes. You should be able to identify the epilimnion, hypolimnion and the thermocline.

The density of the water can be determined from the temperature data (Table 1). Prepare a second graph showing this data as a function of depth.

Elements of Report

In addition to the general requirements of your report, you should include the following information:

- Specific model of equipment used and accuracy

- The density of water is based on a table for pure water. Would the density be different for lake water? Explain.

- Was the temperature, density and DO profile as expected? Why?

- Explain the sequence that causes a lake to "turn over" in the spring and fall.

- Identify plant and aquatic life that you would expect in the different regions within the profile of the lake.

- Description of the site (i.e. location, general water quality, surrounding land use)
- Weather conditions
- Location of measurements, describing any significant differences if more than one location

References

Laboratory Manual for CE 310: Introduction to Environmental Engineering, Spring 2000, Ray, B.T., Southern Illinois University Carbondale.

Introduction to Environmental Engineering and Science, 2nd Edition, G.M. Masters. Prentice Hall, 1997.

Field Manual for Water Quality Monitoring: An Environmental Education Program for Schools. 12th Edition, Mitchell, M.K, and Stapp, W.B., Kendell/Hunt Publishing, 1997.

Introduction to Environmental Engineering, 3rd Edition, M.L. Davis, D.A. Cornwell, WCB McGraw-Hill, 1998.

Water Supply and Sewerage, 6th Edition, T.J. McGhee, McGraw-Hill, 1991.

Lake Profile Lab Data Sheet

Name _____

Date _____

Laboratory Section _____

Location _____

Depth, ft	DO, mg/L	Temp., °C	pH (optional)

Secchi Disk

Location	Depth (lowering)	Depth (raising)

Equipment used (include model numbers):

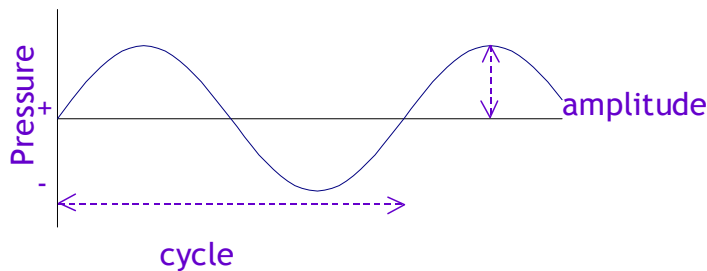NOTES: (include surface temperature, weather conditions, time of day)

NOISE POLLUTION

Introduction

Noise pollution is unwanted sound. This statement is elucidated when one considers a lawn mower early in the morning, a busy highway, or an outdoor concert. The control and abatement of noise pollution is a part of the environmental health and safety of communities and industry alike.

We evaluate sound by at least four distinct characteristics: frequency, loudness, duration and subjectivity. Loudness, frequency and duration are objective measurements of sound. In contrast, your subjective response to noise is not, one person's pleasure may be someone else's noise.

Sound is propagated through air as a cyclic wave of pressure fluctuations. These pressure fluctuations cause the eardrum to flex, which translates into sound. Pure sound travels as a perfect sinusoidal wave (Fig. 1).

Figure 1. Pure sound travels as a perfect sinusoidal wave

The number of cycles per unit time is the frequency, *f*. A common unit of frequency is cycles per second or Hz. Middle A on a piano is 440 Hz, and speech is typically in the range of 1000-4000 Hz. This range is reduced by age and environmental exposure.

The frequency and the wavelength (λ) of sound waves are inversely related:

$$f = \frac{c}{\lambda} \qquad\qquad (1)$$

where c is the speed of sound. In the case of sound waves traveling through air where the air is assumed to behave as an ideal gas:

$$c = 20\sqrt{K} \qquad\qquad (2)$$

where k is the air temperature in degrees Kelvin. In this equation, the units of c are m/s. Sound can travel through different mediums such as water, steel or lead. In this case:

$$c = \sqrt{\frac{E}{\rho}} \qquad\qquad (3)$$

where E is Young's modulus of elasticity (N/m^2) and r is the density of the medium (kg/m^2).

Loudness, or the intensity of the sound, is directly related to the amplitude of the pressure fluctuations. The human ear can detect between 2 x 10^{-5} Pa (low) and 63 Pa (the threshold of pain. The sound pressure level (SPL) is used to describe loudness, and is reported as SPL:

$$SPL(dB) = 10\log\left(\frac{P^2}{P_o^2}\right) = 20\log\left(\frac{P}{P_o}\right) \tag{4}$$

where P_o is the reference pressure 2×10^{-5} Pa and P is the sound pressure of concern (Pa). Table 1 shows the relationship between pressure and dB, indicating their relationship to common sources of sound.

Table 1: Sound pressure and SPL.

Common Outdoor Noise	Sound Pressure (μPa)	Sound Pressure Level (dB)	Common Indoor Noise
	6324555	110	Rock band at 5 m
Jet fly-over at 300 m	2000000	100	
	632456	90	
	200000	80	
	63246	70	
	20000	60	
	6325	50	
	2000	40	
	632	30	Library
Quiet rural nighttime	200	20	
	63	10	
	20	0	

In our complex sound environment, we are constantly hearing sound from several sources. In this case, the SPL can be estimated from:

$$SPL_{total} = 10\log\sum 10^{SPL/10} \tag{5}$$

where the SPL from each source is equated non-linearly.

