Manual of Procedures for the Operation of Bench-Scale Anaerobic Digesters

R. R. Spencer

December 1978

**Prepared for the U.S. Department of Energy
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NOTE

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INTRODUCTION

The successful operation of any laboratory-scale biological system is often a difficult and frustrating experience. This is especially true when dealing with the anaerobic digestion process. Because of the stringent environmental requirements associated with anaerobic digesters, efficient operation of bench-scale units requires rigid monitoring and control. The purpose of this manual is to present the methods and procedures which are followed in bench-scale anaerobic digestion studies at Pacific Northwest Laboratory (PNL). Among the topics discussed are operating parameters, a description of the experimental system, typical digestion substrates, operational procedures, analytical techniques, and safety considerations. The document serves as a technical guide to PNL personnel assigned to a U.S. Department of Energy sponsored program evaluating the effect of powdered activated carbon on the anaerobic digestion of sewage sludge.

It should be noted that the methods described in this manual do not necessarily represent the best or only means of conducting the research. They are merely procedures that have been found to be successful at PNL. It is hoped that this information may be useful to other researchers who are contemplating or pursuing bench-scale studies of their own.

ENVIRONMENTAL REQUIREMENTS

In anaerobic digestion, organic materials are stabilized in a series of two stages mediated by two different groups of microorganisms -- the acid formers and the methane formers. These two classes of bacteria are very different from each other in their physiology and environmental requirements. However, in a typical anaerobic digestion system both sets of microorganisms are placed within the same physical and chemical environment. Therefore, the design and operation of an anaerobic treatment system is based primarily on providing optimum environmental conditions for the slowest growing and most sensitive group of bacteria -- the methane formers.

pH

One of the most important environmental conditions is the maintenance of proper pH in the digesters. Rigid control of pH is required because methane bacteria are extremely sensitive to slight changes in pH. Every effort should be made to maintain the pH in the range of 6.6-7.4, with an optimum value of 7.0. At pH below 6.2, the acidic conditions produced can become quite toxic to the methane formers. Thus, major drops in pH must be avoided if effective treatment is to be provided.

Control of pH is normally accomplished by the bicarbonate buffer system. For most municipal waste sludges, bicarbonate ion is the principal form of alkalinity when volatile acid concentration is low. If volatile acids begin to increase, they are neutralized by the bicarbonate ion, and bicarbonate alkalinity decreases. In normal operation, the bicarbonate buffer is

reformed when the methane bacteria ferment the volatile acid salts. The process of buffer destruction and formation during the digestion of glucose is illustrated in the following equations:

The first equation shows the breakdown of glucose by acid forming bacteria to produce acetic acid. In the second reaction the acid is neutralized by bicarbonate ion, and forms a volatile acid salt. If sufficient buffer is not available, acid accumulation will cause a drop in pH, and the formation of methane via the third reaction is inhibited. However, if the third reaction can proceed, the bicarbonate ion consumed in the second equation is reproduced, and the equilibrium between buffer destruction and formation is maintained.

Chemical Addition

In operating a laboratory digester it is sometimes necessary to add an external source of alkalinity to the system to prevent failure of the process due to low pH. Generally, this is required only during startup or when operating at solids residence times of less than 5 days. A minimum bicarbonate alkalinity of 1000 mg/l should always be maintained in a unit to ensure effective pH control. According to McCarty* bicarbonate alkalinity can be estimated from the total alkalinity and volatile acid concentration as follows:

$$\text{BA} = \text{TA} - [(0.71) (\text{VA})]$$

*P. L. McCarty. "Anaerobic Waste Treatment Fundamentals. Part II. Environmental Requirements and Control," Public Works, Vol. 95, No. 10, p. 125, October 1964.

in which

BA = bicarbonate alkalinity, mg/l as CaCO_3

TA = total alkalinity, mg/l as CaCO_3

VA = volatile acid concentration, mg/l as acetic acid.

Increasing the bicarbonate alkalinity is normally accomplished by the addition of sodium bicarbonate (NaHCO_3). The following equation can be used to calculate the amount of NaHCO_3 required to increase the total alkalinity a specific amount.

$$\text{gm NaHCO}_3 = (1.68 \times 10^{-6}) (\Delta\text{TA}) (V)$$

in which

ΔTA = desired increase in total alkalinity, mg/l as CaCO_3

V = volume of substrate in digester, ml

The laboratory digesters are normally operated with a substrate volume of 3500 ml. Based on this volume, the following table lists the amount of NaHCO_3 required to achieve various increases in the total alkalinity.

<u>Alkalinity (mg/l as CaCO_3)</u>	<u>NaHCO_3 (gm)</u>
100	0.6
200	1.2
300	1.8
400	2.4
500	2.9
600	3.5
700	4.1
800	4.7
900	5.3
1000	5.9
1100	6.5
1200	7.1
1300	7.6
1400	8.2

<u>Alkalinity (mg/l as CaCO₃)</u>	<u>NaHCO₃ (gm)</u>
1500	8.8
1600	9.4
1700	10.0
1800	10.6
1900	11.2
2000	11.8
2250	13.2
2500	14.7
2750	16.2
3000	17.6
3250	19.1
3500	20.6
3750	22.0
4000	23.5
4250	25.0
4500	26.5
4750	27.9
5000	29.4

Excessive addition of NaHCO₃ can cause inhibition of the digestion process due to the toxic effect of the sodium cation. In an attempt to avoid this problem, NaHCO₃ is generally not added in sufficient quantity to increase the total alkalinity above 6000 mg/l. If at this alkalinity the digester pH is still low, lime (CaOH) should be added. From experience the following lime additions are recommended for a substrate volume of 3500 ml:

<u>pH</u>	<u>Lime (gm)</u>
6.8	1.0
6.7	2.0
6.6	2.5
6.5	3.0
6.4	3.5
6.3	4.0
6.2	4.5
6.1	5.0
6.0	5.5

Note: Lime additions may result in the formation of insoluble calcium carbonate according to the following reaction:

The consumption of carbon dioxide associated with this reaction will likely produce a vacuum in the digestion system. In order to avoid the possible suction of salt solution into the digesters from the gas collection columns, the systems should be pressurized with nitrogen gas following the addition of lime.

Whenever making chemical additions it should be remembered that alkali and alkaline-earth cations such as those of sodium, potassium, calcium, and magnesium can cause inhibition of the anaerobic process. Care must be taken to avoid exceeding the toxic concentrations listed below.*

Cation	Concentration (mg/l)	
	Moderately Inhibitory	Strongly Inhibitory
Sodium (Na^+)	3500 - 5500	8,000
Potassium (K^+)	2500 - 4500	12,000
Calcium (Ca^{++})	2500 - 4500	8,000
Magnesium (Mg^{++})	1000 - 1500	3,000

Temperature

It is generally accepted that two temperature ranges exist for anaerobic treatment -- the mesophilic range ($29^\circ - 38^\circ\text{C}$) and the thermophilic range ($49^\circ - 57^\circ\text{C}$). Although treatment proceeds more rapidly at thermophilic temperatures, the additional heat requirement probably offsets this advantage. Therefore, digestion of wastewater sludge is practically always performed in the mesophilic range, a temperature of 35°C commonly considered optimal. In this study, an operating temperature of 35°C has been selected

*P. L. McCarty. "Anaerobic Waste Treatment Fundamentals. Part III. Toxic Materials and Their Control," Public Works, Vol. 95, No. 11, p. 92, November 1964.

for all units. Every effort should be made to maintain the temperature between 34° and 36°C. A temperature change of 2 or 3 degrees can disrupt the dynamic balance between the acid and methane formers. Because the acid formers respond more rapidly than the methane bacteria, acid production will likely exceed acid consumption following a variation in system temperature. The resulting acid buildup may result in digester upset.

Mixing

All of the digestion units are equipped with variable speed gas recirculation mixing devices designed to keep the digester contents completely mixed. Not only does mixing keep the microorganisms in continuous contact with their food supply, but also it helps provide a constant environment throughout the digester. Pockets of highly concentrated toxic materials do not develop in the system. Instead, the concentrations of inhibitory materials are maintained at minimum levels.

Anaerobic Conditions

Even small quantities of oxygen can be harmful to the methane formers and other anaerobic bacteria. Therefore, the digesters are completely sealed from the atmosphere.

Nutrients

The bacteria responsible for anaerobic digestion require nitrogen, phosphorus, and other nutrients for efficient growth. Municipal waste sludge generally contains these required materials, and thus usually provides a favorable environment for growth. However, if synthetic substrates (e.g., glucose, acetate) are to be digested, a specially prepared nutrient-rich dilution water must be added with the feed. Preparation of the dilution water is described in the section of this manual entitled "Digestion Substrates."

ANAEROBIC DIGESTERS

Digester Vessels

The digestion units consist of pyrex reaction flasks. Each vessel is cylindrically shaped with a rounded bottom, and has a volume of four liters. The top of each flask is a separate piece connected to the main body by a ground glass interface. The sections are secured together with a circular clamp. The top of each vessel contains four ground glass fitted openings to which various appurtenances are attached. A schematic diagram of a digester, including supporting equipment, is presented in Figure 1. Detailed drawings of a digester, specifying tubing and stopper sizes, are provided in Appendix A.

Experience has shown that the greased, ground glass joints do not provide an air tight seal even when the digesters are subjected to only low pressure differentials. Thus, a silicone rubber sealent (RTV) is applied to the exposed surfaces of all joints on the digestion vessels. Prior to applying the sealent, surfaces should be thoroughly cleaned with a solvent, such as acetone or MIBK. Approximately 24 hours is required for the RTV to completely dry. A more effective seal is obtained if, during this period, the digesters are subject to a slight vacuum.

It is very important the correct volume of substrate (normally 3500 ml) is maintained in each digester. Therefore, a thin strip of tape is applied to the outside of each vessel to mark the proper liquid level. Substrate levels should be checked at least twice each week and adjusted as required. This procedure shall be documented in the daily log section of the laboratory record book.

FIGURE 1. BENCH SCALE DIGESTION UNIT

Temperature Control

Each digestion flask is equipped with an electrically operated heating mantle. A temperature controller connected to the heating mantle automatically switches power "on" or "off" as required to maintain a constant temperature in the digester. Temperature changes are detected by a thermistor probe inserted through the top of each digestion vessel. Electrical power to the heating mantle is supplied via a variable transformer. By moderating the input wattage the rate of heating is reduced, allowing more precise temperature control. Operating and maintenance instructions for the temperature controllers, heating mantles, and variable transformers are included in Appendix B.

Each digestion unit includes a thermometer for monitoring system temperature. All digesters must be maintained at $35 \pm 1^\circ\text{C}$. Temperatures should be checked at least twice each day, at the beginning and end of each work shift. In order to ensure representative values, temperatures shall be measured only when the gas recirculation pumps have been operating for at least 10 minutes. The data, including date, time, and temperature, shall be recorded on the appropriate log sheet. If the setting on a temperature controller is readjusted, this should be indicated by including an arrow after the temperature entry. An arrow $\uparrow$ indicates the setting was increased, while an arrow $\downarrow$ signifies it was decreased.

Gas Recirculation Mixing

Positive displacement tubing pumps are used to recirculate overhead gases through the digesters for mixing. In each digestion unit, gas is withdrawn from the space above the substrate, transferred through a pump, and then injected via a glass tube into the

bottom of the vessel. A plastic "Y" connector is attached to the glass tube to aid in distributing the gas flow. Rising gas bubbles produce the mixing action in the digester.

Each variable speed drive unit operates two pump heads, each head providing gas flow for one digester. Electrical power to each pump drive is controlled by an automatic timer. As many as four pump drives may operated by a single timer. The timers can be set to turn power either "on" or "off" at 15 minute intervals during a 24 hour period. Generally, timers are set to activate the pump drives for one 15 minute period each hour. In this manner, sufficient mixing is provided to prevent stratification and the formation of thermal gradients, while at the same time, the digester contents are not subject to over-mixing. Operating and maintenance instructions for the pump drives and pump heads are included in Appendix B.

Due to the semi-continuous operation of the gas recirculation pumps, silicone tubing is normally used in the pump heads. This material has a life expectancy about three times that of tygon. Pump head tubing should be replaced at least once each week when using silicone tubing, and every other day when using tygon. Routine replacement is imperative since ruptured tubing can cause air to be introduced into the digesters. About 11 inches of tubing is required for each pump head. Tubing specifications and instructions for replacement are given in Appendix B. The replacement of tubing should be noted in the "daily log" section of the laboratory record book.

Feeding/Sampling System

Sampling and feeding of the digesters are accomplished through a 12 mm OD glass tube inserted through the top of each vessel. The tubes extend to within about four inches of the bottom of the flasks. The upper end of each glass tube is attached to a "feeder/sampler" bottle by about six inches of tygon tubing. The feeder/sampler bottles are made of plastic, approximately 800 ml in volume, and are fitted with a bottom adapter to the tubing, permitting isolation of the feeder/sampler bottles from the digestion vessels.

The actual operations performed in sampling and feeding a digester are quite simple. In order to draw a sample, the gas collection system is adjusted to provide a pressure head of about two feet in the digester. The hose clamps isolating the vented feeder/sampler bottle from the digestion vessel are then opened, displacing sludge into the bottle due to the pressure differential. When the required volume of sludge has been transferred, the hose clamps are shut, and sample collection is complete. Feeding of a digester is accomplished with the gas collection system vented to the atmosphere. The hose clamps to the feeder/sampler bottle are opened, and substrate flows by gravity into the digestion vessel.

As mentioned above, the sampling of a digester required pressure modification in the system. Pressure is indicated by the relative height of the liquid levels in the gas collection column and the confining solution reservoir. If sufficient pressure for sampling has not been provided by digester gas production, the necessary pressure can be created by either of two methods: 1) positioning the reservoir so that its liquid level exceeds the level in the column, or 2) pressurizing with nitrogen gas via the vent line.

The first method is preferable, especially during data collection periods, since it does not change the composition of the digester gas. If, however, the second method is selected, care should be taken to isolate the digester from the gas collection system during pressurization in order to avoid placing excessive stress on the digester seals.

The feeding/sampling operation shall be documented in the "sludge transfer record" section of the laboratory record book.

Leak Testing

Accurate measurement of gas production is absolutely essential in this project. Even small inconsistencies (20-30 ml per hr) can contribute significant error to the total gas production. For this reason it is extremely important that the digestion systems be continuously monitored for gas leakage. Care should be taken to routinely replace the pump head tubing, and to ensure that the associated plastic connectors are securely fastened. Potential leak sites, such as those around rubber stoppers and tubing penetrations, should be routinely inspected with soap solution. Also, each digester should be pressure tested prior to starting a test run, immediately preceding a data collection period, or whenever gas leakage is suspected. Testing is accomplished by injecting a sufficient quantity of nitrogen gas to lower the liquid level in the gas collection column to a point below the 50.0 cm mark. (As mentioned in the previous section, care should be taken to isolate the digester from the gas collection column during pressurization.) With the entire digestion system pressurized and the gas recirculation pump operating, an initial reading on the gas collection column should be obtained. After a 20 minute period the column

should be reread. Any perceptible increase in liquid level indicates gas leakage. Soap solution should be applied to identify the exact location of a suspected leak, and repairs made as soon as possible. The results of leak testing should be noted in the "daily log" section of the laboratory record book.

GAS COLLECTION SYSTEM

Description

The gas production in the anaerobic digesters is collected in plexiglass columns by the displacement of a saturated salt solution. Tygon tubing is used to transfer the overhead gases from the digestion vessels to the gas collection columns. Each transfer line is equipped with a vent line to permit sampling of the digester gas, and to allow for periodic system pressure release. Another section of tygon tubing connects the bottom of each gas collection column to a confining solution reservoir. A diagram illustrating the gas collection system is provided in Figure 2.

Calibration of Gas Collection Columns

Prior to starting the project, all of the gas collection columns were calibrated volumetrically. Each column was found to have a uniform diameter. Thus, a factor was obtained relating liquid level in each column to collected gas volume. Transparent tape marked off in 0.1 cm increments was vertically applied to the columns to facilitate the reading of liquid levels. Actual calibration was accomplished by initially filling each column with water, and then draining incremental volumes into a graduated cylinder or volumetric flask. The change in liquid level was then recorded versus the volume of water withdrawn. The calibration factors determined by this method are as follows:

FIGURE 2. BENCH SCALE DIGESTION SYSTEM

<u>Column No.</u>	<u>Factor (ml/cm)</u>
1	104.1
2	103.4
3	103.7
4	103.2
5	103.6
6	103.6
7	82.6
8	82.1
9	81.1
10	80.5
11	81.2
12	102.9
13	103.2
14	102.8

Gas Measurement

Measurement of gas production in a digester is based on the volume of gas accumulated in its gas collection column. Initially, the column is "zeroed" by opening the vent valve and adjusting the height of the confining solution reservoir so that the liquid level in the column is at the zero mark. The liquid level in the reservoir should be maintained at the same level as in the column in order to provide atmospheric pressure in the digestion system. After zeroing the column, the vent valve is closed. The production of gas in the digester then causes displacement of liquid from the gas collection column to the confining solution reservoir. At the end of the measurement period the volume of gas collected is determined by noting the change in liquid level in the column. Like the initial zeroing, the final reading is obtained with the liquid levels in the gas collection column and confining solution reservoir equalized.

Each gas volume measurement must be converted to an equivalent volume at standard temperature (0°C) and pressure (760 mm Hg). Thus, the gas volume at STP is calculated as follows:

$$\text{gas volume (ml) @ STP} = \frac{H \times F \times P \times 273}{760 \times T}$$

where

H = liquid level reading on column (cm)

F = conversion factor relating gas volume to liquid level
(ml/cm)

P = atmospheric pressure (mm Hg)

T = temperature of gas in column (°K), where °K = °C + 273

This equation can be simplified by multiplying the conversion factor, F, by 273 divided by 760. This new quantity shall be designated, A, and can be computed for each of the gas collection columns as follows:

<u>Column No.</u>	<u>A</u>
1	37.4
2	37.2
3	37.3
4	37.1
5	37.2
6	37.2
7	29.7
8	29.5
9	29.2
10	28.9
11	29.2
12	37.0
13	37.1
14	37.0

Using the conversion factor, A, gas volume at standard temperature and pressure is calculated by the following modified equation:

$$\text{gas volume (ml) @ STP} = \frac{H \times A \times P}{T}$$

Atmospheric pressure (P) and temperature (T) readings must be recorded whenever gas volume is measured. Atmospheric pressure can be determined by using the mercurial barometer located in PSL 506. Instructions for using the barometer are located in Appendix B. The temperature of the gas in the collection columns is assumed to

be the same as the ambient air temperature in the laboratory. Ambient temperature can be obtained from the mercury thermometer attached to the barometer apparatus.

Preparation of Salt Solution

A saturated salt solution is used as the displacing solution in the gas collection columns. This liquid is specially prepared to minimize gas solubility. The solution is prepared as follows:

1. Add about 3000 ml of water to a 4000 ml beaker.
2. Place the beaker on a combination magnetic stirrer/hot plate and continuously mix.
3. Add 0.175 gm Evans Blue dye and completely dissolve.
4. Slowly add 1050 gm of sodium chloride (technical grade), making sure not to interfere with the operation of the magnetic stirring bar.
5. Heat the solution to about 50°C and continue mixing until all of the salt is dissolved. As the salt dissolves, add water to bring the final volume to 3500 ml.
6. Turn off hot plate.
7. Add concentrated sulfuric acid (H_2SO_4), dropwise, to adjust the pH to about 3.
8. Transfer the solution to a one gallon poly bottle for storage.

Note:

The Evans Blue dye may precipitate from solution during storage. Mix the salt solution by shaking to redissolve the dye prior to adding to the gas collection system.

DIGESTION SUBSTRATES

SEWAGE SLUDGE

Raw sludge is generally used as feed for the laboratory digesters. However, digested sludge is required occasionally for seeding the units (i.e., supplying the anaerobes necessary for the digestion process). Sludge is procured from the Richland, Washington sewage treatment plant. Raw sludge is obtained from the transfer line between the primary clarifier sludge hoppers and the digestion tanks. Sludge is transferred every hour on the hour for a duration of about five minutes. It is during this pumping period that the raw sludge sample must be collected. Digested sludge is obtained at the discharge pipe to the sludge drying beds. It is usually pumped only on Monday afternoons between 1:00 and 3:00pm. If digested sludge is required at another time, special arrangements can be made to withdraw sludge directly from the primary digester. However, this should be done only if absolutely necessary as this procedure can be quite messy and requires the assistance of a treatment plant operator. Sludge pumping times should be verified by calling the treatment plant at (509) 943-9161, Ext. 225.

All sludge is to be collected in 5-15 gallon poly bottles. Because the sludge volume expands during storage, bottles should not be filled more than 3/4 full. The bottles shall be immediately capped after filling and then transported to the laboratory. To retard biological degradation, the sludge should be kept in the cold room (10°C) located in PSL 516. Sludge should not be stored longer than five days prior to its use.

As required for digester feed, an appropriate amount of sludge is to be added to the one gallon Waring blender. The blender should then be operated at low speed for about five minutes. The exact length of time of blending should be based on increasing the temperature of the sludge to approximately 30°C. Thus, blending not only homogenizes the sludge, but also increases its temperature so that thermal shock to the digestion units is minimized.

GLUCOSE

In some of the test runs the digesters utilize a glucose substrate (D-glucose anhydrous, $C_6H_{12}O_6$). A glucose concentration of 0.5 percent is usually not exceeded in the digestion units. Operation at higher concentrations has proved unsuccessful, presumably due to the rapid conversion of glucose to organic acids, resulting in a sudden high volatile acid concentration and low pH.

The glucose is dissolved in a specially prepared nutrient-rich dilution water prior to being fed to the system. The dilution water should be heated to 35-40°C to minimize thermal shock to the digestion units. Preparation of the dilution water is described at the end of this chapter.

ACETATE

Occasionally, sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$) is used as a substrate in the digesters. Difficulty has been experienced obtaining good digestion with acetate feed. Some success was achieved with a 1.13 percent sodium acetate substrate.

Like the glucose, sodium acetate is dissolved in a specially prepared nutrient-rich dilution water prior to

being fed to the digesters. Again, the dilution water should be heated to 35-40°C to minimize thermal shock to the digestion units. Preparation of the dilution water is described below.

Preparation of Nutrient-Rich Dilution Water

This dilution water provides sufficient nutrients for the digestion of a 0.6 percent glucose ($C_6H_{12}O_6$) solution or a 1.4 percent sodium acetate ($NaC_2H_3O_2 \cdot 3H_2O$) solution. The procedure must be carefully followed in the sequence given to avoid precipitation of salts. The following instructions are for the preparation of 24 liters of dilution water.

1. Add 33.3 ml of trace salt solution to a 2 liter flask.
2. Add about 1000 ml of water and continuously mix using a magnetic stirrer.
3. Add each of the following with mixing. Do not add a compound until the previous compound is in solution.
 - a. 13.6 gm KH_2PO_4
 - b. 8.3 gm $NaH_2PO_4 \cdot H_2O$
 - c. 5.3 gm $(NH_4)_2SO_4$
 - d. 49.2 gm NH_4Cl
 - e. 4.4 gm $CaCl_2$
 - f. 8.1 gm $MgCl_2 \cdot 6H_2O$
4. Dissolve 3.60 gm of yeast extract in 100 ml of water, with heating and stirring. Do not allow to boil. When cool, add to the flask.
5. Add the solution to a 6.5 gallon poly bottle containing 23 liters of water. (Note: The water should have been allowed to stand for at least 12 hours to allow for dissipation of residual chlorine.) Mix the contents thoroughly and transfer to a dispensing container.

6. Preparation of trace salt solution.

The trace salts are added to distilled water in amounts given below and made to two liters with distilled water. Compounds should be added in the order shown, and each compound should not be added until the previous one is in solution.

- a. 64.8 gm $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$
- b. 9.5 gm $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$
- c. 14.2 gm $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$
- d. 4.1 gm $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$
- e. 5.7 gm $\text{CoCl}_2 \cdot 6\text{H}_2\text{O}$
- f. 2.3 gm $\text{Na}_2\text{B}_4\text{O}_7 \cdot 10\text{H}_2\text{O}$
- g. 353.0 gm Na_3 Citrate
- h. 4.2 gm $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$

7. Total nutrient concentrations in the prepared dilution water are as follows:

N = 559 mg/l	Fe = 9.3 mg/l
P = 207 mg/l	Mn = 1.8 mg/l
K = 163 mg/l	Zn = 2.2 mg/l
Na = 115 mg/l	Cu = 1.1 mg/l
S = 53 mg/l	Co = 0.98 mg/l
Ca = 66 mg/l	B = 0.18 mg/l
Mg = 40 mg/l	Mo = 1.6 mg/l

OPERATIONAL PROCEDURES

The following operational procedures describe the sequence in which the activities of digester sampling, feeding, chemical addition, gas measurement, and sludge analysis are to be performed. Operational procedure No. 1 is applicable during the data collection period. Operational procedure No. 2 is applicable only during the preceding acclimation period, and contains no instructions for gas production measurements or extensive sludge testing. It is emphasized that both sets of procedures provide only the order in which the various operating steps are conducted. For a more detailed description of individual procedural steps refer to the appropriate section in this manual.

Operational Procedure No. 1
(Applicable During Data Collection Period)

NOTE: Those steps marked with an asterisk (*) shall be omitted if the alkalinity, volatile acids, and COD analyses are not required.

1. Check to see that the gas recirculation pumps are operating. The pumps must be operated a minimum of 15 minutes prior to proceeding to step No. 4. Mixing should continue during steps 4, 5, and 6.
2. Transfer the required amount of raw sludge from the storage bottle in the cold room to the blender.
3. Buffer the pH meter.
4. Record the laboratory ambient air temperature and atmospheric pressure. Measure the gas volumes in the gas collection columns.
5. Adjust the pressure in each gas collection system to about two feet of water. (If nitrogen gas is used, ensure that the gas valve on the top of each digester is closed during pressurization.)
6. Discharge the appropriate amount of digested sludge to the feeder/sampler bottles. Following this operation, check that both of the clamps that isolate each digester from its feeder/sampler bottle are shut.
7. Zero the gas collection columns and resume gas collection.
8. Secure the cap on each feeder/sampler bottle and mix by shaking. Then immediately transfer approximately 25 ml of sludge from each bottle to a preweighed crucible. Resecure the caps on the bottles. Promptly weigh the crucibles and place them in the oven.

9. Transfer approximately 40 ml of sludge from each feeder/sampler bottle to a 50 ml centrifuge tube. Then immediately measure the pH of each sludge sample.
- *10. Centrifuge about 40 ml of each sludge sample at about 10,000 rpm for 10 minutes. While centrifuging, preparations can be made for the alkalinity and COD tests.
- *11. Distribute the centrate samples for the alkalinity, COD, and volatile acid analyses.
- *12. Perform the alkalinity test.
13. Dispose of the sludge remaining in the feeder/sampler bottles.
14. Blend the raw sludge feed until its temperature increases to about 30°C. While the blender is operating, calculate and weigh out any required chemical additions.
15. Transfer the blended raw sludge to a plastic bottle (feed bottle). Mix the bottle by shaking, then transfer a 20-30 ml volume of sample into a preweighed crucible, and cover.
16. Fill half of the feeder/sampler bottles with the required volume of feed sludge. Care should be taken to keep the feed sludge well-mixed so that each digester receives substrate of the same consistency.
17. Mix the remaining contents of the feed bottle by shaking, then transfer a 20-30 ml volume of sample into a preweighed crucible, and cover.
18. Fill the remaining feeder/sampler bottles with feed sludge.
19. Mix the remaining contents of the feed bottle by shaking, then transfer a 20-30 ml volume of sample into a preweighed crucible, and cover.

20. Add any required chemicals, including carbon or flyash, to the feeder/sampler bottles. Rinse each carbon/flyash storage vial with 5 ml of distilled water to insure complete transfer of the contents. Secure the caps on the feeder/sampler bottles, then shake thoroughly to completely disperse the additives. (Caution: When mixing sodium bicarbonate, occasionally vent the bottle to prevent a pressure buildup.) Reconnect the feeder/sampler bottles to the digesters, and remove the caps.
21. Check to see that the gas recirculation pumps are operating. Pump operation should continue a minimum of 15 minutes following the completion of step 23.
22. Measure the gas volumes in the gas collection columns, then vent the systems. The amounts of gas collected should be added to the gas volumes measured in step 4. Each sum represents total gas production for the period ending at the time specified in step 24.
23. Discharge the raw sludge feed into the digesters, then shut the clamps isolating each digester from its feeder/sampler bottle.
24. Zero the gas collection columns and resume gas collection.
25. Weigh the three crucibles containing feed sludge and place them in the oven.
26. Remove the feeder/sampler bottles and rinse with tap water, then reconnect them to the system.
- *27. Complete the volatile acid and COD analyses.

Operational Procedure No. 2
(Applicable During Acclimation Period)

NOTE: Those steps marked with an asterisk (*) shall be omitted if the alkalinity analysis is not required.

1. Check to see that the gas recirculation pumps are operating. The pumps must be operated a minimum of 15 minutes prior to proceeding to step No. 4. Mixing should continue during steps 4 and 5.
2. Transfer the required amount of raw sludge from the storage bottle in the cold room to the blender.
3. Buffer the pH meter.
4. Adjust the pressure in each gas collection system to about two feet of water. (If nitrogen gas is used, ensure that the gas valve on the top of each digester is closed during pressurization.)
5. Discharge the appropriate amount of digested sludge to the feeder/sampler bottles. Following this operation, check that both of the clamps that isolate each digester from its feeder/sampler bottle are shut.
6. Transfer approximately 75 ml of sludge from each bottle to a 100 ml beaker.
7. Measure the pH of each sludge sample.
- *8. Centrifuge about 40 ml of each sludge sample at about 10,000 rpm for 10 minutes. While centrifuging, preparations can be made for the alkalinity test.
- *9. Perform the alkalinity test.
10. Blend the raw sludge until its temperature increases to about 30°C. While the blender is operating, calculate and weigh out any chemical additions, and dispose of the sludge remaining in the feeder/sampler bottles.

11. Transfer the blended raw sludge to a plastic bottle (feed bottle).
12. Fill the feeder/sampler bottles with the required volume of feed sludge. Care should be taken to keep the feed bottle well mixed (by shaking) so that each digester receives substrate of the same consistency.
13. Add any required chemicals, including carbon, to the feeder/sampler bottles. Rinse each carbon/flyash storage vial with 5 ml of distilled water to insure complete transfer of the contents. Secure the caps on the feeder/sampler bottles, then shake thoroughly to completely disperse the additives. (Caution: When mixing sodium bicarbonate, occasionally vent the bottle to prevent a pressure buildup.) Reconnect the feeder/sampler bottles to the digesters, and remove the caps.
14. Check to see that the gas recirculation pumps are operating. Pump operation should continue a minimum of 15 minutes following the completion of step 16.
15. Vent the gas collection systems.
16. Discharge the raw sludge feed into the digesters, then shut the clamps isolating each digester from its feeder/sampler bottle.
17. Shut the vent valves on the gas collection system.
18. Remove the feeder/sampler bottles and rinse them with tap water, then reconnect them to the system.

LABORATORY RECORD BOOK

All test data shall be recorded directly in the official laboratory record book. Data shall not be written on scratch paper and then later entered into the book. In this manner errors in transcribing are minimized. Additionally, all entries shall be made in ink. No erasures are permitted. If an error is made, simply cross out the incorrect value with a single line, and insert the proper entry next to the one that is crossed out. Be sure to write legibly. The laboratory record book is worthless if it is not readable. The book shall be reviewed on a daily basis by the Project Engineer, and at least once each week by the Project Manager.

A very important section in the laboratory record book is the daily log. It shall include a brief description of the project work accomplished during the day, and comments on the operational status of the test systems. Tasks that should always be included in the daily log are the checking and adjustment of substrate levels, leak testing, equipment breakdown and repair, and replacement of pump tubing. The person who conducts a work item is responsible for recording the performance of that task in the log. The log should be checked for completeness at the end of each work day by the Project Engineer.

PERSONAL HYGIENE AND SAFETY

Operation of the bench scale anaerobic digesters generally requires frequent handling of municipal sewage sludge. It is a well known fact that the microorganisms present in sludge can cause infection and disease. Contact with these "bugs" can be made during many of the daily work routines. In order to protect oneself from this health hazard, various safety procedures are required.

Rubber gloves, safety glasses, and a laboratory coat should be worn whenever direct contact with sludge is a possibility. Examples of instances when these protective devices are required, include the sampling and feeding of the digesters, and the procurement of sludge at the sewage treatment plant. Safety glasses are required to be worn in the laboratory at all times, regardless of the type of work being performed.

After working with sludge the hands should be washed with soap and hot water before eating or otherwise putting anything from hand to mouth. A stiff bristle brush can be used if necessary. It is desirable to keep the fingernails cut short.

Open sores, cuts, or other breaks in the skin are particularly dangerous. When suffering such an injury, the wound should be cleaned and disinfected immediately. During working hours, treatment can be obtained at the first aid station located in PSL 1120. Covering the wound with a bandage and changing the bandage frequently are necessities.

All persons assigned to the anaerobic digestion project are required to be immunized against typhoid, tetanus, and polio. These immunizations can be obtained at the Benton County Health Department located at 1005 Goethals Drive in Richland.

Several safety considerations regarding work in the anaerobic digester laboratory (PSL 506) should be noted. Methane gas may be present in the laboratory atmosphere, especially following venting of the digesters. For this reason, smoking or any activity which produces a flame (e.g., Bunsen burner) is prohibited. Also, an eyewash fountain is located at the sink on the west wall of the laboratory. If chemicals are splashed into the eyes, the eyes should be immediately irrigated with water. Irrigation should continue until medical help arrives. A safety shower is located in the hallway between PSL 506 and PSL 510.