Because the human ear is more sensitive to higher frequencies than to lower frequency, noise meters have adjustment that correlate to the human response to noise. These adjustments, which are internationally standardized, are referred to as weighting networks. The A weighting is the human response to low sound levels and has been adopted in many laws and ordinances. The B and C weighting are adjustments for moderate and high sound levels. The output signal for noisemeters is dB. Therefore, the notation used for these adjustments are dB(A), dBA or dBa for the A weighting, with similar notation for B and C. Figure 2 show the relative response, or correction, for a range of frequencies.
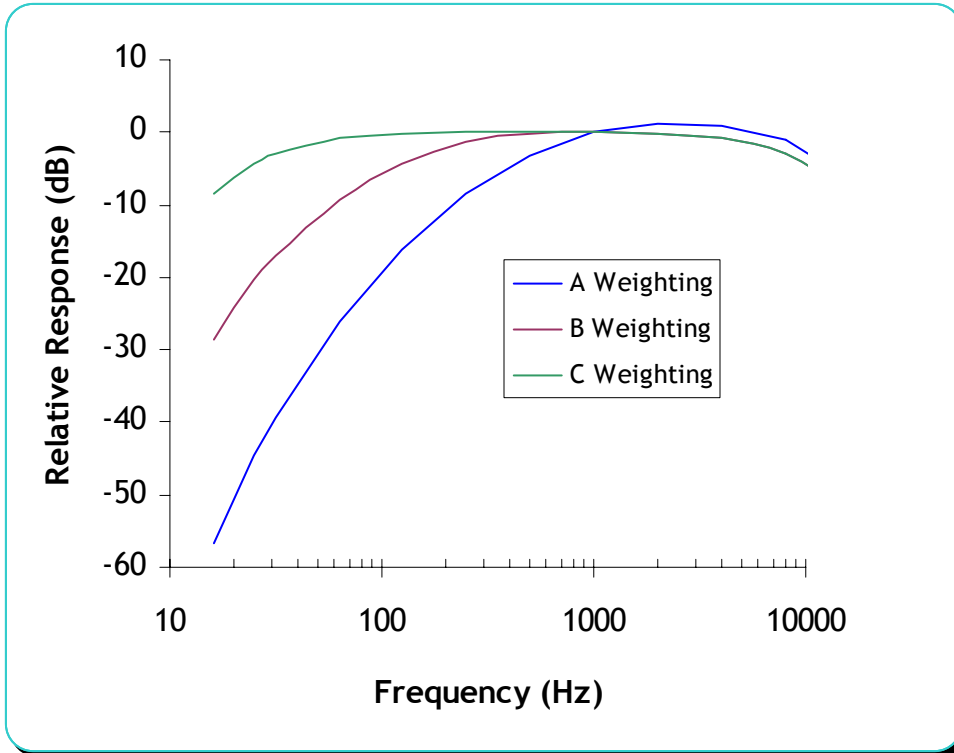
Figure 2: The relative response characteristics of the three basic weighting networks.

Another significant characteristic of sound is the duration. If 60 dB is the maximum sound pressure level that occurs during a 1 hour period weighted by the A scale, it is reported as 60dB(A):L_{max}(1hr).   Other commonly used community noise descriptors are L_{dn} (24 hour day/night level) and L_{90}(t), which is the SPL exceeded 90% of the time for a specified time.
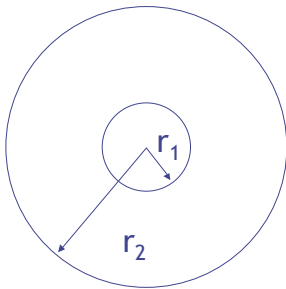

Figure 3: Geometry of a point source model

Another aspect of sound that we will consider in this lab is how sound travels as the sound waves move away from the source.   Two simplistic models we will evaluate are the point source and the line source models. The point source model can be used to evaluate an air conditioner or blower, whereas high traffic highways would be modeled as a line source. For a point source:

$$\Delta SPL(dB) = 10\log\left(\frac{r_1}{r_2}\right)^2$$

where r_1 is the distance from the source at point 1 and r_2 is the distance at point 2 (Fig 3). Further evaluation of this model shows that we reduce the noise level by 6 dB every time we double the distance. The line source model is:

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$$\Delta SPL(dB) = 10\log\left(\frac{r_1}{r_2}\right) \qquad (7)$$

these simplified equations do not account for sound wave interaction with obstacles. Figure 4 shows one of many ways that a sound wave can reflect away from objects in the environment.

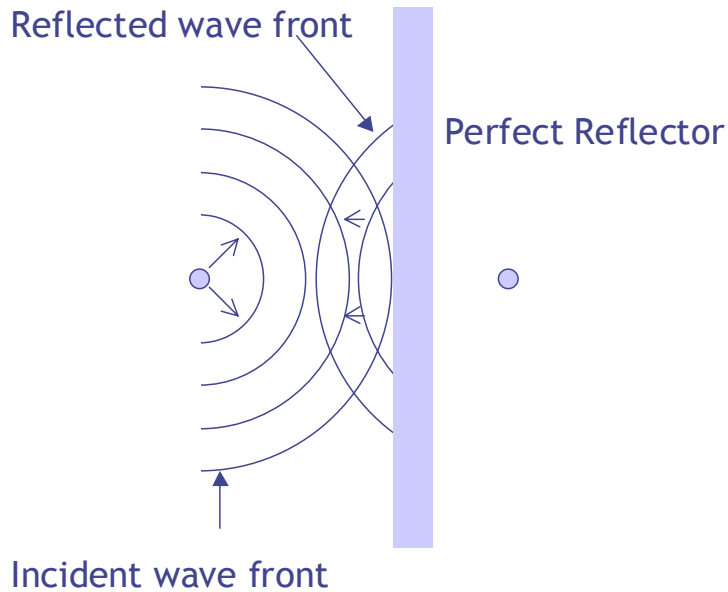Reflected wave front

Perfect Reflector

Incident wave front

Figure 4: Sound waves from a point source reflected from an ideal reflector

Materials and Supplies

The materials needed for this lab are fairly simple:

- Noise Meter
- Tape measure
- For the third experiment listed in the procedure, the noise meter must be capable of reading at the A-,B- and C-scales.

Procedure

Part 1: Sound and distance

As we move away from the source of a sound, the SPL decreases. Choose a source of sound. Using a noise meter, measure the sound pressure level. Record the measurement, the distance from the source and the weighting used (A, B or C). Move away from the source. Measure the sound pressure level again, using the same weighting. Record this measurement and the distance from the source.

Part 2: How loud is it?

Using a noise meter, measure a range of SPL's from different sources.

Part 3: Weighting Scales

Measure low and high frequency sounds using the three different weight scales. Record the different results.

Part 4: Multiple Sounds

Equation 5 provides a basis for determining the sound from multiple sources. To test this equation, choose three sources of sound that you can turn off and on in relatively close proximity. Standing in one position, record the sound pressure level for each source independently. Next, record the sound pressure level when two of the sources are on, then with all three on.

Analysis

For part 1, evaluate the use of the point or the line source model for the data you collected. For part 2, develop a table similar to Table 1, clearly indicating your data relative to the data shown in Table 1. For part 3, discuss whether the difference in scales is more significant at lower or higher frequencies and how these results relate to Figure 2. For part 4, apply the equation for multiple sources. Compare your measured results with the theoretical results.

Report

For this report, clearly address the results and application of each experiment. In addition, you should list the brand and model number of your noise meter, and any unique features that it has.

References

Cooper, C.D., Dietz, J.D, and Reinhart, D.R., 2000. Foundations of Environmental Engineering. Waveland Press.

Cunniff, P.F., 1977, Environmental Noise Pollution. John Wiley and Sons.

Data Sheet

Name _____

Date _____

Section No. _____

Part 1

Source _____

Weighting Scale _____

Model Used (point or line source) _____

Distance	SPL	Distance	SPL	Δ SPL	Δ SPL

Part 2

Weighting Scale _____

Source	SPL

Part 3

Source	A	B	C

Part 4

Source		SPL measured	SPL theoretical
1			N/A
2			N/A
3			N/A
1+2			
1+3			
2+3			
1+2+3			

Settleability of Solids

Introduction

In both water and wastewater treatment, we rely on gravity settling to remove solids. This may be done in primary or secondary settling tanks or clarifiers. Therefore, the design and operation of the facilities are dependent on predicting the settling characteristics. In this laboratory, we will measure the settling characteristics of influent wastewater and activated sludge.

It is important to recognize the difference between suspended and settable solids in practical application. The purpose of measuring the influent wastewater is to determine the amount of settable solids that can be removed from conventional gravity settling during primary settling. To do this, a well mixed sample will be placed in an Imhoff cone, and allowed to settle for one hour. The Imhoff cone is transparent with graduation marks, so you will be able to visually observe and measure the amount of solid matter settled. At an operational level, the settleability of the influent will indicate the rate at which solids will build up in bottom of the tank. In order to maintain the system, these solids must be removed. An average value of settable solids in a medium strength untreated domestic wastewater is 10 mL/L.

For activated sludge, we will measure the sludge volume index, SVI. The SVI indicates the tendency of activated sludge solids to thicken or become concentrated during secondary sedimentation. A good separation will result in a denser biological floc in the bottom of the secondary clarifier that not only occupies a smaller volume of the tank, but also requires a lower pumping rate to keep the bio-solids in circulation. A lower SVI indicates better settling. For properly operating diffused air activated sludge treatment plants, the SVI is usually from 50-150 mL/g,. The reciprocal of SVI, with appropriate conversion, is the sludge density index (SDI). Of note, SDI is also known as the Donaldson Index and the SVI is also known as the Mohlman Index.

Equipment and Material

- Stopwatch
- Imhoff Cone
- Stand
- Glass rod
- Vacuum system
- Filtration apparatus
- Drying oven (set at 103°C)
- Tongs

- Desiccators (provided with a desiccant containing a color indicator of moisture concentration)

- Analytical balance capable of weighing to 0.1 mg

- Glass fiber filters, Whatman 934AH or equivalent

- Wide bore pipet (large hole)

- Graduated cylinder

- Crucibles, prefired at 550° C and cooled in a desiccator

- Wastewater samples prior to primary sedimentation and from the aeration basin.

Procedure

Imhoff Cone

In this experiment, you will need a sample of wastewater effluent after the grit chamber. Fill an Imhoff cone to the 1-L mark with a well mixed sample. Allow the sample to settle for 45 minutes. Gently agitate the sample near the sides of the cone with a glass rod to remove any particulate matter or floc that has not settled with the bulk of the liquid, then settle for 15 additional minutes. Record this final volume of settable solids in the cone as milliliters per liter

Total Suspended Solids

In this procedure, you will need a well mixed sample of mixed liquor from an aeration basin. This procedure is also outlined in the Solids Lab. The total suspended solids is determined by filtering the sample through a 1.2 μm pore size glass fiber filter. The amount that remains on the filter is the total suspended solids, whereas the amount that passes through is the total dissolved solids.