ANALYTICAL PROCEDURES

I. pH

Reference: (Standard Methods, 14th Edition, Page 460)

Apparatus

1. Electronic pH meter
2. Combination electrode

Reagents

1. pH 7 buffer solution
2. pH 4 buffer solution

Procedure

1. Check liquid level in combination electrode to insure that level is in upper (wide) portion of probe. If required add electrode filling solution (4 MKCl saturated with AgCl).
2. Remove electrode from distilled water and dry by gentle wiping with a soft cloth.
3. Standardize the instrument with the electrode immersed in the pH 7 buffer solution. The temperature compensator on the meter should be adjusted to the temperature of the buffer.
4. Remove electrode from the buffer, rinse thoroughly with distilled water, and dry.
5. Immerse electrode in the pH 4 buffer solution. Adjust temperature compensator if required. The pH reading should be between 3.9 and 4.1. If the reading is outside this range, replace the electrode.
6. Rinse electrode thoroughly with distilled water, dry, and immerse in the sample.
7. Measure the sample temperature and set the temperature compensator.
8. Note and record the pH and temperature.
9. Rinse electrodes with distilled water and dry prior to next sample reading.

NOTES:

1. Keep the combination electrode immersed in distilled water when not in use.
2. The pH meter should be standardized at least once each day, and whenever accuracy of instrument is in doubt.
3. Instrument should always be in "standby" mode when it is not in use, or whenever the electrode is not immersed in solution.
4. Plug on upper portion of electrode should be open. If closed, pressure changes can cause probe to rupture.
5. Sludge samples should not be stirred. Loss of carbon dioxide due to stirring will result in an apparent pH value which is too high.
6. Measurement of pH should be made as soon as possible after sampling.
7. Report pH values to nearest 0.05 pH unit.

II. Alkalinity

Reference: (Standard Methods, 14th Edition, Page 278)

Apparatus

1. Centrifuge and 50 ml centrifuge tubes.
2. 250 ml beakers.
3. Magnetic stirrer.
4. Volumetric pipet.
5. 50 ml Burette.
6. pH meter.

Reagents

1. Sulfuric Acid (H_2SO_4), 0.1N. Dilute 100 ml of 1.00 N sulfuric acid stock solution to 1.0 liter in a volumetric flask.
2. Sodium hydroxide (NaOH), 1.00 N. Standard stock solution.

Standardization

1. Each preparation of 0.1 N H_2SO_4 titrant should be standardized against the 1.00 NaOH standard solution. Standardization should also be performed whenever there is reason to believe that the concentration of the sulfuric acid may be different than that previously determined.
2. Add about 100 ml of distilled water to a 250 ml beaker. Then pipet exactly 3.0 ml of 1.00 N NaOH into the beaker.
3. Place the beaker on a magnetic stirrer and continuously mix.
4. Immerse the pH electrode in the solution.
5. Titrate to a pH of 7.0 with the H_2SO_4 titrant. Record the amount of titrant required.
6. Calculate the normality of the H_2SO_4 as follows:

$$\text{Normality of } \text{H}_2\text{SO}_4 = \frac{3.0}{\text{mls of titrant}}$$

7. The normality of the sulfuric acid determined by standardization should be used in all alkalinity calculations.

Procedure

1. Centrifuge the sludge sample at approximately 10,000 rpm for at least 10 minutes. The supernatant obtained from this operation should be used for both the total alkalinity and the volatile acids test.

2. Add about 100 ml of distilled water to a 250 ml beaker. Then pipet 15.0 ml of supernatant sample into the beaker.
3. Place the beaker on a magnetic stirrer and continuously mix during titration.
4. Immerse the pH electrode in the solution.
5. Titrate to a pH of 3.7 with 0.1 N H_2SO_4 . Record to amount of titrant required.
6. Calculate total alkalinity as follows:

$$\text{Total Alkalinity } \left(\frac{\text{mg}}{\text{l}} \text{ as } \text{CaCO}_3 \right) = \frac{A \times N \times 50,000}{\text{mls of sample}}$$

where A = mls of H_2SO_4 used

N = normality of H_2SO_4

7. Bicarbonate alkalinity can be estimated from the total alkalinity and volatile acids concentration as follows:

$$\text{Bicarbonate Alkalinity } \left(\frac{\text{mg}}{\text{l}} \text{ as } \text{CaCO}_3 \right) = \text{TA} - 0.71 \text{ VA}$$

where TA = total alkalinity, mg/l as CaCO_3

VA = volatile acid concentration, mg/l as acetic acid

Notes

1. Values for alkalinities should be reported to three significant figures.
2. The correct sample size can be estimated from the following table:

<u>Estimated Total Alk. ($\frac{\text{mg}}{\text{l}}$)</u>	<u>Sample Size (ml)</u>
Less than 1000	100
1000-2000	50
2000-3000	25
3000-6000	15
6000-10,000	10

III. Chemical Oxygen Demand (Soluble)

Reference: (Standard Methods, 13th Edition, Page 495)

Apparatus

1. Reflux apparatus, including 250 ml erlenmeyer flasks, condensers, and hot plates.
2. Centrifuge and 50 ml centrifuge tubes.
3. 25 ml or 50 ml Burette.
4. Volumetric pipette.
5. 25 ml and 50 ml graduated cylinders.

Reagents

1. Standard potassium dichromate solution, 0.240 N. Dissolve exactly 12.259 gm $K_2Cr_2O_7$, primary standard grade, previously dried at $103^\circ C$ for 2 hours, in distilled water and dilute to 1.0 liter in a volumetric flask.
2. Sulfuric acid reagent. Dissolve 22 gm silver sulfate (Ag_2SO_4) in a 9 pound bottle of concentrated sulfuric acid.
3. Standard ferrous ammonium sulfate titrant. Dissolve 39 gm $Fe (NH_4)_2 (SO_4)_2 \cdot 6H_2O$ in distilled water in a 1.0 liter volumetric flask. Add 20 ml concentrated H_2SO_4 , cool, and dilute to 1.0 liter.
4. Ferroin indicator solution.
5. Mercuric sulfate ($HgSO_4$).
6. Sulfamic acid.

Standardization

1. The standard ferrous ammonium sulfate titrant should be standardized against the standard potassium dichromate solution each time a COD analysis is performed.
2. Dilute exactly 10.0 ml of standard $K_2Cr_2O_7$ solution to about 100 ml in a 250 ml erlenmeyer flask.
3. Add 30 ml of the sulfuric acid reagent and cool.
4. Add 3 drops ferroin indicator.
5. Titrate with ferrous ammonium sulfate titrant to a reddish brown endpoint. Record the amount of titrant required.

- Calculate the normality of the standard ferrous ammonium sulfate as follows:

$$\text{Normality} = \frac{2.5}{\text{mls Fe (NH}_4)_2(\text{SO}_4)_2}$$

Procedure

- Centrifuge the sludge sample at approximately 10,000 rpm for exactly 10 minutes.
- Place 0.4 gm HgSO_4 in a refluxing flask. Similarly add 0.4 gm HgSO_4 to each of two other flasks, which will serve as blanks.
- Pipet a suitable amount of supernatant sample to the refluxing flask. (Note: Only soluble COD is being measured. Care should be taken to avoid transferring any particulate material with the sample.) The correct sample size can be determined from the following table:

<u>Estimated COD (mg/l)</u>	<u>Sample Size (ml)</u>
6000-12,000	1.0
4000- 6,000	2.0
3000- 4,000	3.0
2000- 3,000	4.0
1000- 2,000	5.0
500- 1,000	10.0
200- 500	20.0

- Dilute with distilled water to provide a volume of 20 ml in the flask.
- Add 20 ml of distilled water to each of the two flasks serving as blanks. These will be carried through the analysis in the same manner as the flask containing the sample.
- Mix the contents of each flask by swirling.
- Add exactly 10.0 ml of standard potassium dichromate solution to each flask.
- Add several glass beads to each container. (Note: Glass beads should have been previously ignited at 600°C for 1 hour.)
- Attach each flask to a condenser and start the cooling water.
- Slowly add 30 ml of sulfuric acid reagent through the open end of each condenser, mixing thoroughly by swirling, while adding the acid. (Note: Mix the reflux mixture thoroughly before heat is applied; if this is not done, local heating occurs in the bottom of the flask and the mixture may be blown out of the condenser.)

11. Apply heat to refluxing flasks. Once the mixture begins to boil, reflux for two hours.
12. Cool and then wash down each condenser with distilled water.
13. Dilute the mixture in each flask to about 150 ml with distilled water, then cool to room temperature. (Note: Cooling of the mixtures can be hastened by placing the flasks in a water bath.)
14. Add 3 drops ferroin indicator to each flask.
15. Titrate with standard ferrous ammonium sulfate to an endpoint characterized by a sharp color change from blue-green to reddish brown. Record the amount titrant required.
16. Calculate the soluble COD as follows:

$$\text{COD (mg/l)} = \frac{(A-B) \times N \times 8000}{\text{ml sample}}$$

where A = mls Fe (NH₄)₂ (SO₄)₂ used for blank

B = mls Fe (NH₄)₂ (SO₄)₂ used for sample

N = normality of Fe (NH₄)₂ (SO₄)₂

Notes

1. If upon addition of the ferroin indicator the sample turns a reddish brown color, then too large a sample was used. The analysis must be repeated using a smaller sample size.
2. Values for COD's should be reported to three significant figures.
3. The HgSO₄ may be conveniently measured using a reagent spoon - one level spoonful being approximately equal to 0.4 gm.

Safety Precautions

This procedure requires the handling of concentrated sulfuric acid and mercuric sulfate powder, and the boiling of strong sulfuric acid solutions. Sulfuric acid is very corrosive to skin tissue. Mercuric sulfate is extremely toxic and can be introduced into the body by ingestion, breathing, and adsorption through the skin. If improperly handled, both of these materials can present a serious safety hazard to the analyst. The following list describes specific safety precautions that should be observed when performing this procedure.

1. Rubber apron, face shield, and rubber gloves are required to be worn when handling concentrated sulfuric acid.

2. Rubber gloves, laboratory coat, and safety glasses must be worn during all other steps of the procedure.
3. In reference to Step 10, the 30 ml of concentrated sulfuric acid should be added to each reflux flask in about 5 ml portions. Care should be taken to mix by swirling between each addition. More rapid addition may cause boiling and a sudden release of acid vapors. As an added precaution, the condenser opening should be pointed away from the face during this step.
4. Remember to add boiling beads to each refluxing flask prior to heating (see Step 8). Failure to do so may lead to a sudden and violent vaporation. Release of the acid mixture through the condenser opening, and breakage of the flask may occur.
5. Ensure that the cooling water is flowing at a sufficient rate to prevent vapors from escaping during refluxing. Insufficient condenser cooling may allow the release of toxic fumes, and possible breakage of the reflux flask.
6. In reference to Step 12, make sure that each reflux flask has cooled to room temperature before rinsing the condenser with distilled water. The addition of water to an acid solution that is not fully cooled may cause the mixture to boil.

IV. Sludge Solids

Reference: (Standard Methods, 14th Edition, Page 96)

Apparatus

1. Crucibles, 50 ml capacity.
2. Analytical balance, capable of weighing to 1.0 mg.
3. Drying oven, 103°C.
4. Muffle furnace, 550°C.
5. Desiccator.

Procedure

1. Ignite a clean crucible at 550°C for 1 hour in a muffle furnace.
2. Cool in a desiccator. Weigh to nearest 1 mg and record as "Dish Weight." Store crucible in desiccator until ready for use.
3. Place 20-30 ml of well-mixed sludge sample in the crucible. Weigh to nearest 10 mg and record as "Weight of Dish and Wet Sample."
4. Compute "Weight of Wet Sample" by subtracting "Dish Weight" from "Weight of Dish and Wet Sample."
5. Evaporate the sample in an oven set at 103°C for approximately 10 hours.
6. Cool in a desiccator. Weigh to nearest 1 mg and record as "Weight of Dish and Dry Solids."
7. Compute "Weight of Dry Solids" by subtracting "Dish Weight" from "Weight of Dish and Dry Solids."
8. Ignite the crucible and dried residue in a furnace set at 550°C for 1 hour.
9. Cool in a desiccator to room temperature. Weigh to nearest 1 mg and record as "Weight of Dish and Ash."
10. Compute "Weight of Ash" by subtracting "Dish Weight" from "Weight of Dish and Ash."

11. Calculate total solids, volatile solids, and fixed solids as follows:

$$\% \text{ Total Solids} = \frac{\text{Weight of Dry Solids} \times 100}{\text{Weight of Wet Sample}}$$

$$\% \text{ Volatile Solids} = \frac{(\text{Weight of Dry Solids} - \text{Weight of Ash}) \times 100}{\text{Weight of Wet Sample}}$$

$$\% \text{ Fixed Solids} = \frac{\text{Weight of Ash} \times 100}{\text{Weight of Wet Sample}}$$

Notes

1. If a sludge sample contains powdered activated carbon the contribution of the carbon to the weight of the sample in each step of the analysis must be deducted. In this manner the computed solids composition will reflect only the true nature of the sludge. The fraction of carbon remaining at each step in the procedure can be determined by performing the solids analysis on a powdered carbon sample. By weight difference, the percentages of the carbon remaining after drying and ignition can be calculated. A series of samples should be run for each carbon type, and average values determined. Knowing the initial carbon concentration, the experimentally determined factors can be applied to subtract the effect of carbon in the analysis. This procedure can be used to adjust for any other additive (e.g., flyash, clay) that may be present in the sludge.
2. Be sure that each sludge sample is thoroughly mixed and is representative of the material being sampled.
3. Due to the nonuniform nature of raw sludge, these samples should be analyzed in triplicate.
4. During ignition be certain that samples are exposed to a temperature of 550°C for at least 1 hour.
5. Values for % solids should be reported to 3 significant figures.

V. Volatile Acids

Reference: (Standard Methods, 14th Edition, Page 527)

Apparatus

1. Centrifuge and 50 ml centrifuge tubes.
2. Buchner Funnels, with fritted discs, 30 ml capacity.
3. Separatory funnel, 2.0 liter.
4. Beakers, 50 ml.
5. Vacuum flask, 250 ml.
6. Volumetric pipette.
7. Graduated cylinder, 50 ml.

Reagents

1. Silicic acid, 50 to 200 mesh. Remove fines by slurring the acid in distilled water and decanting the supernatant after settling for 15 minutes. Repeat several times. Dry the washed acid in an oven at 103°C until absolutely dry, then store in a desiccator.
2. Chloroform-butanol reagent: Mix 1200 ml reagent-grade chloroform, 400 ml n-butanol, 160 ml 1.0 N H_2SO_4 , and 160 ml distilled water in a 2.0 liter separatory funnel. Let the aqueous and organic layers separate. Drain off the lower organic layer through a filter paper into a dry bottle.
3. Phenolphthalein indicator solution: Dissolve 80 mg phenolphthalein in 100 ml absolute methanol.
4. Sulfuric acid (H_2SO_4), concentrated.
5. Standard sodium hydroxide (NaOH), 0.02 N: Dilute 20 ml 1.0 N NaOH stock solution to 1.0 liter with absolute methanol.
6. Standard sodium hydroxide (NaOH), 0.005 N: Dilute 5.0 ml 1.0 N NaOH stock solution to 1.0 liter with absolute methanol.

Standardization

1. The normalities of basic alcohol solutions decrease with time, particularly when subjected to repeated exposure to the atmosphere. Therefore, the NaOH titrants should be standardized before being used, and at least weekly thereafter when volatile acid tests are being performed.

2. Add about 100 ml of distilled water to a 250 ml beaker. For the 0.02 N titrant, pipet exactly 4.0 ml of approximately 0.1 N H₂SO₄ into the beaker. For the 0.005 N titrant, pipet exactly 1.0 ml into the beaker. (Note: Exact normality of H₂SO₄ should have been determined as specified in the Alkalinity procedure.)
3. Place the beaker on a magnetic stirrer and continuously mix.
4. Immerse the pH electrode in the solution.
5. Titrate to a pH of 7.0 with the NaOH titrant. Record the amount of titrant required.
6. Calculate the normality of the NaOH as follows:

$$\text{Normality of NaOH} = \frac{\text{mls of H}_2\text{SO}_4 \times \text{normality of H}_2\text{SO}_4}{\text{mls of titrant}}$$

7. The normality of the NaOH titrant determined by standardization should be used in all volatile acid calculations.

Procedure

1. Centrifuge the sludge sample at approximately 10,000 rpm for at least 10 minutes. The supernatant obtained from this operation should be used for both the volatile acids and total alkalinity tests.
2. Place 10 to 15 ml of supernatant in a 50 ml beaker.
3. Add concentrated H₂SO₄, dropwise, to obtain a pH of 1.0 to 1.2.
4. Place about 12 grams of silicic acid in a fritted glass funnel and apply suction to pack the column. (Note: 12 grams can be conveniently estimated by filling the funnel to level between the designations "ASTM" and "30 ml" on the side of the funnel.)
5. With a pipet, distribute 5.0 ml of acidified sample as uniformly as possible over the surface of the column. Apply suction momentarily to draw the sample into the silicic acid. Release the vacuum as soon as the last portion of the sample has entered the column.
6. Quickly add 65 ml of chloroform-butanol reagent and apply suction.
7. Discontinue the suction just before the last of the reagent enters the column.

8. Remove the funnel and purge the sample with nitrogen gas for at least 1 minute, and continue purging during titration. Purging with nitrogen will prevent contact with atmospheric carbon dioxide and also mix the sample during titration.
9. Add a half a dropper full of phenolphthalein indicator to the liquid in the vacuum flask.
10. Titrate the sample with standard NaOH to the phenolphthalein end point (light purple). Use the 0.02 N titrant if the volatile acids concentration in the sample is estimated to be greater than 500 mg/l. The 0.005 N titrant should be used for concentrations less than 500 mg/l.
11. Repeat the above procedure using a blank consisting of 5.0 ml of acidified distilled water, extract with reagent and titrate in a similar manner. Use the same standard NaOH solution as was used in the sample titration.
12. Calculate total volatile acids as follows:

$$\begin{aligned} \text{Total Volatile Acids } \left(\frac{\text{mg}}{\text{l}} \text{ as Acetic Acid} \right) \\ = \frac{(A-B) \times N \times 60,000}{\text{ml sample}} \end{aligned}$$

where

A = ml NaOH used for sample

B = ml NaOH used for blank

N = normality of NaOH

Notes

1. At least once each week a standard 2100 $\frac{\text{mg}}{\text{l}}$ acetic acid solution should be tested. Based on an average recovery of 95 percent, the experimentally determined value should range between 1900 and 2100 mg/l as acetic acid. If the acid concentration is outside this range the cause of the deviation should be determined.
2. The standard 2100 $\frac{\text{mg}}{\text{l}}$ acetic acid solution can be prepared by diluting exactly 1.0 ml of glacial acetic acid (reagent grade) to 500 ml in a volumetric flask.
3. The shade of the phenolphthalein endpoint will vary between analysts. Error is reduced if each set of sample is tested by only one analyst, and if he consistently titrates to the same endpoint (color).

VI. Sludge Filtration

Apparatus

1. Buchner funnel, 5 1/2 inch diameter, porcelain, with fixed perforated plate.
2. Plastic support screen, cut to cover perforated plate of Buchner funnel.
3. Vacuum flask, 4000 ml, with 100 ml graduated cylinder secured in flask.
4. No. 2 Whatman Filter paper, 12.5 cm diameter.
5. Vacuum gage, 0-30 inches Hg vacuum.
6. Stop watch.

Procedure

1. Filtration assembly should be set up as shown in Figure 3.
2. Obtain approximately 150 ml of sludge sample.
3. Measure the total solids content of the well-mixed sample.
4. Allow the sludge sample to come to laboratory ambient temperature. Measure and record the ambient temperature.
5. Transfer a well-mixed sludge sample to a 100 ml graduated cylinder. Fill to the 100 ml mark.
6. Add the 100 ml of sludge to the Buchner funnel and allow time for a cake to form (about 10 seconds).
7. Apply vacuum to the system and immediately start the stop watch.
8. Record the volume of filtrate collected at the following time intervals: 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 25, and 30 minutes.
9. During the test periodically observe the reading on the vacuum gage. Record the range of values observed during the test period.
10. Calculate the specific resistance of the sludge as described below.

Calculation

1. Plot t/V vs V , where t is the time in seconds, and V is the volume of filtrate collected in milliliters.
2. Determine the slope of the line. The slope is designated as b (sec/cm^6).

3. Specific conditions of the test:

A = area of filter paper (cm^2), 123 cm^3 for 12.5 cm diameter paper

P = average vacuum pressure (gm/cm^2), $\text{gm/cm}^2 = 34.6 \times \text{in Hg}$

C = total solids content of initial sludge (gm/ml), $\text{gm/ml} = 0.01 \times \%$

μ = filtrate viscosity (poises), poise = gm/cm sec ,
poises = $0.01 \times \text{centipoises}$.

The filtrate viscosity (μ) can be assumed to be the same as that of water at the same temperature. Use the following chart to determine viscosity:

<u>Temp.</u> <u>(°C)</u>	<u>Viscosity</u> <u>(Poise)</u>	<u>Temp.</u> <u>(°C)</u>	<u>Viscosity</u> <u>(Poise)</u>
15	0.0114	23	0.0094
16	0.0111	24	0.0091
17	0.0108	25	0.0089
18	0.0106	26	0.0087
19	0.0103	27	0.0085
20	0.0100	28	0.0084
21	0.0098	29	0.0082
22	0.0096	30	0.0080

4. Compute the specific resistance, r:

$$r(\text{sec}^2/\text{gm}) = \frac{(2)(P)(A^2)(b)}{(\mu)(C)}$$

FIGURE 3. SLUDGE FILTRATION ASSEMBLY

VII. Sludge Centrifugation

Apparatus

1. Centrifuge and 50 ml centrifuge tubes.
2. Stopwatch.
3. Equipment for total suspended solids analysis.
4. Equipment for total solids analysis.

Procedure

1. Obtain about 75 ml of sludge sample.
2. Perform total solids analysis (see Section IV) on a well-mixed portion of the sample.
3. Transfer about 35 ml of well-mixed sample to a 50 ml centrifuge tube.
4. Place the tube in the centrifuge. Counterbalance as necessary with tubes containing water. Prepare the centrifuge for operation.
5. Turn the large dial on the front of the centrifuge to 10, and immediately start the stopwatch. This is the start of the test. After exactly 15 seconds have elapsed, turn the dial to 20. Continue increasing the setting by intervals of 10 every 15 seconds until the dial reads 50.
6. Continue operating at a dial setting of 50 until exactly 7 minutes have elapsed since the start of the test, then turn the main toggle switch to the off position. (Important: During slowdown do not utilize the braking system or in any other way interfere with the natural deceleration of the centrifuge head.)
7. When the centrifuge head has come to a complete stop, remove the tubes and analyze the centrate for total suspended solids and total solids.
8. The efficiency of centrifugation is determined by computing percent recovery.

$$\% \text{ recovery} = \frac{C_i - C_c}{C_i - C_c + C_s} \times (100)$$

where:

C_i = total solids present in initial sludge sample (%)

C_c = total solids present in centrate after centrifugation (%)

C_s = total suspended solids present in centrate after centrifugation (%).

APPENDIX A
DRAWINGS/SPECIFICATIONS

DIGESTER ELEVATION VIEW

DIGESTER PLAN VIEW

Approx. 1 1/2' Tygon Tubing
Between Digester and "Quick
Disconnect" Fittings

Plastic "Quick Disconnect"
Fittings, Size to Fit 1/4"
ID Tygon Tubing

GAS RECIRCULATION SCHEMATIC

APPENDIX B
OPERATING AND MAINTENANCE INSTRUCTIONS

INSTRUCTIONS

for

YSI**THERMISTEMP®****MODEL 63RC****TEMPERATURE****CONTROLLER**

Scientific Division

Yellow Springs Instrument Co., Inc.

Yellow Springs, Ohio 45387, U.S.A. • Phone 513-767-7241

GENERAL DESCRIPTION

The YSI Model 63RC Temperature Controller is a compact, sensitive electronic controller capable of maintaining temperature within narrow limits. Since both coarse and fine controls are provided, the instrument can be set very precisely over a wide range of temperature.

Temperature is sensed by means of a thermistor probe which forms one leg of an alternating current bridge. If the temperature of the probe deviates from the setting of the controller, the bridge becomes unbalanced, and the unbalance voltage or error signal is amplified to operate a control relay. The contacts of the control relay are used to switch the external load on or off in accordance with the demands of the controller. Because of the sensitive probe and the high amplification the "dead zone" of the controller is very narrow; that is, a very slight temperature deviation from the control point will cause the load to be switched on or off.

SPECIFICATIONS 63RC

-20 to 120°C Probes 601, 611, 621, 631, 641,
(0 to 250°F) 651, 661 (green center lead)

95 to 260°C Probes 602, 612, 622, 632, 642,
(200 to 500°F) 652, 662 (red center lead)

-75 to 40°C Probes 603, 613, 623, 633, 643,
(-100 to 100°F) 653, 663 (blue center lead)

Dead Zone: Less than 0.05°C (0.1°F)

Controls: Coarse and fine, ratio to approximately 20 to 1, calibrated in arbitrary units, 0-100. Remove knobs to convert to screwdriver adjustment.

Relay: Single pole, double-throw; contacts rated 10 amperes at 117 VAC; 5 amperes at 230 VAC, non-inductive load.

Power: 117 or 230 volts, 50-60 Hz, 5 watts.

INSTALLATION

The probe may be located up to several hundred feet from the controller. Almost any wire may be used for distances up to 20 feet; for runs of greater length, No. 14 wire in conduit is recommended.

Important: Observe polarity. The outside (shield braid) conductor of the probe must be connected to the PROBE GND terminal. As supplied, shield terminates in black pigtail.

Probe placement is important when close control is desired. If the probe is located close to the source of heat which is being controlled, often the temperature will be held to narrower limits than the dead zone of the controller. If the thermal load on the system varies widely, locating the probe at a greater distance from the heater will result in better average temperature stability, but at the cost of somewhat greater under-shoot and over-shoot about the control point.

External Wiring Diagram

GUARANTEE

The YSI Model 63RC temperature controller and temperature probes carry a one-year unconditional guarantee on all workmanship and components. Damage through misuse, accident, or tampering will be repaired at nominal charge, if possible. If you are experiencing difficulty with any YSI product, even if the guarantee has expired, it may be returned to any authorized YSI dealer or to the YSI factory.

NOTE:

1. TRANSFORMER MUST BE PHASED AS SHOWN.

ALL RESISTORS ARE 1/2 WATT 10%
UNLESS OTHERWISE SPECIFIED.

ALL CAPACITORS ARE IN mfd/V.D.C.

MODEL 63RC TEMPERATURE CONTROLLER

THE VALUES SHOWN ON THE SCHEMATIC
MAY DIFFER FROM THOSE IN THE INSTRUMENT;
IF SO, EITHER VALUE CAN BE USED
FOR REPLACEMENT PURPOSES.

C-41402-C

FOR 230V REWIRE AS SHOWN.
SEE LABEL INSIDE OF INSTRUMENT.

CARE AND OPERATION OF THE GLAS-COL HEATING MANTLE

With proper care and operation, the Glas-Col Mantle will give long and efficient service. Chemical spillage, overheating and general misuse will greatly reduce the life of the mantle.

The Glas-Col mantle consists of a simple insulated electrical resistance heater and requires only an electrical power supply. However, use of a variable transformer or an automatic controller is recommended to prevent overheating and to effect accurate temperature control. In some instances, it may be desirable to use a variable transformer and an automatic device together for very accurate control. Instructions for connection and operation of this arrangement are available from Glas-Col on request.

For maximum safety, the three-prong plug of the cord on the Series M, TM and STM mantles should always be inserted into a grounded outlet. Since the exterior of Series O mantles is an insulator, these mantles are furnished with two wire cords.

Maintenance of the Glas-Col mantle on a regular schedule is not required. Of course, any damage which occurs to the mantle should be repaired immediately. Glas-Col mantles should be protected from chemical spillage and corrosive atmospheres so far as practical. Damage from spillage on Series M or TM mantles can be reduced greatly by using the Glas-Col Splash Guard or Poncho safety shield.

The only limitation in the operation of the Glas-Col mantle is the maximum heating zone temperature limit of 450° C for the glass fabric in Series O, M and TM mantles and 650° C for Series S, STM and RFM mantles. Most Series O, M and TM mantles are equipped with iron constantan thermocouples to measure this temperature. Under normal conditions 650° C will not be exceeded and, therefore, Series S, STM and RFM mantles do not have thermocouples except on special order.

Overheating of Series O spherical and hemispherical mantles can be prevented effectively by using the appropriate Glas-Col support. (Cat. No. O-524 thru O-550 extension supports, O-505 and O-510 tripod supports). The use of these supports is the only method approved by Glas-Col and we cannot assume responsibility for mantles damaged as a result of being supported otherwise. For example — on ring stands, cork rings, lab jacks, etc.

In Series O spherical mantles of 12-liters capacity and larger, there are three heating circuits — two in the lower half and one in the upper half. The heat input in each circuit should be controlled with a suitable variable transformer. The two lower circuits furnish heat for boiling the liquid contents, while the upper circuit prevents condensation of the vapors. It will rarely be necessary to operate the upper circuit on more than 60 or 70 Volts. For low boiling liquids the upper circuit need not be used. When the flask is more than half full of liquid, the two bottom circuits may be operated at the rated voltage. When the liquid level falls below the halfway mark in the flask, the voltage in the upper circuit of the lower half should be reduced to 70 or less. This will prevent superheating of the vapors, and overheating of the glass fabric in this circuit.

A similar procedure should be followed when using a Series M, TM, S or STM mantle with a Series MO heating top.

Glas-Col Apparatus Company is not responsible for damage to apparatus due to improper installation or through attempts to operate the apparatus beyond its rated capacity, intentional or otherwise. Glas-Col warrants products of its manufacture to be free from defects in material and workmanship and agrees to repair or replace without charge any products found defective upon examination at the factory. With proper installation, avoidance of contamination and excess temperature, Glas-Col mantles should provide efficient operation and long service life.

For full details and prices on all standard Glas-Col heating mantles for the laboratory, request Bulletin 73-L. For special heating applications, contact our Engineering Department.

INSTRUCTIONS

These devices are manufactured under one or more of the following U.S. Patents: 3,466,585; 3,529,348. Patented Canada 1968.

for
**INSTALLATION
 OPERATION
 and
 MAINTENANCE**

POWERSTAT®

Variable Transformers

MANUALLY OPERATED SINGLE UNITS

**116BU-40, 116B, 117B, 216B, 217B Series
 with POWERKOTE™ COILS**

The right to make engineering refinements on all products is reserved. Dimensions and other details are subject to change.

THE SUPERIOR ELECTRIC COMPANY
 Bristol, Connecticut 06010

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INSPECTION

A POWERSTAT Variable Transformer is a precision product packed with care. When unpacking, examine carefully for any shipping damage. Inspect the brush contact with particular care. The "Damage and Shortage" instructions packed with the unit outline the procedure to follow if any parts are damaged or missing.

PRECAUTIONS

- Be absolutely certain that the line voltage, phase and frequency are correct for the unit.
- If not already provided, incorporate fuses in the hot output leads as recommended in the circuit diagram.
- Prevent the radiator from striking sharply against its stop because this tends to weaken the entire structure.

CONNECTIONS AND RATINGS

COIL TO TERMINAL CONNECTIONS for all POWERSTAT Variable Transformers included in these instructions are given in Figures A, B and C.

DERATING OF OUTPUT CURRENT AT AMBIENT TEMPERATURES ABOVE 50°C is shown in Figure D. At ambient temperatures between -20°C and +50°C use the current ratings given in the charts.

DERATING OF OUTPUT CURRENT WHEN OPERATING ON LOW INPUT VOLTAGE TAP for 216B units is shown in Figure E.

MAXIMUM TIME UNITS MAY BE SUBJECTED TO VARIOUS OVERLOADS is shown by the "maximum on time" curve in Figure F. When used with repetitive overloads, the units must be allowed sufficient "off" time as indicated by the "minimum off

time" curve to prevent excessive steady-state temperatures. For overloads where "on" time is less than the maximum shown, the "off" time can be calculated using the following equation:

$$\left(\frac{\text{OVERLOAD CURRENT}}{\text{RATED CURRENT}} \right)^2 - 1 = \frac{\text{OFF TIME}}{\text{ON TIME}}$$

BASIC UNIT	RECOMMENDED FUSE (AMPERES)	
	CONSTANT CURRENT LOAD	CONSTANT IMPEDANCE LOAD
116BU-40	25	30
116B	10††	15
117B	15	15††
216B	4††	5
217B	5	8††

††Cord-and-plug units supplied with these fuses.