Prior to use, the glass filter(s) must be prepared. Insert the glass fiber filter, wrinkled side up in the filtration apparatus. Apply a vacuum and wash the filter with three 20 mL volumes of distilled water. Place the filter in a crucible. Place the crucible and filter in the muffle furnace for 20 minutes, then cool in a desiccator. Repeat this procedure to obtain a constant mass of the crucible and filter. Record the mass of the filter and crucible combination on your data sheet (m_{if}).

Place the filter back into the filter apparatus and restart the vacuum. Wet the filter with a small volume of distilled water to seat it. Filter through enough well mixed sample volume to yield between 2.5 and 200 mg of dried residue. For the mixed liquor, you will probably need to filter between 10-25 mL of sample. After the sample is filtered through, wash the filter with three successive 10 mL volume of distilled water, allowing complete drainage between washings, and continue the suction for about three minutes after the filtration of the distilled water is complete.

Place 10 mL of sample into the filter apparatus. Record this volume as V_f. If the suspended material clogs the filter and prolongs filtration, it may be necessary to decrease the sample volume.

Once the filtering is complete, remove the filter from the filtration apparatus, place it in its crucible, and dry to a constant mass at 103°C. Remove the filter and crucible from the oven, and cool it in a desiccator. After cooling, weigh the filter and crucible. As with previous steps, check that you have a constant mass by returning the filter and crucible to the dessicator, and weighing it again after 10 minutes. Repeat this step as needed. Record the mass on the data sheet (m_{ff}). This will be used to determine the total suspended solids concentration.

Sludge Volume Index, SVI

In this procedure, you will need a sample of mixed liquor from an aeration basin. Place 1 liter of well mixed sample in a graduated cylinder. In some cases, specialized glassware or a settleometer may be used. For the purposes of this lab however, the graduated cylinder is sufficient. Record the volume of settled solids after 30 minutes of settling.

Analysis

Imhoff Cone

The amount of settable solids in the wastewater influent is reported as mL/L:

$$Settleable\ Solids = \frac{mL\ settled\ solids\ after\ 60\ minutes}{L\ of\ sample}$$

Total Suspended Solids

The total suspended solids is calculated from the following data:

$$TSS = \frac{m_{ff} - m_{fi}}{V_f}$$

where:

TSS = total suspended solids (mg/L)

V_f = the volume of sample filtered (L)

m_{fi} = initial filter mass (mg)

m_{ff} = filter mass after drying (mg)

Sludge Volume Index, SVI

The SVI is the volume in milliliters occupied by 1 g of a suspension after 30 minutes of settling.

$$SVI = \frac{settled\ sludge\ volume\left(mL/_L\right) \times 1000}{suspended\ solids\left(mg/_L\right)}$$

The SDI can then be calculated as:

$$SDI = \frac{100}{SVI}$$

Report

Within your report, you should include the following items specific to your experiment:

- Name, location and general description of wastewater facility
- Specific equipment (manufacturer and model) used and accuracy

References

Standard Methods for the Examination of Water and Wastewater, 20th Ed. Published jointly by APHA, AWWA and WPCF, 1998.

Sincero, A.P and Sincero, G.A. 1996. Environmental Engineering a Design Approach. Prentice Hall

Nazaroff, W.W. and Alvarez-Cohen, L. 2001, Environmental Engineering Science, Wiley.

Data Sheet

Name _____

Section No. _____

Date _____

Name and Location of Plant _____

Date of Collection _____

Imhoff Cone

Volume of Settable Solids after 60 minutes	

Suspended Solids

Mass of filter and crucible prior to filtering, m_{if}	
Volume of sample, V_f	
Mass of filter, crucible and suspended solids, m_{ff}	

SVI

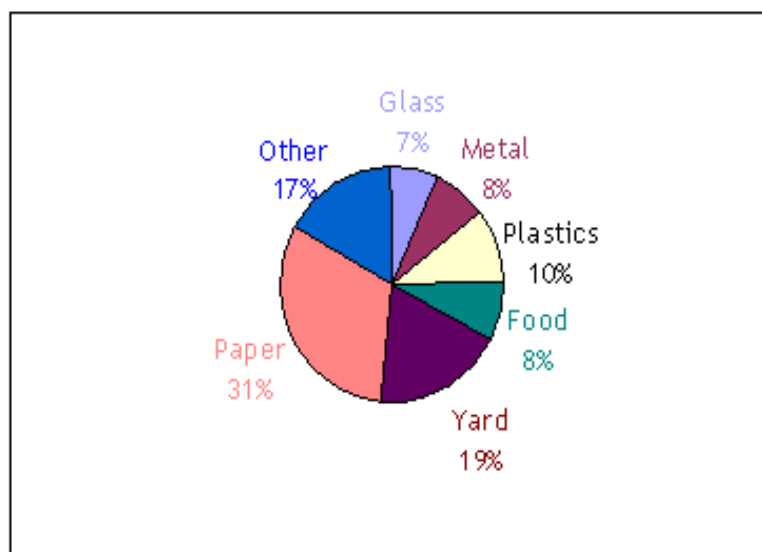|	
Volume of settled sludge after 30 minutes	

SOLID WASTE

Introduction

The United States generates approximately 8 lb of solid waste per person per day (8 lb/capita-day) when considering waste from residential, commercial and industrial sources. If all human sources are considered, such as agriculture, construction, and mining, the total solid waste produced in this country is an astounding 90 lb per person per day. Disposal of this waste is a national problem, with landfills space depleting while the amount of waste increases. Figure 1 shows the composition of municipal solid waste in 1990.