FIGURE A
116B TYPES

FIGURE B
216B TYPES

FIGURE C
116BU-40, 117B
AND 217B TYPES

FIGURE D

FIGURE E

FIGURE F

TYPE	INPUT		OUTPUT						KNOB ROTA- TION	TERMINALS			
	VOLTS	HERTZ	VOLTS	CONSTANT CURRENT LOAD		CONSTANT IMPEDANCE LOAD		KNOB ON RADIATOR END		KNOB ON BASE END			
				MAX. AMP.	MAX. KVA	MAX. AMP.	MAX. KVA	INPUT		OUTPUT	INPUT	OUTPUT	
116BU-40	40	60	0-40	25	1.0	30	1.2	CW	1-4	1-3	1-4	3-4	
								CCW	1-4	3-4	1-4	1-3	
116B VS116B 3PN116B VS3PN116B 116BT VS116BT 116BU	120	50/60	0-120	10	1.2	13	1.6	CW	1-4	1-3	1-4	3-4	
								CCW	1-4	3-4	1-4	1-3	
			0-140	10	1.4	—	—	CW	1-2†	1-3‡	4-5	3-4	
								CCW	4-5	3-4	1-2	1-3	
2PF117B VS2PF117B 3PN117B VS3PN117B 117BT VS117BT 117BU	120	60	0-120	12	1.4	15	1.8	CW	1-4‡	1-3‡	1-4	3-4	
								CCW	1-4	3-4	1-4	1-3	
216B VS216B 3PN216B VS3PN216B 216BT VS216BT 216BU	240	50/60	0-240	3.5	0.84	5	1.2	CW	1-4	1-3	1-4	3-4	
								CCW	1-4	3-4	1-4	1-3	
			0-280	3.5	0.98	—	—	CW	1-2†	1-3‡	4-5	3-4	
								CCW	4-5	3-4	1-2	1-3	
	120	50/60	0-280	3.5*	0.42†	—	—	CW	1-6	1-3	4-7	3-4	
								CCW	4-7	3-4	1-6	1-3	
2PF217B VS2PF217B 3PN217B VS3PN217B 217BT VS217BT 217BU	240	60	0-240	5	1.2	7	1.7	CW	1-4‡	1-3‡	1-4	3-4	
								CCW	1-4	3-4	1-4	1-3	

*Maximum output current in output voltage range from 0 to 25 percent above line voltage. At higher output voltages output current must be reduced according to rating curve Figure E.

†Maximum KVA at maximum output voltage. Maximum KVA at lower output voltages may be calculated from rating curve Figure E.

‡Cord and plug units wired this way when shipped.

• Switch on Cord and Plug types only.

☆ Fuses recommended on all units. See fusing chart for ratings.

§ Voltmeter on "VS" types only.

MAINTENANCE

When installed and operated in accordance with these instructions, a POWERSTAT Variable Transformer should require no servicing except possible replacement of the brush assembly. The brushes should be inspected periodically and replaced if they are badly worn. Use only the correct Superior Electric replacement brush assembly. The brushes must be of a special material if proper operation is to be attained.

REPLACEMENT BRUSH ASSEMBLY

SERIES	BRUSH ASSEMBLY NO.
116BU-40	RB116B-40
116B	RB116B
117B	RB117B
216B	RB216B
217B	RB217B

VARIABLE SPEED

MASTERFLEX

PUMP DRIVES

7545 Series Variable Speed Drive
Standard Pump Head No. 7017
Add-On Pump Head No. 7017-20

Cole Parmer Instrument Co.
7425 N. Oak Park Avenue
Chicago, Illinois 60648

A-1299-4
EDITION 4675

DESCRIPTION

Masterflex variable speed drives are available in several configurations; the drive and controller alone or packaged in kits containing an assortment of pump heads. Several gear ratios are offered, and the systems can be purchased for use on either 115V AC or 230V AC, 50-60 HZ. All of the systems use the same type of solid state speed control circuit, with some differences between the 115V and 230V units.

The drives connect directly to the pump heads. The Masterflex pumps are carefully engineered peristaltic pumps that accept a continuous length of tubing for contamination free pumping. The liquid only contacts the tubing and not the other pump parts. The pump can be used for gases, liquids, and vacuum applications. They are completely self-priming. A highly efficient three roller rotor assembly is used within a uniquely designed, polycarbonate housing. As many as ten pumps can be operated with one drive, depending on the type of tubing and speeds desired.

OPERATION

Operation of the variable speed drive is simple: select and install the desired pump head and tubing, connect the drive to the controller, and connect the controller line cord to a grounded, three wire AC receptacle. Adjust the speed control knob to the desired speed. If necessary, use the reversing switch to change the direction of the pump's rotation (stop the pump before changing the direction).

A few cautionary notes must be added. The speed control knob graduations are for reference only;

they are not calibrated. Some drives will not start to rotate until the knob is at position '4'. This is caused by component tolerances and is a normal condition. Speeds slower than the stated minimum speed can be obtained but they are not recommended. The motor would operate at a higher temperature, and the speed regulation circuit would allow greater fluctuations in the speed and hence the pump flow. Care should be taken, when using the rotation reversing switch, to make sure that the pump is brought to a full stop before reversing rotation. Failure to bring the pump to a full stop may cause an overload condition that will result in blowing the controller fuse and perhaps other electronic components. Do not replace the fuse with one of a higher rating. That would increase the possibility of component failure.

MULTIPLE HEAD USAGE

The variable speed drives and pump heads have been designed so that the drives can operate several heads, at once; the number dependent on the drive and type of tubing used. A list is provided with the drives and the recommended maximum number of pump heads that each can operate. This assumes that standard Tygon, Silicone, or Viton tubing is used. 'Food Grade' Tygon tubing requires approximately twice the torque as the standard Tygon, and this reduces the capacity of the drives by fifty percent. Hence, 7545-10 drives, using Food Grade Tygon should be limited to five heads. Standard heads attach directly to the drive, while Add-On heads attach only to other heads, either Standard or Add-On. Use a Standard head as the first channel and Add-On heads for additional channels in multiple channel applications.

VARIABLE SPEED MASTERFLEX SCHEMATIC

CONTROLLER PARTS LIST NO. 1

230 V AC 50-60 HZ (7546, 7546-10)

SYMBOL	PART NO.	ITEM
F	B-1115-8	0.75 A-SLO-BLOW FUSE
R1	B-1113-52	2 OHM 10W
R2	B-1113-43	56K
R3	B-1113-108	680 OHM
R4	B-1113-111	8K , 8 W
R5	B-1117-10	4.7 K TRIM
R6	B-1117-2	25K SPEED CONTROL
R7	B-1113-110	82 K, 5%
R8	B-1113-2	47 OHM
L1	A-1067	NEON LAMP
D1 to D4	B-1119-7	2.5 A, 1000V DIODE
D5 , D6	B-1119-2	1.0A, 1000V DIODE
C1	B-1114-29	0.1 MFD. 400V
C2	B-1114-19	0.47 MFD 250V
Z1	B-1126-7	12V, 1W, ZENER
T1	B-1118-2	UNIJUNCTION 2N1671
TP TS	A-1103	PULSE TRANSFORMER
SCR	B-1120-6	SCR 2A, 600V

CONTROLLER PARTS LIST NO. 2

115V AC 50-60 HZ (7545, 7545-10)

SYMBOL	PART NO.	ITEM
F	B-1115-3	1.5 A SLO-BLOW FUSE
R1	B-1113-64	4 OHM 10W
R2		0 OHM
R4	B-1113-109	4K , 5W
R7	B-1113-105	43K, 5%
C1	B-1114-13	0.1 MFD, 250V
SCR	B-1120-3	SCR 2A, 200V

The other components
are the same as in 7546
all resistors 10%, $\frac{1}{2}$ W
unless otherwise noted

ML* PER REVOLUTION

7013	0.06	7015	1.67
7014	0.21	7017	2.80
7016	0.80	7018	3.80

*approximate flow

PUMP SYSTEMS

CATALOG NUMBER	DESCRIPTION	SPEED RANGE RPM	MAXIMUM NUMBER OF PUMPS
7545	115V-AC-MOTOR & CONTROLLER	30 to 600	2
7545-10	115V-AC-MOTOR & CONTROLLER	5 to 100	10
7546	230V-AC-MOTOR & CONTROLLER	30 to 600	2
7546-10	230V-AC-MOTOR & CONTROLLER	5 to 100	10
7550-45	KIT: 7545 & 4 PUMP HEADS	30 to 600	2
7550-46	KIT: 7546 & 4 PUMP HEADS	30 to 600	2
7550-85	KIT: 7545 & 8 PUMP HEADS	30 to 600	2
7550-86	KIT: 7546 & 8 PUMP HEADS	30 to 600	2

All systems operate on 50 or 60 HZ

PUMP ROTOR REPLACEMENT

Each rotor assembly has three cylindrical rollers held between two circular discs. These rollers compress the tubing and force the liquid along the tubing as the rotor assembly rotates. The 7015 pump has a rotor which is different from the rotors in the other pump heads. The rollers of the 7015 rotor are flush with the outer edge of the circular discs. The rollers of the other pump heads extend approximately 1/16" beyond the outer edge of the discs. If the wrong rotor is used in any of the pump heads, improper tubing occlusion will occur.

MASTERFLEX PUMP HEAD MOUNTING HARDWARE (Plated Steel)

For 7013 to 7018 Series Pumps

<u>Part No.</u>	<u>Description</u>
B-1238-3	For 1 channel
B-1238-8	For 2 channels
B-1238-6	For 3 channels
B-1238-7	For 4 channels
B-1238-16-CR	For 5 channels
B-1238-17-CR	For 6 channels
B-1238-18-CR	For 7 channels
B-1238-19-CR	For 8 channels
B-1238-20-CR	For 9 channels
B-1238-21-CR	For 10 channels

MASTERFLEX PUMP HEAD MOUNTING HARDWARE (Stainless Steel)

B-1238-9	For 1 channel
B-1238-10	For 2 channels

MASTERFLEX PUMP REPLACEMENT PARTS

(Metal parts are plated steel)

STANDARD PUMP HEAD	ADD-ON PUMP HEAD	PLASTIC PUMP HEAD SECTION	ROTOR ASSEMBLY
7013		A-1106-2	B-1061-1
	7013-20	A-1106-2	B-1289-1
7014		A-1106-3	B-1061-1
	7014-20	A-1106-3	B-1289-1
7016		A-1106-5	B-1061-1
	7016-20	A-1106-5	B-1289-1
7015		A-1106-1	B-1061
	7015-20	A-1106-1	B-1289-2
7017		A-1106-4	B-1061-1
	7017-20	A-1106-4	B-1289-1
7018		A-1106-6	B-1061-1
	7018-20	A-1106-6	B-1289-1

All rotor assemblies use teflon
thrust washers, A-1184.

MASTERFLEX PUMP REPLACEMENT PARTS

(Metal parts are Stainless Steel)

STANDARD PUMP HEAD	ADD-ON PUMP HEAD	PLASTIC PUMP HEAD SECTION	ROTOR ASSEMBLY
7013-10		A-1400-1	B-1290-1
	7013-21	A-1400-1	B-1291-1
7014-10		A-1400-2	B-1290-1
	7014-21	A-1400-2	B-1291-1
7016-10		A-1400-5	B-1290-1
	7016-21	A-1400-5	B-1291-1
7015-10		A-1400-3	B-1290-2
	7015-21	A-1400-3	B-1291-2
7017-10		A-1400-4	B-1290-1
	7017-21	A-1400-4	B-1291-1
7018-10		A-1400-6	B-1290-1
	7018-21	A-1400-6	B-1291-1

All rotor assemblies use teflon thrust washers,
A-1184.

MOTOR REPAIR PARTS

ITEM	PART NO.	DRIVE
MOTOR BRUSHES (set of 2)	A-1138-CR	7545, 7545-10 7546, 7546-10
BRUSH CAP	A-1791-CR	ALL DRIVES NOTED ABOVE
GEAR CASE GASKET	B-1467	ALL DRIVES NOTED ABOVE
ARMATURE	A-1793-CR* A-1808-CR**	7545
ARMATURE	A-1808-CR	7545-10
ARMATURE	A-1792-CR* A-1809-CR**	7546
ARMATURE	A-1809-CR	7546-10
OUTPUT GEAR ASSEMBLY	7545-06	7545, 7546
OUTPUT GEAR ASSEMBLY	B-1125	7545-10, 7546-10
COMPOUND GEAR	B-1127	7545-10, 7546-10

NOTE:

* VERSION A (OVERALL LENGTH=6.453")

** VERSION B (OVERALL LENGTH=6.143")

MAINTENANCE

The speed control circuit has solid state components which do not require servicing. A tubing rupture may result in a motor overload which could cause some electrical parts to fail.

The rear motor bearing should be given two drops of #20 non detergent oil every three months. Do not over-oil. Exact motor brush and communator life will depend on the speed and the number of pump heads. Brushes should be inspected and replaced when less than 0.300" long. The communator should be periodically inspected and cleaned if necessary. If preventive maintenance is not performed, excessive communator wear or 'bridging' between communator segments will cause excessive current through the controller circuit.

WARRANTY

The Cole-Parmer Instrument Company warrants the product to be free from defects in material and workmanship for a period of six months. If repair or adjustment is necessary and has not been the result of abuse or misuse within the six month period, please return, freight prepaid, and correction of the defect will be made without charge (see note on return of items.)

For your protection, items being returned must be carefully packed to prevent damage in shipment and insured against possible damage or loss. Cole-Parmer will not be responsible for damage resulting from careless or insufficient packing.

Out of warranty products will be repaired for a nominal charge.

RETURN OF ITEMS

Authorization must be obtained from our Customer Service Department before returning items for any reason. When applying for authorization, please include data regarding the reason the items are to be returned. A 15% restocking charge will be made on all unauthorized returns.

NOTE

Technical information and advice on the use of the product in specific applications may be obtained. Modifications can be made to adapt the unit to special customer applications. Contact the Engineering Department for information.

The Cole-Parmer Instrument Company reserves the right to make improvements in design, construction and appearance of our products without notice.

COLE-PARMER INSTRUMENT COMPANY

7425 NORTH OAK PARK AVE. • CHICAGO, ILLINOIS 60648
312/647-0272

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INSTRUMENT COMPANY

P306-75410

Standard Pump Head No. 7017
Add-On Pump Head No. 7017-20

MASTERFLEX® TUBING CHARACTERISTICS

Proper performance of Masterflex Pumps requires correct tubing selection. Tubing listed below has been custom made to stringent specifications and is offered for its compatibility with these pumps. Use of tubing other than recommended may result in premature tubing failure, tubing slippage, decreased pressure and vacuum characteristics, and/or other malfunction.

Technical assistance in selecting the appropriate pump head size and correct tubing is available on request.

To select the tubing suited to your requirements, first check the applications table below for general characteristics of Masterflex tubing materials. Once the proper tubing material has been determined, specify that tubing from the tubing ordering information table for the pump head size to be used.

Operating temperature ranges for the various tubing materials are as follows: #6408 Tygon, -20° to $+165^{\circ}\text{F}$; #6401 Tygon Special, $+10^{\circ}$ to $+180^{\circ}\text{F}$; #6419 Tygon Food and #6415 Tygon Sterile, 0° to $+180^{\circ}\text{F}$; #6411 Silicone, -80° to $+500^{\circ}\text{F}$; and #6412 Viton, -10° to $+400^{\circ}\text{F}$.

Tygon Sterile tubing and Silicone tubing are medical grade. Both are non-toxic and non-reactive to blood, tissues, etc. The #6408 Tygon and #6419 Tygon Food tubings are non-toxic. Silicone tubing and all Tygon tubings (except Tygon Special) are autoclavable. Tygon Sterile tubing is supplied autoclaved, sterilized, and packaged in 10-foot lengths.

#6411 Silicone tubing provides maximum tubing life (assuming circulant compatibility) and most stable flow characteristics. Life of this tubing is consistently 150 hours or more at 550 rpm (450 hours or more at 200 rpm)*.

Life of #6408 Tygon tubing and #6401 Tygon Special tubing is about 50 hours at 550 rpm. #6419 Tygon Food tubing and #6415 Tygon Sterile tubing life is about 40 hours at 550 rpm. Viton tubing life is about 30 hours at 550 rpm.

Life of a given section of tubing is inversely proportional to pump speed. In general, reducing the pump speed by $\frac{1}{2}$ will approximately double the tubing life.

*Except for #6411-09 Silicone tubing with a 70-hour life at 550 rpm.

Wear or fatigue of tubing is normal in any tubing pump; Masterflex Pump Heads are designed to minimize such wear and provide longer tubing life than competitive units. Assuming compatibility with fluid being pumped, three basic factors influence tubing life: (1) pump speed, (2) tubing material, and (3) tubing dimensional tolerances.

Pump Speed. Any given tubing is capable of undergoing a finite number of compressive cycles before fatiguing and eventual failure. Therefore, it is generally advisable to select a larger size Masterflex Pump Head to be run at lower speeds rather than a small size to be run at high speed.

Tubing Material. No. 6411 Silicone tubing provides about 300% greater tubing life than Tygon; No. 6412 Viton tubing may be expected to provide about 60% the life of Tygon tubing.

Tubing Dimensional Tolerances. Proper performance of Masterflex Pumps requires correct tubing selection. Loose tolerance tubing will cause over-stress and premature failure of tubing. We strongly recommend use of Masterflex Tubing only.

TUBING RECOMMENDATIONS FOR MASTERFLEX PUMPS

NOTE: The applications table at right should be used to match tubing characteristics with the requirements of a specific application. Always specify catalog number suffix to indicate tubing size. Ratings in the table are generalized and based on average applications. A sample of tubing should always be subjected to immersion tests in the fluid to be pumped before ordering required quantities. If such tests indicate incompatibility, our engineering staff can assist you in selecting special tubing materials.