Figure 1: Composition of municipal solid waste in 1990.

The objective of this lab is to become familiar with the characteristics of municipal solid wastes while investigating techniques used to determine the different fractions of solid waste. Students will separate domestic solid waste into ferrous metal, nonferrous metal, glass, paper, plastic, wood, food products, yard trimmings and unspecified. The volume and mass fractions of each category will

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be determined. If the source of the solid waste is known, the generation per person per capita day will also be calculated.

Materials and Equipment

The following equipment is needed for this laboratory:

- Trash
- Scales
- Ruler
- Tape measure
- Magnet
- Volumetric containers (i.e. buckets, beakers)

Procedure

Weigh the solid waste that is to be used for this laboratory. This will give you the total mass (M_t). Estimate the volume of the solid waste by placing (not packing) it in a container and measuring the dimensions. This will give you the total volume (V_t).

Separate the solid waste into fractions containing ferrous and nonferrous metal, glass, paper, plastic, wood, food products, yard trimmings and unspecified. Weigh each fraction. Record each of these individual fractions as M_1, M_2, etc.

Using the ruler and tape measure, estimate the volume of each fraction of the solid waste. You may also use volumetric containers such as beakers or buckets. Keep in mind that solid wastes do not usually conform to geometric shapes. Use your imagination and engineering reasoning! Record each of these individual fractions as V_1, V_2, etc. The sum of these weights should equal V_t.

Analysis

Calculate the mass fraction, X_{mi}, of each category of solid waste using the following formula:

$$X_{mi} = \frac{M_1}{M_t}$$

where M_t is the total mass and M_i is the mass of each individual category (M_1, M_2, etc.). Once you have calculated X_{mi} for each category of waste, the sum of these fractions should equal 1.00.

Similarly, calculate the volume fraction, X_{vi}, of each category using the following formula:

$$X_{vi} = \frac{V_i}{V_t}$$

where V_t is the total volume and V_i is the volume of each individual category. As with the mass, the sum of these fractions should equal 1.00.

Elements of Report

Within your report, you should include or discuss the following items:

- A table that includes the raw data plus the calculation of the density, mass fraction and volume fraction of each category.

- A pie chart for both the mass fraction and volume fraction. How does this compare to Figure 1?

- Suggest improvements for determining the characteristics of solid waste.

- Discuss why the waste wasn't packed into containers for volume estimation.

- If the source of the solid waste is known, calculate the amount per person per capita day. How does this compare to the average amount per person per capita day in the U.S.?

References

Laboratory Manual for CE 310: Introduction to Environmental Engineering, Spring 2000, Bill T. Ray, Southern Illinois University Carbondale.

Environmental Engineering, Bill T. Ray, 1995. PWS Publishing Company.

Solid Waste Lab Data Sheet

Name _____

Date _____

Laboratory Section _____

Source of Solid Waste _____

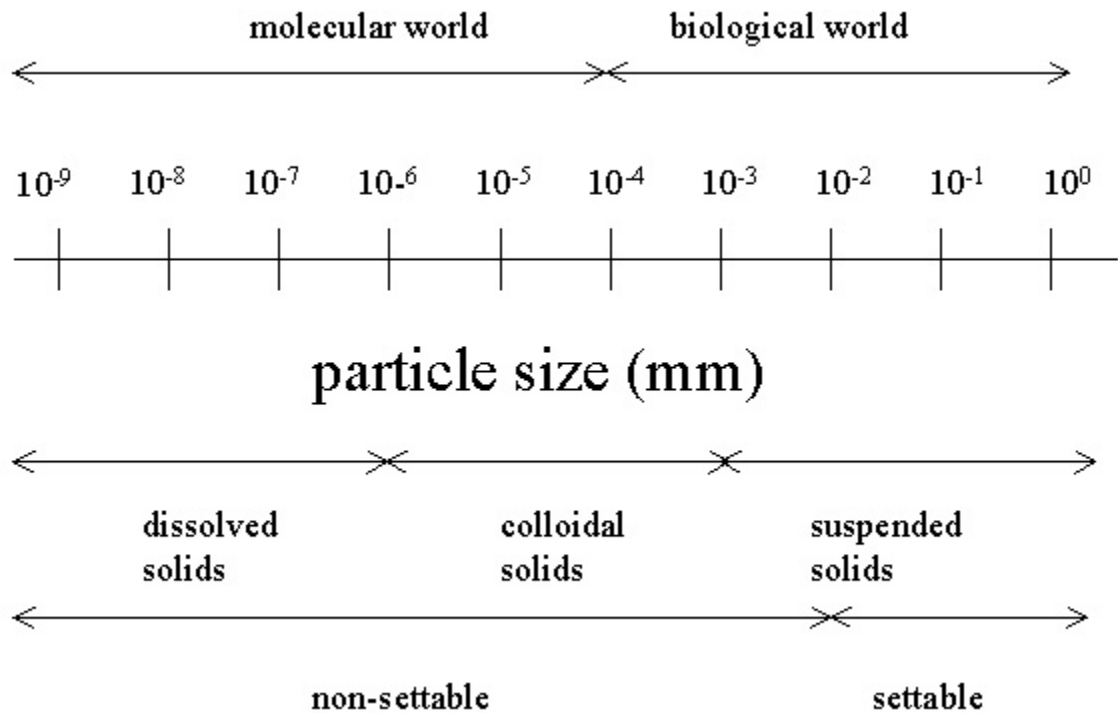| Source	Mass, g	Volume, m^3
Before separation		
Ferrous metal		
Nonferrous metal		
Glass		
Plastic		
Paper		
Wood		
Food products		
Yard trimmings		
Other (specify)		
Not otherwise specified		

NOTES:

SOLIDS

Introduction

As with the BOD, the solids content of water and wastewater is a significant parameter in characterization as well as treatment processes. In fact, the EPA considers both BOD_5 and the total suspended solids (TSS) a conventional pollutant. The term "solids" refers to matter suspended or dissolved in water. Water high in dissolved solids generally taste bad, requiring water treatment facilities to reduce the dissolved solids concentration below 500 mg/L. Water high in suspended solids may be deemed unsuitable for bathing or cooking. High mineral content, whether suspended or dissolved, may make water unsuitable for industrial processes. As with BOD_5, the concentration of solids in wastewater effluent may be used to determine compliance with wastewater discharge permits and to monitor treatment plant performance.

The total solids, TS, is the residual remaining after evaporating a representative sample of water/wastewater. Evaporation is usually conducted in an oven set at 103°C, which is slightly above the boiling point of water. In drinking water or river water samples, it is common to further subdivide the TS into the suspended and dissolved fractions (TSS and TDS). Filtering through a 1.2 mm pore size glass fiber filter does this. Because the colloidal fraction of the TS will also pass through this filter, it is commonly included with the dissolved fraction. However, it is important to note that colloidal particles are largely from clay, ranging in size from 10^{-3} to 1 mm. They remain suspended due to their electrical charge and subsequent slow settling velocity (< 0.1 mm/s). In wastewater treatment, particularly processes involving sludge treatment, the TS, TSS, and TDS are further divided into either organic or inorganic. The organic fraction is referred to as the volatile fraction, whereas the inorganic fraction is considered the fixed fraction. To determine the fraction of each, samples remaining from the measurement of the TS and TSS are placed in an oven at 550°C. The remaining residual is assumed to be the inorganic fraction. However, some inorganic material, such as mineral salts, may burn at this high temperature.

Figure 1 graphically shows the particle size classification of solids in water and wastewater. It also introduces a further classification of settable and non-settable fractions, with the size of settable particles being greater than 10^{-2} mm.

Table 1 shows examples of industrial wastewater concentrations for BOD_5 and SS. BOD_5 ranges from a low of 50 mg/L at an ammunition production facility to as high as 7000 mg/L at a tannery. A similar trend is shown in the concentration of SS. In the unit processes used for industrial wastewater treatment, as well as municipal wastewater treatment, tanks are designed specifically to reduce the SS concentration, and hence the BOD. The typical concentrations in untreated domestic wastewater are shown in Table 2. Here, the SS range from 100-300 mg/L. The total dissolved solids concentrations are higher than the SS in domestic wastewater, ranging between 200-1000 mg/L.

Supplemental data is included with this laboratory. The samples were obtained from the Carbondale Wastewater Treatment Facility.

Figure 1: Particle size classification (adapted from Kiely 1997)

Table 1: Examples of industrial wastewater concentrations for BOD and SS (Davis and Cornwell 1998).

Industry	BOD_5 (mg/L)	SS (mg/L)
Ammunition	50-300	70-1,700
Fermentation	4,500	10,000
Slaughterhouse (cattle)	400-2,500	400-1,000
Pulp and paper (kraft)	100-350	75-300
Tannery	700-7,000	4,000-20,000

Table 2: Typical composition of untreated domestic wastewater (Davis and Cornwell 1998).

Constituent	Weak	Medium (mg/L)	Strong
BOD_5 (as O_2)	100	200	300
COD (as O_2)	250	500	1000
SS	100	200	350
TDS	200	500	1000
TOC (as C)	75	150	300

Materials and Equipment

- Vacuum system
- Filtration apparatus
- Drying oven (set at 103°C)
- Muffle furnace (set at 550°C)
- Insulated gloves
- Tongs
- Desiccators (provided with a desiccant containing a color indicator of moisture concentration)
- Analytical balance capable of weighing to 0.1 mg
- Glass fiber filters, Whatman 934AH or equivalent
- Wide bore pipet (large hole)
- Graduated cylinder
- Crucibles, prefired at 550° C and cooled in a desiccator
- Influent and effluent sample of wastewater from a local municipal wastewater treatment facility. Refrigerate samples at 4° C until the time of analysis. It is preferable not to hold samples more than 24 hours. In no case hold samples more than 7 days.

Alternative: Sample from a water treatment facility prior to primary sedimentation.

Procedure

All data should be run in triplicate.