TUBING TYPE AND CATALOG NUMBER		TYGON 6408	TYGON 6401	TYGON 6419	TYGON 6415	SILICONE 6411	VITON 6412
A	PRESSURE	G	G	G	G	G	E
	VACUUM	G	G	G	G	E	F
P	CORROSIVES	ACID	G	F	—	F	E
		BASE	G	P	—	F	E
L	SOLVENTS	GENERAL	G	G	—	F	E
		HIGHLY ACTIVE	F	F	—	F	G
A	TEMPERATURE	HIGH	F	F	F&A	E & A	E
		LOW	G	F	F	E	F
I	EXTRA LOW	N/R	N/R	N/R	N/R	E	N/R
O	SPECIAL	—	*	Food**	Medical**	Food** & Medical**	—
N	TUBING LIFE	G	G	G	G	E	F

E=excellent G=good P=poor A=autoclavable
*Especially suited for gasoline, fuels, oils and lubricants

N/R=not recommended
**Meet USDA specifications

FOR ALL PUMP HEAD PREFIX NOS.	TUBING SIZE* ID"xOD"	Tygon		Tygon Special		Tygon Food		Tygon Sterile**		Silicone**		Viton	
		Cat. No.	Per 50-Ft.	Cat. No.	Per 50-Ft.	Cat. No.	Per 50-Ft.	Cat. No.	Per 10-Fl.	Cat. No.	Per 25-Ft.	Cat. No.	Per Foot
7013-	0.0315x0.1625	6408-41	\$11.00	6401-41	\$11.00	6419-41	\$11.00	—	—	6411-41	\$13.75	6412-41	\$0.90
7014-	0.0655x0.1945	6408-43	11.00	6401-43	11.00	6419-43	11.00	—	—	6411-43	15.00	6412-43	1.75
7016-	0.1250x0.2510	6408-02	12.00	6401-44	12.00	6419-02	12.00	—	—	6411-02	17.50	6412-44	1.95
7015-	0.1925x0.3920	6408-45	22.00	6401-45	22.00	6419-45	22.00	6415-30	5.34	6411-45	20.00	6412-45	4.10
7017-	0.2550x0.3900	6408-06	20.00	6401-47	20.00	6419-06	20.00	6415-40	4.88	6411-47	18.75	6412-47	3.30
7018-	0.3130x0.4390	6408-09	23.50	6401-48	23.50	6419-09	23.50	—	—	6411-09	21.25	6412-48	3.40
DISCOUNTS:		Two or More 50-Ft. Coils.....Less 20%						Twelve or More 10-ft coils. Less 10%		50 or More Feet***.....Less 10%			

*These are typical dimensions indicative of the different size tubings—actual specified dimensions with special tolerances are different for different formulations.

**Especially suitable for medical, surgical, and pharmaceutical applications—Tygon Sterile is supplied in pre-sterilized 10-foot lengths.

***Maximum continuous length of Silicone tubing is 25 feet.

ALL DIMENSIONS SUBJECT TO CHANGE WITHOUT NOTICE

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INSTALLATION OF MASTERFLEX® STANDARD PUMP HEAD AND TUBING

Align either of the two interchangeable halves of the pump head with the two pins protruding from the face of the drive unit. Attach in position with the two fillister head screws provided, placing the screws through the two diagonally opposed recessed holes. Install the longer end of the rotor assembly shaft through the pump head bearing and fully mate the shaft cross slot with the drive unit shear pin by rotating the shaft while exerting gentle pressure inwards; mating will be indicated by complete seating of the rotor assembly within the head. Rotate the rotor assembly to position one of the rollers between the tubing inlet and outlet recesses molded into the head.

While maintaining the position of one of the rotor assembly rollers between the tubing recesses, position the tubing about the other two rollers and press the tubing downwards with the thumbs until the tubing is fully seated within the pump head cavity and rollers. On large diameter tubing and tubings of higher Shore durometer ratings a tongue depressor or similar object may be used to assist full seating of the tubing. **CAUTION:** Use of hard or sharp objects such as screwdrivers may damage both the tubing and the pump head.

When the tubing has been fully seated within the pump head cavity and the two rollers, hold the free ends of the tubing in the head inlet and outlet recesses and, while exerting a slight tension on the tubing ends, place the remaining half of the pump head over the rotor assembly shaft and against the installed pump head half. **CAUTION:** Failure to hold slight tension on the tubing may result in excess tubing slack within the pump head that may cause binding and shearing of the drive unit shear pin.

While pressing gently inward on the outer pump head half, rotate the rotor assembly shaft with a screwdriver to ensure that the rotor assembly is fully seated with the drive unit shaft, that no gap remains between the interfaces of the two pump head halves, and that there is no binding between the tubing and the rollers of the rotor assembly. **CAUTION:** Failure to ensure this proper seating before operating the pump may result in damage to both the drive unit gearing and shear pin.

Using the two thumbscrews and flat washers provided, insert these attaching parts in the two mounting holes not occupied by the initially installed screws and, using finger pressure only, attach the assembled pump head to the drive unit. **CAUTION:** Excessive torque on any of the four screws may cause distortion and cracking of the pump head.

The pump head is now properly installed and ready for operation. If a subsequent change of tubing is desired, complete removal of the pump head is not necessary. Merely remove the two thumbscrews, washers, outer pump head half and tubing, and repeat steps one through five.

1. A tongue depressor or similar object may be used to assist in full seating of tubing within the pump head; however, hard or sharp objects such as a screwdriver should not be used.
2. When installing the pump heads on some gear head drive units, rotation of the rotor assembly is not possible with rotor shaft engaged to drive. In these cases, either (1) follow the procedure outlined in Step 2 of the Standard head installation instructions or (2) install the tubing as described in Step 3 of the Add-On instructions before placing the pump head on the mounting studs.

INSTALLATION OF MASTERFLEX® ADD-ON PUMP HEAD AND TUBING

1

This Add-On head is packed complete with all hardware required for mounting on a Standard Masterflex head. For multi-channel applications, with more than one Add-On head, longer studs will be required. These will be supplied at no charge on request (please specify configuration, i.e. three or four channel application).

To install, insert (finger-tight) each of the four studs into the motor face.

2

Place either of the two interchangeable halves of the Standard pump head on the studs, aligning the head with the two pins protruding from the face of the drive unit. Install the longer end of the Standard rotor assembly shaft through the pump head bearing and fully mate the shaft cross slot with the drive unit shear pin by rotating the shaft while exerting a slight pressure inward. Mating will be indicated by complete seating of the rotor assembly within the head.

3

Install the tubing by positioning it around the rollers and rotating the rotor assembly with one hand while depressing the tubing ahead of the rollers with the thumb of the other hand (see illustration above). Continue this rotation until the tubing is fully seated within the head cavity and rollers. A tongue depressor or similar object may be used to assist full seating if necessary.

4

When the tubing has been fully seated, hold the free ends of tubing in the head inlet and outlet recesses and, while exerting a slight tension on the tubing ends, place the remaining half of the Standard pump head over the rotor assembly shaft and against the installed pump head half. **CAUTION:** Failure to hold slight tension on the tubing may result in excess tubing slack within the pump head that may cause binding and shearing of the drive unit shear pin.

5

Place either of the two interchangeable halves of the "Add-On" pump head on the mounting studs, in contact with the Standard head already installed. Then place the non-slotted end of the "Add-On" rotor assembly into the pump head bearing and mate the shaft with the cross slot of the shaft previously installed by rotating with slight inward pressure. Then repeat steps (3) and (4).

6

After checking to be sure there is no space at any of the pump head interfaces, install the four wingnuts using finger pressure only. **CAUTION:** Excessive tightening of any of the wingnuts may cause distortion of the pump heads.

NOTE: For multi-channel applications, repeat step (5) for as many "Add-On" heads that are to be used before attaching wingnuts.

INSTRUCTION BOOKLET

for use with

PRINCO

U.S. SIGNAL CORPS TYPE BAROMETERS

Manufactured by

PRINCO INSTRUMENTS, INC.

1020 Industrial Highway

Southampton, Pa. 18966

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THE "PRINCO" BAROMETER

The "Princo" Standard Mercurial Barometer, U.S. Signal Corps type, is a Fortin type barometer. The glass tube is closed at the top, open at the bottom. The open end extends into the reservoir. The reservoir is so constructed that the level of the mercury within may be raised or lowered. A lower portion of the reservoir consists of a flexible chamois skin bag. Projecting from the bottom of the reservoir casing is a milled head adjusting screw. By means of the adjusting screw the mercury level is lowered or raised, permitting adjustment of the mercury level to the zero point. Further, the air in the reservoir can be expelled by means of the same screw. An ivory point projecting downward from the top of the cistern forms the fixed and definite zero point. It is to this zero point that the level of the mercury in the cistern is adjusted when taking readings.

The barometer tube is enclosed in a metal casing partially fenestrated at the upper end, exposing to view the glass tube and mercury column. The scale of the barometer is engraved on a separate metal strip attached to the metal casing opposite the fenestration. The scale is equipped with a vernier operated by a smoothly working rack and pinion movement. Attached to the metal casing is a thermometer.

The barometer is furnished with a mounting panel. The panel is equipped with white reflectors to facilitate observation of the cistern and mercury meniscus. A suspension post and a centering ring provide the means of mounting the barometer vertically on the panel.

UNPACKING AND SETTING UP

A barometer is a very delicate instrument and should be handled with great care. It is shipped with the glass tube completely full of mercury. Should the barometer arrive at its destination broken, notify the carrier at once so that their inspector may call to examine the damaged instrument and the manner in which it was packed and marked for shipment.

Keep the barometer in a horizontal position until the barometer board is prepared for its reception. Then carefully and slowly turn the barometer right side up. First place the reservoir through the centering ring at the lower end of the board before passing the suspension ring at the top of the case over the suspension post at the top of the board. Very gradually, release the adjusting screw at the bottom of the reservoir casing until the surface of the mercury in the reservoir is adjusted to zero; i.e., until the surface of the mercury exactly coincides with the tip of the ivory zero point. The mercury level should be lowered very slowly to permit sufficient time for the air to enter the reservoir through the chamois diaphragm at the top. Too sudden lowering of the mercury level would cause a partial vacuum in the reservoir which would draw in air bubbles through the chamois bag, with the possibility that some air might enter the barometer tube.

PREPARATION FOR SHIPMENT

When the barometer is to be moved from one place to another, it should be inclined carefully and slowly to an angle of approximately 45° . The mercury in the barometer tube will, in so doing, slowly rise to the top of the tube and fill it completely. If the barometer is free of air and moisture, the mercury column will strike the top of the glass tube with an audible metallic sound or click. Care should be taken in tilting it slowly, since a sudden or violent movement may cause the mercury to rise quickly and with its impact break the top of the glass tube. The characteristic click may be heard plainly if the barometer is held close to the ear during the process. When the glass tube is completely filled with mercury, incline the barometer further to an angle of approximately 35° . While in this position turn the adjusting screw until mercury completely fills the reservoir. When the glass tube and the reservoir are thus completely filled with mercury, invert the barometer; i.e., turn it upside down. If the barometer is then held vertically in the inverted position, it may be carried about or prepared for shipment. If this position is not maintained, sudden sharp jars may cause the mercury to drop short distances in the tube and to rebound with sufficient force to break the top of the tube.

In shipping the barometer, be sure it is packed suitably in a strong box. In its packing box, the instrument should be in the horizontal position. When packed for shipment the instrument should be thoroughly imbedded on all sides and at both ends in at least four inches of resilient packing material. The packing box should be clearly marked "DO NOT STAND ON END."

(continued on page 7)

Table 1. TEMPERATURE CORRECTION, English Units

To reduce the reading of the barometer to standard temperature

Temperature F	Observed Reading of the Barometer in Inches											
	20"	21"	22"	23"	24"	25"	26"	27"	28"	29"	30"	31"
	ALL CORRECTIONS SUBTRACTIVE											
30	.002	.003	.003	.003	.003	.003	.003	.003	.003	.004	.004	.004
32	.006	.006	.007	.007	.007	.008	.008	.008	.009	.009	.009	.009
34	.010	.010	.011	.011	.012	.012	.013	.013	.014	.014	.015	.015
36	.013	.014	.015	.015	.016	.017	.017	.018	.019	.019	.020	.021
38	.017	.018	.019	.020	.020	.021	.022	.023	.024	.025	.026	.026
40	.021	.022	.023	.024	.025	.026	.027	.028	.029	.030	.031	.032
42	.024	.025	.027	.028	.029	.030	.032	.033	.034	.035	.036	.038
44	.028	.029	.031	.032	.033	.035	.036	.038	.039	.040	.042	.043
46	.031	.033	.035	.036	.038	.039	.041	.043	.044	.046	.047	.049
48	.035	.037	.039	.040	.042	.044	.046	.047	.049	.051	.053	.054
50	.039	.041	.043	.045	.046	.048	.050	.052	.054	.056	.058	.060
52	.042	.044	.047	.049	.051	.053	.055	.057	.059	.061	.064	.066
54	.046	.048	.051	.053	.055	.057	.060	.062	.064	.067	.069	.071
56	.050	.052	.055	.057	.060	.062	.064	.067	.069	.072	.074	.077
58	.053	.056	.059	.061	.064	.066	.069	.072	.074	.077	.080	.082
60	.057	.060	.062	.065	.068	.071	.074	.077	.080	.082	.085	.088
62	.060	.063	.066	.069	.073	.076	.079	.082	.085	.088	.091	.094
64	.064	.067	.070	.074	.077	.080	.083	.086	.090	.093	.096	.099
66	.068	.071	.074	.078	.081	.085	.088	.091	.095	.098	.101	.105
68	.071	.075	.078	.082	.085	.089	.093	.096	.100	.103	.107	.110
70	.075	.079	.082	.086	.090	.094	.097	.101	.105	.109	.112	.116
72	.078	.082	.086	.090	.094	.098	.102	.106	.110	.114	.118	.122
74	.082	.086	.090	.094	.098	.103	.107	.111	.115	.119	.123	.127
76	.086	.090	.094	.098	.103	.107	.111	.116	.120	.124	.128	.133
78	.089	.094	.098	.103	.107	.112	.116	.120	.125	.129	.134	.138
80	.093	.097	.102	.107	.111	.116	.121	.125	.130	.135	.139	.144
82	.096	.101	.106	.111	.116	.121	.125	.130	.135	.140	.145	.149
84	.100	.105	.110	.115	.120	.125	.130	.135	.140	.145	.150	.155
86	.104	.109	.114	.119	.124	.130	.135	.140	.145	.150	.155	.161
88	.107	.113	.118	.123	.129	.134	.139	.145	.150	.155	.161	.166
90	.111	.116	.122	.127	.133	.138	.144	.150	.155	.161	.166	.172
92	.114	.120	.126	.132	.137	.143	.149	.154	.160	.166	.172	.177
94	.118	.124	.130	.136	.142	.147	.153	.159	.165	.171	.177	.183
96	.122	.128	.134	.140	.146	.152	.158	.164	.170	.176	.182	.188
98	.125	.131	.138	.144	.150	.156	.163	.169	.175	.181	.188	.194

Table 2. TEMPERATURE CORRECTION, Metric Units

To reduce the reading of the barometer to standard temperature

Temperature C	Observed Reading of the Barometer in Millimetres or Millibars												
	540	560	580	600	620	640	660	680	700	720	740	760	780
	ALL CORRECTIONS SUBTRACTIVE												
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	.09	.09	.09	.10	.10	.10	.11	.11	.11	.12	.12	.12	.13
2	.18	.18	.19	.20	.20	.21	.22	.22	.23	.24	.24	.25	.25
3	.26	.27	.28	.29	.30	.31	.32	.33	.34	.35	.36	.37	.38
4	.35	.37	.38	.39	.40	.42	.43	.44	.46	.47	.48	.50	.51
5	0.44	0.46	0.47	0.49	0.51	0.52	0.54	0.56	0.57	0.59	0.60	0.62	0.64
6	.53	.55	.57	.59	.61	.63	.65	.67	.69	.71	.72	.74	.76
7	.62	.64	.66	.69	.71	.73	.75	.78	.80	.82	.85	.87	.89
8	.70	.73	.76	.78	.81	.84	.86	.89	.91	.94	.97	.99	1.02
9	.79	.82	.85	.88	.91	.94	.97	1.00	1.03	1.06	1.09	1.12	1.15
10	0.88	0.91	0.95	0.98	1.01	1.04	1.08	1.11	1.14	1.17	1.21	1.24	1.27
11	.97	1.00	1.04	1.08	1.11	1.15	1.18	1.22	1.26	1.29	1.33	1.36	1.40
12	1.06	1.10	1.13	1.17	1.21	1.25	1.29	1.33	1.37	1.41	1.45	1.49	1.53
13	1.14	1.19	1.23	1.27	1.31	1.36	1.40	1.44	1.48	1.53	1.57	1.61	1.65
14	1.23	1.28	1.32	1.37	1.41	1.46	1.51	1.55	1.60	1.64	1.69	1.73	1.78
15	1.32	1.37	1.42	1.47	1.52	1.56	1.61	1.66	1.71	1.76	1.81	1.86	1.91
16	1.41	1.46	1.51	1.56	1.62	1.67	1.72	1.77	1.82	1.88	1.93	1.98	2.03
17	1.50	1.55	1.61	1.66	1.72	1.77	1.83	1.88	1.94	1.99	2.05	2.10	2.16
18	1.58	1.64	1.70	1.76	1.82	1.88	1.93	1.99	2.05	2.11	2.17	2.23	2.29
19	1.67	1.73	1.79	1.86	1.92	1.98	2.04	2.10	2.17	2.23	2.29	2.35	2.41
20	1.76	1.82	1.89	1.95	2.02	2.08	2.15	2.21	2.28	2.34	2.41	2.47	2.54
21	1.85	1.91	1.98	2.05	2.12	2.19	2.26	2.32	2.39	2.46	2.53	2.60	2.67
22	1.93	2.01	2.08	2.15	2.22	2.29	2.36	2.43	2.51	2.58	2.65	2.72	2.79
23	2.02	2.10	2.17	2.25	2.32	2.40	2.47	2.54	2.62	2.69	2.77	2.84	2.92
24	2.11	2.19	2.26	2.34	2.42	2.50	2.58	2.66	2.73	2.81	2.89	2.97	3.05
25	2.20	2.28	2.36	2.44	2.52	2.60	2.68	2.77	2.85	2.93	3.01	3.09	3.17
26	2.28	2.37	2.45	2.54	2.62	2.71	2.79	2.88	2.96	3.04	3.13	3.21	3.30
27	2.37	2.46	2.55	2.63	2.72	2.81	2.90	2.99	3.07	3.16	3.25	3.34	3.42
28	2.46	2.55	2.64	2.73	2.82	2.91	3.00	3.10	3.19	3.28	3.37	3.46	3.55
29	2.55	2.64	2.73	2.83	2.92	3.02	3.11	3.21	3.30	3.39	3.49	3.58	3.68
30	2.63	2.73	2.83	2.93	3.02	3.12	3.22	3.32	3.41	3.51	3.61	3.71	3.80
31	2.72	2.82	2.92	3.02	3.12	3.22	3.32	3.43	3.53	3.63	3.73	3.83	3.93
32	2.81	2.91	3.02	3.12	3.22	3.33	3.43	3.54	3.64	3.74	3.85	3.95	4.05
33	2.89	3.00	3.11	3.22	3.32	3.43	3.54	3.64	3.75	3.86	3.97	4.07	4.18
34	2.98	3.09	3.20	3.31	3.42	3.53	3.64	3.75	3.87	3.98	4.09	4.20	4.31

Table 2 Continued. TEMPERATURE CORRECTION, Metric Units

To reduce the reading of the barometer to standard temperature

Temperature C	Observed Reading of the Barometer in Millimetres or Millibars												
	800	820	840	860	880	900	920	940	960	980	1000	1020	1040
	ALL CORRECTIONS SUBTRACTIVE												
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1	.13	.13	.14	.14	.14	.15	.15	.15	.16	.16	.16	.17	.17
2	.26	.27	.27	.28	.29	.29	.30	.31	.31	.32	.33	.33	.34
3	.39	.40	.41	.42	.43	.44	.45	.46	.47	.48	.49	.50	.51
4	.52	.54	.55	.56	.57	.59	.60	.61	.63	.64	.65	.67	.68
5	0.65	0.67	0.69	0.70	0.72	0.73	0.75	0.77	0.78	0.80	0.82	0.83	0.85
6	.78	.80	.82	.84	.86	.88	.90	.92	.94	.96	.98	1.00	1.02
7	.91	.94	.96	.98	1.01	1.03	1.05	1.07	1.10	1.12	1.14	1.17	1.19
8	1.04	1.07	1.10	1.12	1.15	1.17	1.20	1.23	1.25	1.28	1.31	1.33	1.36
9	1.17	1.20	1.23	1.26	1.29	1.32	1.35	1.38	1.41	1.44	1.47	1.50	1.53
10	1.30	1.34	1.37	1.40	1.44	1.47	1.50	1.53	1.57	1.60	1.63	1.66	1.70
11	1.44	1.47	1.51	1.54	1.58	1.61	1.65	1.69	1.72	1.76	1.79	1.83	1.87
12	1.57	1.60	1.64	1.68	1.72	1.76	1.80	1.84	1.88	1.92	1.96	2.00	2.03
13	1.70	1.74	1.78	1.82	1.86	1.91	1.95	1.99	2.03	2.08	2.12	2.16	2.20
14	1.83	1.87	1.92	1.96	2.01	2.05	2.10	2.14	2.19	2.24	2.28	2.33	2.37
15	1.96	2.00	2.05	2.10	2.15	2.20	2.25	2.30	2.35	2.40	2.44	2.49	2.54
16	2.09	2.14	2.19	2.24	2.29	2.35	2.40	2.45	2.50	2.55	2.61	2.66	2.71
17	2.22	2.27	2.33	2.38	2.44	2.49	2.55	2.60	2.66	2.71	2.77	2.82	2.88
18	2.35	2.40	2.46	2.52	2.58	2.64	2.70	2.76	2.81	2.87	2.93	2.99	3.05
19	2.48	2.54	2.60	2.66	2.72	2.78	2.85	2.91	2.97	3.03	3.09	3.16	3.22
20	2.60	2.67	2.74	2.80	2.87	2.93	3.00	3.06	3.13	3.19	3.26	3.32	3.39
21	2.73	2.80	2.87	2.94	3.01	3.08	3.14	3.21	3.28	3.35	3.42	3.49	3.56
22	2.86	2.94	3.01	3.08	3.15	3.22	3.29	3.37	3.44	3.51	3.58	3.65	3.72
23	2.99	3.07	3.14	3.22	3.29	3.37	3.44	3.52	3.59	3.67	3.74	3.82	3.89
24	3.12	3.20	3.28	3.36	3.44	3.51	3.59	3.67	3.75	3.83	3.90	3.98	4.06
25	3.25	3.33	3.42	3.50	3.58	3.66	3.74	3.82	3.90	3.99	4.07	4.15	4.23
26	3.38	3.47	3.55	3.64	3.72	3.81	3.89	3.97	4.06	4.14	4.23	4.31	4.40
27	3.51	3.60	3.69	3.78	3.86	3.95	4.04	4.13	4.21	4.30	4.39	4.48	4.57
28	3.64	3.73	3.82	3.91	4.01	4.10	4.19	4.28	4.37	4.46	4.55	4.64	4.73
29	3.77	3.87	3.96	4.05	4.15	4.24	4.34	4.43	4.53	4.62	4.71	4.81	4.90
30	3.90	4.00	4.10	4.19	4.29	4.39	4.49	4.58	4.68	4.78	4.88	4.97	5.07
31	4.03	4.13	4.23	4.33	4.43	4.53	4.63	4.73	4.84	4.94	5.04	5.14	5.24
32	4.16	4.26	4.37	4.47	4.57	4.68	4.78	4.89	4.99	5.09	5.20	5.30	5.41
33	4.29	4.40	4.50	4.61	4.72	4.82	4.93	5.04	5.15	5.25	5.36	5.47	5.57
34	4.42	4.53	4.64	4.75	4.86	4.97	5.08	5.19	5.30	5.41	5.52	5.63	5.74

Table 3. GRAVITY CORRECTION

To reduce the reading of the barometer to standard gravity

Latitude N or S	Height of the mercury column														
	Inches					Millimetres						Millibars			
	26	27	28	29	30	680	700	720	740	760	780	900	950	1000	1050
	LATITUDE 0° TO 45° THE CORRECTION IS TO BE SUBTRACTED														
	LATITUDE 46° TO 90° THE CORRECTION IS TO BE ADDED														
90°	+0.067	+0.070	+0.073	+0.075	+0.078	+1.76	+1.82	+1.87	+1.92	+1.97	+2.02	+2.33	+2.46	+2.59	+2.72
88	.067	.070	.072	.075	.078	1.76	1.81	1.86	1.91	1.97	2.02	2.33	2.46	2.59	2.72
86	.067	.069	.072	.074	.077	1.75	1.80	1.85	1.90	1.95	2.00	2.31	2.44	2.57	2.70
84	.066	.068	.071	.074	.076	1.72	1.77	1.83	1.88	1.93	1.98	2.28	2.41	2.54	2.66
82	.065	.067	.070	.072	.075	1.69	1.74	1.79	1.84	1.89	1.94	2.24	2.37	2.49	2.62
80	+0.063	+0.066	+0.068	+0.071	+0.073	+1.65	+1.70	+1.75	+1.80	+1.85	+1.90	+2.19	+2.31	+2.43	+2.56
78	.061	.064	.066	.069	.071	1.61	1.65	1.70	1.75	1.80	1.84	2.13	2.25	2.36	2.48
76	.059	.062	.064	.066	.068	1.55	1.60	1.64	1.69	1.74	1.78	2.05	2.17	2.28	2.40
74	.057	.059	.061	.064	.066	1.49	1.53	1.58	1.62	1.66	1.71	1.97	2.08	2.19	2.30
72	.054	.056	.058	.061	.063	1.42	1.46	1.50	1.54	1.59	1.63	1.88	1.98	2.09	2.19
70	+0.051	+0.053	+0.055	+0.057	+0.059	+1.34	+1.38	+1.42	+1.46	+1.50	+1.54	+1.78	+1.87	+1.97	+2.07
68	.048	.050	.052	.054	.056	1.26	1.30	1.33	1.37	1.41	1.44	1.67	1.76	1.85	1.94
66	.045	.046	.048	.050	.052	1.17	1.20	1.24	1.27	1.31	1.34	1.55	1.63	1.72	1.80
64	.041	.043	.044	.046	.047	1.07	1.10	1.13	1.17	1.20	1.23	1.42	1.50	1.58	1.65
62	.037	.039	.040	.041	.043	0.97	1.00	1.03	1.06	1.08	1.11	1.28	1.36	1.43	1.50
60	+0.033	+0.034	+0.036	+0.037	+0.038	+0.86	+0.89	+0.91	+0.94	+0.97	+0.99	+1.14	+1.21	+1.27	+1.33
58	.029	.030	.031	.032	.033	0.75	0.78	0.80	0.82	0.84	0.86	1.00	1.05	1.11	1.16
56	.024	.025	.026	.027	.028	0.64	0.66	0.68	0.69	0.71	0.73	0.84	0.89	0.94	0.99
54	.020	.021	.021	.022	.023	0.52	0.54	0.55	0.57	0.58	0.60	0.69	0.73	0.77	0.80
52	.015	.016	.016	.017	.018	0.40	0.41	0.42	0.44	0.45	0.46	0.53	0.56	0.59	0.62
50	+0.011	+0.011	+0.011	+0.012	+0.012	+0.28	+0.29	+0.29	+0.30	+0.31	+0.32	+0.37	+0.39	+0.41	+0.43
48	.006	.006	.006	.007	.007	0.15	0.16	0.16	0.17	0.17	0.18	0.20	0.21	0.23	0.24
46	+0.001	+0.001	+0.001	+0.001	+0.001	+0.03	+0.03	+0.03	+0.03	+0.03	+0.03	+0.04	+0.04	+0.04	+0.04
45	-.001	-.001	-.001	-.001	-.001	-.003	-.003	-.004	-.004	-.004	-.004	-.004	-.005	-.005	-.005
44	.004	.004	.004	.004	.004	0.10	0.10	0.10	0.11	0.11	0.11	0.13	0.13	0.14	0.15
42	.008	.009	.009	.009	.010	0.22	0.23	0.23	0.24	0.25	0.25	0.29	0.31	0.33	0.34
40	-.013	-.014	-.014	-.015	-.015	-.035	-.036	-.037	-.038	-.039	-.040	-.046	-.048	-.051	-.053
38	.018	.019	.019	.020	.021	0.47	0.48	0.50	0.51	0.52	0.54	0.62	0.65	0.69	0.72
36	.022	.023	.024	.025	.026	0.59	0.61	0.62	0.64	0.66	0.67	0.78	0.82	0.86	0.91
34	.027	.028	.029	.030	.031	0.71	0.73	0.75	0.77	0.79	0.81	0.93	0.99	1.04	1.09
32	.031	.033	.034	.035	.036	0.82	0.84	0.87	0.89	0.92	0.94	1.08	1.14	1.20	1.27
30	-.036	-.037	-.038	-.040	-.041	-.093	-.096	-.098	-.101	-.104	-.107	-.123	-.130	-.137	-.144
28	.040	.041	.043	.044	.046	1.04	1.07	1.10	1.13	1.16	1.19	1.37	1.45	1.52	1.60
26	.043	.045	.047	.048	.050	1.14	1.17	1.20	1.24	1.27	1.30	1.50	1.59	1.67	1.75
24	.047	.049	.051	.053	.054	1.23	1.27	1.30	1.34	1.38	1.41	1.63	1.72	1.81	1.90
22	.051	.052	.054	.056	.058	1.32	1.36	1.40	1.44	1.48	1.52	1.75	1.85	1.94	2.04
20	-.054	-.056	-.058	-.060	-.062	-.141	-.145	-.149	-.153	-.157	-.161	-.186	-.196	-.207	-.217
18	.057	.059	.061	.063	.065	1.48	1.53	1.57	1.61	1.66	1.70	1.96	2.07	2.18	2.29
16	.059	.062	.064	.066	.068	1.55	1.60	1.64	1.69	1.73	1.78	2.05	2.17	2.28	2.40
14	.062	.064	.066	.069	.071	1.61	1.66	1.71	1.76	1.80	1.85	2.14	2.26	2.37	2.49
12	.064	.066	.069	.071	.074	1.67	1.72	1.77	1.82	1.87	1.91	2.21	2.33	2.45	2.58
10	-.066	-.068	-.071	-.073	-.076	-.172	-.177	-.182	-.187	-.192	-.197	-.227	-.240	-.252	-.265
8	.067	.070	.072	.075	.077	1.75	1.81	1.86	1.91	1.96	2.01	2.32	2.45	2.58	2.71
6	.068	.071	.073	.076	.079	1.78	1.84	1.89	1.94	1.99	2.05	2.36	2.49	2.62	2.76
4	.069	.072	.074	.077	.080	1.81	1.86	1.91	1.97	2.02	2.07	2.39	2.52	2.66	2.79
2	.070	.072	.075	.078	.080	1.82	1.87	1.93	1.98	2.03	2.09	2.41	2.54	2.67	2.81
0	-.070	-.072	-.075	-.078	-.080	-.182	-.188	-.193	-.198	-.204	-.209	-.241	-.255	-.268	-.282

Tables 1 thru 3 are condensed from the "Smithsonian Meteorological Tables", Sixth Revised Edition 1949, Fifth Reprint 1971; and are corrected for consistency with the recommendations contained in the "International Meteorological Tables", World Meteorological Organization, 1966, with amendments thru July 1973.

CARE OF THE BAROMETER

The barometer should not be subjected to quick or sudden movements, nor should its position be shifted suddenly. All changes of position should be made slowly and steadily.

Do not handle or carry the barometer about in an upright position. Observe the directions for preparing the barometer for shipment, and transport the instrument in the horizontal position, with the mercury resting against the top of the glass tube.

Do not force or strain the adjusting screw.

The barometer should be handled as little as possible. It should be protected from the entrance of air, dust, moisture, etc.

If the mercury appears dull or tarnished, it is an indication that the mercury has become contaminated in some way. It frequently occurs that air, dirt, and moisture are admitted into the barometer tube. In such event the instrument will no longer give accurate readings. For proper cleaning of the tube and refilling with pure mercury, the instrument should be sent to the factory.

DIRECTIONS FOR CLEANING A BAROMETER RESERVOIR

Occasionally, mercury in a Fortin barometer reservoir becomes dusty or oxidized. If the mercury in the barometer tube is still nice and clean, it is sometimes possible, by exercising extreme care, to clean the mercury in the reservoir without the necessity of returning the barometer to the factory for repair. Use the following procedure:

1. Take and record several comparative readings with another barometer.
2. Provide two dry, clean cups or glasses. Avoid the use of damp, unclean or metal cups. Provide some clean cloths, tissue paper for cleaning the glass cistern and a few pieces of clean, white paper, 4" by 6" for use in filtering the mercury. A most convenient position for cleaning a barometer is to be seated in front of a desk, with a drawer at top and side partly open. This affords convenient corners in which the barometer can be rested in an upright position during the process. If the floor is very slippery, provide something to stand the barometer on so that it will not slip and fall down.
3. Screw up the adjusting screw until the mercury level rises to near the top of the barometer tube. Remove the barometer from its panel and invert it slowly to a position with the reservoir end up.
4. Without changing the position of the adjusting screw, unscrew the reservoir cover and remove it from the barometer. You will then see the kidskin reservoir and the two plastic cistern parts.
5. With the barometer in this inverted position with the reservoir end up, reach in and pull out the small wood button which is in the middle of the kidskin reservoir. Pull this straight up to release any mercury which may be trapped in it.
6. Unscrew the one portion of the plastic cistern. The other part is full of mercury.
7. Pour the mercury from the cistern into a clean porcelain cup. Do this slowly and steadily. Do not shake or jar the barometer. The important thing is not to lose any mercury from the barometer tube. It is not necessary to get the last drop out of the cistern. In pouring the mercury out, do not elevate the barometer to more than a 45° position because the pressure of atmosphere would not hold the mercury in the barometer tube and some mercury would be lost.
8. Support the barometer in its inverted position against a desk drawer and remove the three cistern screws which hold together the two metal parts of the cistern on both sides of the glass cylinder.
9. Remove the glass cylinder of the barometer reservoir and catch the last few drops of mercury which may be left in it.
10. Clean the glass cylinder with cloth or tissue paper. If necessary, use soap and water but be careful to dry it well before reassembling it.
11. Be careful to preserve the washers which are on each end of the glass cylinder. If these become torn or badly creased, they can be replaced with new ones.
12. Reassemble the cistern, replacing first one washer, then the glass cylinder. Next, place the one plastic cistern part in the metal part of the cistern and attach it to the glass cylinder with a washer between the glass cylinder and the plastic flange. This should all be held together with the three cistern screws. Do not tighten them one at a time. Place them together loosely at first and make sure the glass cylinder is seating properly between the two washers. Then tighten all three screws a little at a time so that the pressure around the glass cylinder is equally distributed.