Total Solids

Weigh a crucible that has been previously fired at 550°C for one hour and cooled in a desiccator. This firing process removes any traces or organic matter that might add to your results. Record the mass on the sample data sheet (m_{ci}). Using a pipet, transfer a well-mixed raw sample into the crucible. Record this volume on your data sheet (V). For the influent wastewater, transfer 15 mL. For the effluent sample, increase this to 20 mL. The volume chosen may need to vary in order to achieve a final residual between 2.5 and 200 mg. This upper range is critical since excessive residue in the dish may form a water-trapping crust. In some cases, it may be necessary to dispense successive sample portions to the dish following evaporation to ensure a final residual within the necessary range.
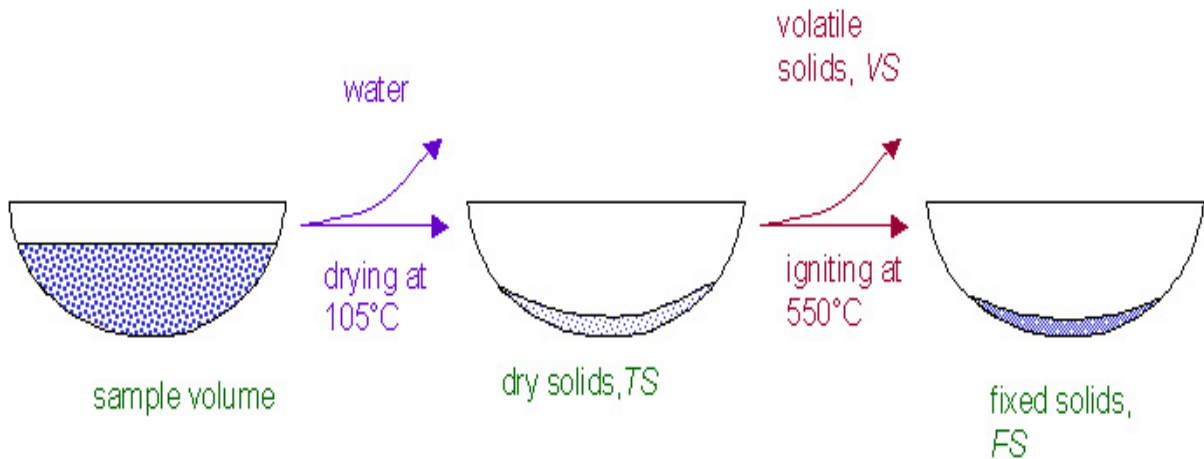
Place the crucible with the liquid sample in an oven set to about 98°C (to prevent boiling) until the sample is near dryness. Then increase the temperature to 103°C and dry to a constant weight, cooling the sample in a desiccator prior to

weighing. The heating-desiccator cooling-weighing step may need to be performed several times in order to achieve a constant mass. A constant mass is achieved when the mass loss is either 1) less than 4% of the previous mass or 2) less than 0.5 mg. The minimum drying time is 1 hour.

Once the sample reaches a constant mass, record the mass on your data sheet (m_{cf}). This data will be used to determine the total solid concentration.

Place the crucible in a muffle furnace at 550°C for 20 minutes. Place the crucible in a desiccator and cool to a constant mass. Weigh the crucible and record the mass (m_{cx}). This data will be used to determine the total volatile and fixed solids concentration.

Figure 1: Generalized schematic of steps to determine *TS*, *VS*, and *FS*.

Suspended solids

Prior to use, the glass filter(s) must be prepared. Insert the glass fiber filter, wrinkled side up in the filtration apparatus. Apply a vacuum and wash the filter with three 20 mL volumes of distilled water. Place the filter in a crucible. Place the crucible and filter in the muffle furnace for 20 minutes, then cool in a desiccator. As with the total solids, repeat this procedure to obtain a constant mass of the crucible and filter. Record the mass of the filter and crucible combination on your data sheet (m_{if}).
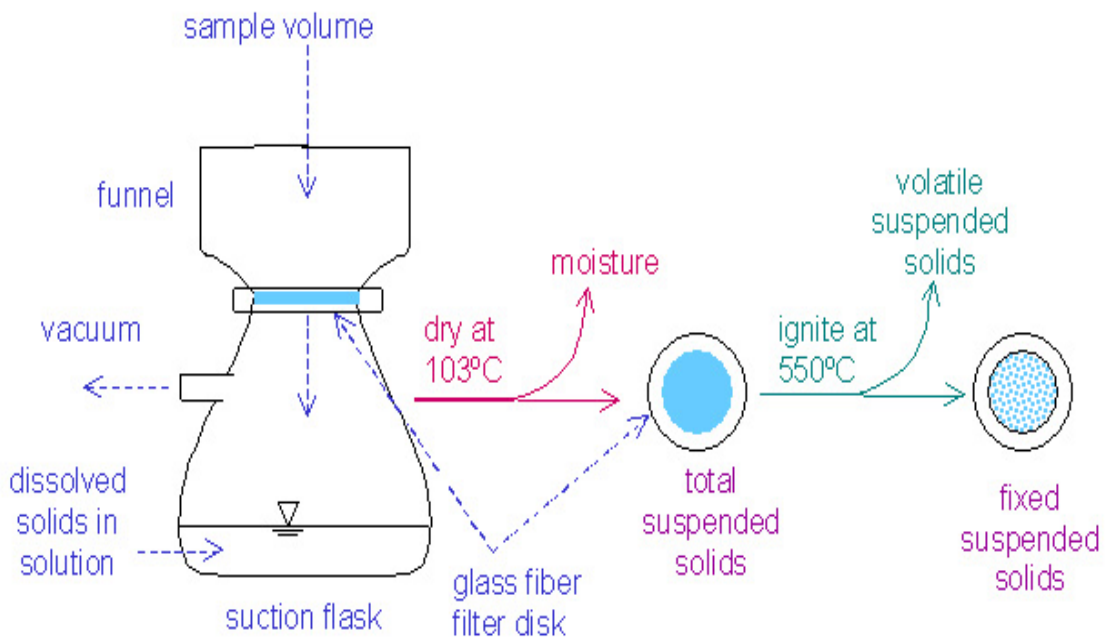
Place the filter back into the filter apparatus and restart the vacuum. Wet the filter with a small volume of distilled water to seat it. Filter through enough sample volume to yield between 2.5 and 200 mg of dried residue. After the sample is filtered through, wash the filter with three successive 10 mL volume of distilled water, allowing complete drainage between washings, and continue the suction for about three minutes after the filtration of the distilled water is complete.