13. Clean the mercury by pouring it through a paper funnel. The paper funnel is made by using a piece of 4 by 6" white paper. It is coned into a funnel shape with only a small pin hole for an opening. The mercury will run through the pin hole and the dust or oxidized mercury will adhere to the paper. One or two pourings, using fresh paper each time, will usually restore the mercury to a nice clean, bright condition.
14. Pour the mercury back into the lower part of the barometer cistern. If a few drops of mercury have been lost, it will not affect the accuracy of the barometer because the zero point is adjusted before each reading is taken.
15. Screw on the half of the plastic cistern which contains the chamois bag.
16. Push the wood button back into the middle of the plastic cistern.
17. Replace the cistern cover, being careful to get the adjusting screw in the middle of the wood button.
18. Invert the barometer slowly to an upright position. Replace it on the barometer panel and lower the mercury until the level of mercury in the cistern coincides with the ivory point. The barometer is then in condition to be used again.

READING THE BAROMETER

Before reading the barometer be sure it is mounted securely in a vertical position. The most reliable readings are obtained when the temperature has not changed greatly over the past four hours. When reading the barometer the reader's eye should be in the same horizontal plane as the top of the mercury meniscus and the lower edge of the vernier plate. This position can be checked by getting the eye in line with the bottom of the vernier plate and the bottom of the metal guide in back of the mercury column directly in back of the vernier plate.

Readjustment to zero should be made whenever necessary in reading the barometer; i.e., the adjusting screw at the bottom of the reservoir casing should be manipulated until the surface of the mercury exactly coincides with the tip of the ivory zero point which is visible inside the reservoir.

The height of the meniscus will be greater for a rising mercury column than for a falling column. In order to bring the meniscus to its approximate, average height, tap the barometer lightly with your fingers before taking a reading.

The reading then observed should be corrected by use of the correction tables. For explanation of the tables, refer to the following section.

CORRECTIONS TO BE APPLIED

Barometers are adjusted at the factory as nearly as possible by comparison with a certified standard. The adjustment is so made that no further correction for capillarity need be made.

The standard temperature for the metric scales is 0°C and that of English scales is 62°F. The standard temperature for the density of mercury is 0°C or 32°F. Since the scales and the mercury have different coefficients of expansion, the pressure indications will be affected by variations in temperature; therefore, in order to obtain the true pressure every reading must be corrected for temperature. The Temperature Correction tables given in this pamphlet combine the corrections for the length of the scales and the density of mercury.

Further, the pressure indication will be affected by the gravity of the place at which the reading is taken. Latitudes from 0° to 45° have a subtractive correction; latitudes from 46° to 90° have an additive correction. More precise determinations of the true pressure may be made by using the Gravity Correction tables in conjunction with the observed readings corrected for temperature.

METRIC EXAMPLE: If the barometer reads 760.0 mm at 22.5°C, the temperature correction (interpolating in Table 2 between 22 and 23°C) is -2.78 mm, yielding a temperature corrected reading of 757.22 mm. At 40° latitude Table 3 gives a gravity correction of -0.39 mm, so that the true pressure rounded off to a tenth of a millimetre would be 756.8 mm.

ENGLISH EXAMPLE: If the barometer reads 30.00" at a temperature of 71°F, the temperature correction (interpolating in Table 1 between 70 and 72°F) is -.115", yielding a temperature corrected reading of 29.885". At 40° latitude Table 3 gives a gravity correction of -.015", so that the true pressure rounded off to a hundredth of an inch would be 29.87".

A barometer with a bore of 0.25" diameter is suitable for readings to 0.2 mm or 0.01". A barometer with a bore of 0.5" is suitable for readings of 0.05 mm or 0.002".

If it is desired to convert a metric reading to an English reading, or vice versa, always apply the temperature and gravity corrections before making the conversion.

To get a true barometer indication at the place of observation it is not necessary to correct for altitude. However, if you wish to correct to sea level pressure for comparison with National Weather Service values, a sea level differential (approximately 0.027 mm or 0.001" per foot of elevation) would have to be added to the barometric pressure at your altitude.

NOTICE

BAROMETER SHIPPING DAMAGE

Due to possible rough handling or temperature changes, a small quantity of mercury may be forced through the cistern seals of this barometer during shipment. This small mercury loss does not normally indicate that air has gotten into the barometer tube and, therefore, will not normally affect the reading of the barometer. The small change in the quantity of mercury is automatically compensated for by the cistern adjusting screw, when the mercury level is set to the ivory point prior to each reading.

However, if air has gotten into the barometer tube or if there is obvious shipping damage, the carrier should be notified at once so that their inspector may examine the instrument and the manner in which it was packed and labeled.

Air in the barometer tube will necessitate return of the barometer to the factory for repair, including replacement of the barometer tube with a new vacuum filled and degassed barometer tube.

CHECKING FOR AIR IN THE BAROMETER TUBE

You may check for air in the barometer tube in three ways.

(1) Examine the barometer tube for air bubbles which may have adhered to the walls.

(2) With the barometer in the upright position and the cistern screw adjusted so that mercury fills the cistern but does not come to the top of the small diameter barometer tube, slowly tilt the barometer until the mercury strikes the top of the barometer tube (about 30° off the vertical). A sharp click indicates a good vacuum, a dull thud indicates a poor vacuum.

(3) Compare the barometer with another mercurial barometer known to be accurate. The barometers must be side by side for accurate comparison, in which case no temperature, gravity or altitude corrections need to be applied.

COMPARISON WITH REPORTED BAROMETRIC PRESSURE

The weather services always report barometric pressure adjusted to sea level. When reconciling your barometer with reported sea level barometric pressure, allowance must be made for the substantial decrease of pressure from sea level to your elevation (approximately 0.027 millimetres or 0.001 inches per foot of elevation). Your barometer reads more accurately than the pressure that can be obtained by this method. The scales of your barometer were adjusted at the factory for the life of the instrument and should not be tampered with.

APPENDIX C
GENERAL INFORMATION

Conversion Chart

Length

1 centimeter	0.394 inch
1 inch	2.540 centimeters
1 meter	3.2808 feet
1 foot	0.305 meter
1 meter	1.0936 yards
1 yard	0.9144 meter
1 kilometer	0.62137 mile
1 mile	1.60935 kilometers

Area

1 square centimeter	0.1550 square inch
1 square inch	6.452 square centimeters
1 square meter	10.764 square feet
1 square foot	0.09290 square meter
1 square meter	1.1960 square yards
1 square yard	0.8361 square meter
1 square kilometer	0.3861 square mile
1 square mile	2.590 square kilometers
1 acre (U.S.)	4840 square yards

Volume

1 cubic centimeter	0.0610 cubic inch
1 cubic inch	16.3872 cubic centimeters
1 cubic meter	35.314 cubic feet
1 cubic foot	0.02832 cubic meter
1 cubic meter	1.3079 cubic yards
1 cubic yard	0.7646 cubic meter

Capacity

1 milliliter	0.03382 ounce (U.S. liquid)
1 ounce (U.S. liquid)	29.573 milliliters
1 milliliter	0.2705 dram (U.S. Apothecaries)
1 dram (U.S. Apothecaries)	3.6967 milliliters
1 liter	1.05671 quarts (U.S. liquid)
1 quart (U.S. liquid)	0.94633 liter
1 liter	0.26418 gallon (U.S. liquid)
1 gallon (U.S. liquid)	3.78533 liters

Mass

1 gram	15.4324 grains
1 grain	0.0648 gram
1 gram	0.03527 ounce (Avoirdupois)
1 ounce (Avoirdupois)	28.3495 grams
1 gram	0.03215 ounce (Troy)
1 ounce (Troy)	31.10348 grams
1 kilogram	2.20462 pounds (Avoirdupois)
1 pound (Avoirdupois)	0.45359 kilogram

Power

1 watt	0.73756 foot pound per second
1 foot pound per second	1.35582 watts
1 watt	0.056884 BTU per minute
1 BTU per minute	17.850 watts
1 watt	0.001341 horsepower (U.S.)
1 horsepower (U.S.)	745.7 watts
1 watt	0.01433 kilogram-calorie per minute
1 kilogram-calorie per minute	69.767 watts
1 watt	1×10^7 ergs per second
1 lumen	0.001496 watt

PERIODIC TABLE OF THE ELEMENTS

1a	2a	3b	4b	5b	6b	7b	8	1b	2b	3a	4a	5a	6a	7a	0	Orbit		
1 H 1.00797 +1 -1		<div>Atomic Number → 50 Symbol → Sn Atomic Weight → 118.69</div> <div>← Oxidation States KEY TO CHART ← Electron Configuration</div>														2 He 4.0026 0	K	
3 Li 6.939 +1 2-1	4 Be 9.0122 +2 2-2	Transition Elements										5 B 10.811 +3 2-3	6 C 12.01115 +2 2-4	7 N 14.0067 +1 2-5	8 O 15.9994 -2 2-6	9 F 18.9984 -1 2-7	10 Ne 20.183 0 2-8	K-L
11 Na 22.9898 +1 2-8-1	12 Mg 24.312 +2 2-8-2	Group 8										13 Al 26.9815 +3 2-8-3	14 Si 28.086 +4 2-8-4	15 P 30.9738 +3 2-8-5	16 S 32.064 +4 2-8-6	17 Cl 35.453 +1 2-8-7	18 Ar 39.948 0 2-8-8	K-L-M
19 K 39.102 +1 -8-8-1	20 Ca 40.08 +2 -8-8-2	21 Sc 44.956 +3 -8-9-2	22 Ti 47.90 +4 -8-10-2	23 V 50.942 +5 -8-11-2	24 Cr 51.996 +6 -8-13-1	25 Mn 54.9380 +7 -8-13-2	26 Fe 55.847 +2 -8-14-2	27 Co 58.9332 +3 -8-15-2	28 Ni 58.71 +2 -8-16-2	29 Cu 63.546 +1 -8-18-1	30 Zn 65.37 +2 -8-18-2	31 Ga 69.72 +3 -8-18-3	32 Ge 72.59 +4 -8-18-4	33 As 74.9216 +3 -8-18-5	34 Se 78.96 +4 -8-18-6	35 Br 79.904 +1 -8-18-7	36 Kr 83.80 0 -8-18-8	-L-M-N
37 Rb 85.47 +1 -18-8-1	38 Sr 87.62 +2 -18-8-2	39 Y 88.905 +3 -18-9-2	40 Zr 91.22 +4 -18-10-2	41 Nb 92.906 +5 -18-12-1	42 Mo 95.94 +6 -18-13-1	43 Tc (97) +7 -18-13-2	44 Ru 101.07 +8 -18-15-1	45 Rh 102.905 +3 -18-16-1	46 Pd 106.4 +4 -18-18-0	47 Ag 107.865 +1 -18-18-1	48 Cd 112.40 +2 -18-18-2	49 In 114.82 +3 -18-18-3	50 Sn 118.69 +4 -18-18-4	51 Sb 121.75 +3 -18-18-5	52 Te 127.60 +4 -18-18-6	53 I 126.9044 +1 -18-18-7	54 Xe 131.30 0 -18-18-8	-M-N-O
55 Cs 132.905 +1 -18-8-1	56 Ba 137.34 +2 -18-8-2	57* La 138.91 +3 -18-9-2	72 Hf 178.49 +4 -32-10-2	73 Ta 180.948 +5 -32-11-2	74 W 183.85 +6 -32-12-2	75 Re 186.2 +7 -32-13-2	76 Os 190.2 +8 -32-14-2	77 Ir 192.2 +3 -32-15-2	78 Pt 195.09 +4 -32-16-2	79 Au 196.967 +1 -32-18-1	80 Hg 200.59 +2 -32-18-2	81 Tl 204.37 +3 -32-18-3	82 Pb 207.19 +4 -32-18-4	83 Bi 208.980 +3 -32-18-5	84 Po (210) +4 -32-18-6	85 At (209) +1 -32-18-7	86 Rn (222) 0 -32-18-8	-N-O-P
87 Fr (223) +1 -18-8-1	88 Ra (226) +2 -18-8-2	89** Ac (227) +3 -18-9-2																-O-P-Q

*Lanthanides	58 Ce 140.12 +3 -19-9-2	59 Pr 140.907 +3 -20-9-2	60 Nd 144.24 +3 -22-8-2	61 Pm (145) +3 -23-8-2	62 Sm 150.35 +3 -24-8-2	63 Eu 151.96 +3 -25-8-2	64 Gd 157.25 +3 -25-9-2	65 Tb 158.924 +3 -26-9-2	66 Dy 162.50 +3 -28-8-2	67 Ho 164.930 +3 -29-8-2	68 Er 167.26 +3 -30-8-2	69 Tm 168.934 +3 -31-8-2	70 Yb 173.04 +3 -32-8-2	71 Lu 174.97 +3 -32-9-2	-N-O-P
**Actinides	90 Th 232.038 +4 -19-9-2	91 Pa (231) +5 -20-9-2	92 U 238.03 +3 -21-9-2	93 Np (237) +3 -22-9-2	94 Pu (244) +4 -23-9-2	95 Am (243) +3 -24-9-2	96 Cm (247) +3 -25-9-2	97 Bk (247) +3 -26-9-2	98 Cf (251) +3 -28-8-2	99 Es (254) +3 -29-8-2	100 Fm (257) +3 -30-8-2	101 Md (256) +3 -31-8-2	102 Lw (254) +3 -32-8-2	103 Lw +3 -32-8-2	-O-P-Q

Numbers in parentheses are mass numbers of most stable isotope of that element.

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INSTALLATION OF MASTERFLEX® STANDARD PUMP HEAD AND TUBING

Align either of the two interchangeable halves of the pump head with the two pins protruding from the face of the drive unit. Attach in position with the two fillister head screws provided, placing the screws through the two diagonally opposed recessed holes. Install the longer end of the rotor assembly shaft through the pump head bearing and fully mate the shaft cross slot with the drive unit shear pin by rotating the shaft while exerting gentle pressure inwards; mating will be indicated by complete seating of the rotor assembly within the head. Rotate the rotor assembly to position one of the rollers between the tubing inlet and outlet recesses molded into the head.

While maintaining the position of one of the rotor assembly rollers between the tubing recesses, position the tubing about the other two rollers and press the tubing downwards with the thumbs until the tubing is fully seated within the pump head cavity and rollers. On large diameter tubing and tubings of higher Shore durometer ratings a tongue depressor or similar object may be used to assist full seating of the tubing. **CAUTION:** Use of hard or sharp objects such as screwdrivers may damage both the tubing and the pump head.

When the tubing has been fully seated within the pump head cavity and the two rollers, hold the free ends of the tubing in the head inlet and outlet recesses and, while exerting a slight tension on the tubing ends, place the remaining half of the pump head over the rotor assembly shaft and against the installed pump head half. **CAUTION:** Failure to hold slight tension on the tubing may result in excess tubing slack within the pump head that may cause binding and shearing of the drive unit shear pin.

While pressing gently inward on the outer pump head half, rotate the rotor assembly shaft with a screwdriver to ensure that the rotor assembly is fully seated with the drive unit shaft, that no gap remains between the interfaces of the two pump head halves, and that there is no binding between the tubing and the rollers of the rotor assembly. **CAUTION:** Failure to ensure this proper seating before operating the pump may result in damage to both the drive unit gearing and shear pin.

Using the two thumbscrews and flat washers provided, insert these attaching parts in the two mounting holes not occupied by the initially installed screws and, using finger pressure only, attach the assembled pump head to the drive unit. **CAUTION:** Excessive torque on any of the four screws may cause distortion and cracking of the pump head.

The pump head is now properly installed and ready for operation. If a subsequent change of tubing is desired, complete removal of the pump head is not necessary. Merely remove the two thumbscrews, washers, outer pump head half and tubing, and repeat steps one through five.

1. A tongue depressor or similar object may be used to assist in full seating of tubing within the pump head; however, hard or sharp objects such as a screwdriver should not be used.
2. When installing the pump heads on some gear head drive units, rotation of the rotor assembly is not possible with rotor shaft engaged to drive. In these cases, either (1) follow the procedure outlined in Step 2 of the Standard head installation instructions or (2) install the tubing as described in Step 3 of the Add-On instructions before placing the pump head on the mounting studs.