For the influent wastewater, you will probably need to filter a 10 mL of sample. For the effluent, increase this to 40 mL. Record this volume as V_f. If the suspended material clogs the filter and prolongs filtration, it may be necessary to increase the diameter of the filter or decrease the sample volume.

Once the filtering is complete, remove the filter from the filtration apparatus, place it in its crucible, and dry to a constant mass at 103°C. Remove the filter and crucible from the oven, and cool it in a desiccator. After cooling, weigh the filter and crucible. As with previous steps, check that you have a constant mass by returning the filter and crucible to the dessicator, and weighing it again after 10 minutes. Repeat this step as needed. Record the mass on the data sheet (m_{ff}). This will be used to determine the total suspended solids concentration.

Place the crucible and filter combination in the muffle furnace at 550°C for 20 minutes. Remove the filter and crucible from the muffle furnace and cool in a desiccator to a constant mass. Record the mass on the data sheet (m_{fx}). This data will be used to determine the volatile suspended solids concentration.

Of note, the total dissolved solids *(TDS)*, volatile dissolved solids *(VDS)* and fixed dissolved solids *(FDS)* concentrations can be determined once the total solids *(TS)*, total suspended solids *(TSS)*, volatile suspended solids *(VSS)* and fixed suspended solids *(FSS)* concentrations are calculated from the experimental data.

Figure 2: Generalized schematic of steps to determine *TSS*, *VSS*, and *FSS*.

Analysis

Total Solids

Initially, the water from a well-mixed sample was evaporated in an oven set at approximately 103° C. From this data, the total solids concentration can be calculated as:

$$TS = \frac{m_{cf} - m_{ci}}{V}$$

where:

TS = total solids (mg/L)

m_{ci} = initial crucible mass (mg)

m_{cf} = crucible mass after drying (mg)

V = sample volume (L)

Afterwards, the sample was placed in a muffle furnace. From this data determine the volatile fraction from:

$$VS = \frac{m_{cf} - m_{cx}}{V}$$

where:

VS = volatile solids (mg/L)

m_{cx} = crucible mass after ignition (mg)

The fixed fraction can then be determined from the difference between the two calculated fractions

FS = TS – VS

Suspended Solids

The data from the filtered samples are now needed to calculate the fraction of suspended solids.

$$TSS = \frac{m_{ff} - m_{fi}}{V_f}$$

where:

TSS = total suspended solids (mg/L)

V_f = the volume of sample filtered (L)

m_{fi} = initial filter mass (mg)

m_{ff} = filter mass after drying (mg)

The sample was then placed in a muffle furnace to burn of the organic fraction. The remaining sample can be used to determine the volatile suspended fraction:

$$VSS = \frac{m_{ff} - m_{fx}}{V_f}$$

where:

m_{fx} = final filter mass (including crucible)(mg)

The FSS can be calculated as the difference between the TSS and the VSS

FSS = TSS - VSS

From this data, the remaining fractions can be determined:

DS = TS – SS

VDS = VS – VSS

FDS = FS – FSS

Elements of Report

Within your report, you should include the following items specific to your experiment

- Name and general description of wastewater facility, including typical flow rates and a generalized schematic of the unit operations within the plant. If the plant treats industrial waste, what industry? If the plant only treats municipal waste, what is the population?

- Specific model of equipment used and accuracy.

- Prepare flow charts similar to the ones shown in the example.

- If a groundwater very low in total solids infiltrated into the sewer system, how would your results be affected (i.e., how would the measured values for TS, TSS, VSS, etc. change)?

- If a brackish water high in TDS, but low in TSS, infiltrated into the sewer system, how would your results change?

References

Standard Methods for the Examination of Water and Wastewater, 20th Ed. Published jointly by APHA, AWWA and WPCF, 1998.

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Introduction to Environmental Engineering, 3rd Edition, M.L. Davis, D.A. Cornwell, WCB McGraw-Hill, 1998.

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Environmental Engineering and Science: An Introduction, R.S. Gupta, Government Institutes, 1997.

Solids Lab Data Sheet

Name _____

Date _____

Treatment Facility _____

Laboratory Section _____

Total Solids				
Crucible #	Initial wt. m_{ci} (g)	Vol V (mL)	103° C wt m_{cf} (g)	550° C wt m_{cx} (g)
Suspended Solids				
Crucible #	Initial wt. m_{fi} (g)	Vol V_f (mL)	103° C wt m_{ff} (g)	550° C wt m_{fx} (g)

NOTES: