

Method 375.2, Revision 2.0: Determination of Sulfate by Automated Colorimetry

METHOD 375.2

DETERMINATION OF SULFATE BY AUTOMATED COLORIMETRY

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METHOD 375.2

375.2-1

DETERMINATION OF SULFATE IN WATER BY AUTOMATED COLORIMETRY

1.0 SCOPE AND APPLICATION

- 1.1 This automated method is applicable to drinking, ground and surface water, domestic and industrial wastes.
- 1.2 The applicable range is 3-300 mg SO₄/L. The sensitivity of the method can be increased by a minor modification to analyze samples in the range of 0.5-30 mg SO₄/L. Approximately 30 samples per hour can be analyzed.

2.0 SUMMARY OF METHOD

- 2.1 The sample is first passed through a sodium form cation-exchange column to remove multivalent metal ions. The sample containing sulfate is then reacted with an alcohol solution of barium chloride and methylthymol blue (MTB) at a pH of 2.5-3.0 to form barium sulfate. The combined solution is raised to a pH of 12.5-13.0 so that excess barium reacts with MTB. The uncomplexed MTB color is gray; if it is all chelated with barium, the color is blue. Initially, the barium and MTB are equimolar and equivalent to 300 mg SO₄/L; thus the amount of uncomplexed MTB is equal to the sulfate present.
- 2.2 Reduced volume versions of this method that use the same reagents and molar ratios are acceptable provided they meet the quality control and performance requirements stated in the method.
- 2.3 Limited performance-based method modifications may be acceptable provided they are fully documented and meet or exceed requirements expressed in Section 9.0, Quality Control.

3.0 DEFINITIONS

- 3.1 **Calibration Blank (CB)** -- A volume of reagent water fortified with the same matrix as the calibration standards, but without the analytes, internal standards, or surrogate analytes.
- 3.2 **Calibration Standard (CAL)** -- A solution prepared from the primary dilution standard solution or stock standard solutions and the internal standards and surrogate analytes. The CAL solutions are used to calibrate the instrument response with respect to analyte concentration.
- 3.3 **Instrument Performance Check Solution (IPC)** -- A solution of one or more method analytes, surrogates, internal standards, or other test substances used to evaluate the performance of the instrument system with respect to a defined set of criteria.

- 3.4 **Laboratory Fortified Blank (LFB)** -- An aliquot of reagent water or other blank matrices to which known quantities of the method analytes are added in the laboratory. The LFB is analyzed exactly like a sample, and its purpose is to determine whether the methodology is in control, and whether the laboratory is capable of making accurate and precise measurements.
- 3.5 **Laboratory Fortified Sample Matrix (LFM)** -- An aliquot of an environmental sample to which known quantities of the method analytes are added in the laboratory. The LFM is analyzed exactly like a sample, and its purpose is to determine whether the sample matrix contributes bias to the analytical results. The background concentrations of the analytes in the sample matrix must be determined in a separate aliquot and the measured values in the LFM corrected for background concentrations.
- 3.6 **Laboratory Reagent Blank (LRB)** -- An aliquot of reagent water or other blank matrices that are treated exactly as a sample including exposure to all glassware, equipment, solvents, reagents, internal standards, and surrogates that are used with other samples. The LRB is used to determine if method analytes or other interferences are present in the laboratory environment, the reagents, or the apparatus.
- 3.7 **Linear Calibration Range (LCR)** -- The concentration range over which the instrument response is linear.
- 3.8 **Material Safety Data Sheet (MSDS)** -- Written information provided by vendors concerning a chemical's toxicity, health hazards, physical properties, fire, and reactivity data including storage, spill, and handling precautions.
- 3.9 **Method Detection Limit (MDL)** -- The minimum concentration of an analyte that can be identified, measured and reported with 99% confidence that the analyte concentration is greater than zero.
- 3.10 **Quality Control Sample (QCS)** -- A solution of method analytes of known concentrations that is used to fortify an aliquot of LRB or sample matrix. The QCS is obtained from a source external to the laboratory and different from the source of calibration standards. It is used to check laboratory performance with externally prepared test materials.
- 3.11 **Stock Standard Solution (SSS)** -- A concentrated solution containing one or more method analytes prepared in the laboratory using assayed reference materials or purchased from a reputable commercial source.

4.0 **INTERFERENCES**

- 4.1 The ion exchange column eliminates interferences from multivalent cations. A mid-scale sulfate standard containing Ca^{++} should be analyzed periodically to insure that the column is functioning properly.

- 4.2 Samples with pH below 2 should be neutralized because high acid concentrations elute cations from the ion exchange resin.
- 4.3 Turbid samples should be filtered or centrifuged.
- 4.4 Method interferences may be caused by contaminants in the reagent water, reagents, glassware, and other sample processing apparatus that bias analyte response.

5.0 SAFETY

- 5.1 The toxicity or carcinogenicity of each reagent used in this method have not been fully established. Each chemical should be regarded as a potential health hazard and exposure should be as low as reasonably achievable. Cautions are included for known extremely hazardous materials or procedures.
- 5.2 Each laboratory is responsible for maintaining a current awareness file of OSHA regulations regarding the safe handling of the chemicals specified in this method. A reference file of Material Safety Data Sheets (MSDS) should be made available to all personnel involved in the chemical analysis. The preparation of a formal safety plan is also advisable.
- 5.3 The following chemicals have the potential to be highly toxic or hazardous, consult MSDS.
 - 5.3.1 Barium chloride (Section 7.2)
 - 5.3.2 Hydrochloric acid (Section 7.3)

6.0 EQUIPMENT AND SUPPLIES

- 6.1 Balance -- Analytical, capable of accurately weighing to the nearest 0.0001 g.
- 6.2 Glassware -- Class A volumetric flasks and pipets as required.
- 6.3 Automated continuous flow analysis equipment designed to deliver and react sample and reagents in the required order and ratios.
 - 6.3.1 Sampling device (sampler)
 - 6.3.2 Multichannel pump
 - 6.3.3 Reaction unit or manifold
 - 6.3.4 Colorimetric detector
 - 6.3.5 Data recording device

7.0 REAGENTS AND STANDARDS

- 7.1 Reagent water: Distilled or deionized water, free of the analyte of interest. ASTM Type II or equivalent.
- 7.2 Barium chloride: Dissolve 0.7630 g of barium chloride dihydrate ($\text{BaCl}_2 \cdot 2\text{H}_2\text{O}$) (CASRN 10326-27-9) in 250 mL of reagent water and dilute to 500 mL.
- 7.3 Methylthymol blue: Dissolve 0.1182 g of methylthymol blue (3'3-bis-N,N-bis(carboxymethyl)-amino methylthymolsulfone-phthalein pentasodium salt) (CASRN 1945-77-3) in 25 mL of barium chloride solution (Section 7.2). Add 4 mL of 1.0 N hydrochloric acid (CASRN 7647-01-0) which changes the color to bright orange. Add 71 mL of reagent water and dilute to 500 mL with ethanol. The pH of this solution is 2.6. This reagent should be prepared the day before and stored in a brown plastic bottle in the refrigerator.
- 7.4 Buffer, pH 10.5 ± 0.5 : Dissolve 6.75 g of ammonium chloride (CASRN 12125-02-9) in 500 mL of reagent water. Add 57 mL of concentrated ammonium hydroxide (CASRN 1336-21-6) and dilute to 1 L with distilled water.
- 7.5 Buffered EDTA: Dissolve 20 g of tetrasodium EDTA (CASRN 64-02-8) in pH 10.5 buffer (Section 7.4), and dilute to 500 mL with buffer.
- 7.6 Sodium hydroxide solution (50%): Dissolve 250 g NaOH (CASRN 131073-2) in 300 mL of reagent water, cool, and dilute to 500 mL.
- 7.7 Sodium hydroxide, 0.18 N: Dilute 7.2 mL of sodium hydroxide solution (Section 7.6) to 500 mL.
- 7.8 Ion exchange resin: Bio-Rex 70, 20-50 mesh, sodium form, Bio-Rad Laboratories, Richmond, California. Free from fines by stirring with several portions of reagent water and decant the supernate before settling is complete.
- 7.9 Dilution Water: Add 0.75 mL of sulfate stock solution (Section 7.10) and three drops of Brij-35 (CASRN 9002-92-0) to 2 L of reagent water.
- 7.10 Sulfate stock solution, 1 mL = 1 mg SO_4 : Dissolve 1.479 g of dried (105°C) Na_2SO_4 (CASRN 7757-82-6) in reagent water and dilute to 1 L.
- 7.11 Dilute sulfate solution, 1 mL = 0.1 mg SO_4 : Dilute 50 mL of sulfate stock solution (Section 7.10) to 500 mL with reagent water.

8.0 SAMPLE COLLECTION, PRESERVATION AND STORAGE

- 8.1 Samples should be collected in plastic or glass bottles. All bottles must be thoroughly cleansed and rinsed with reagent water. Volume collected should be sufficient to insure a representative sample, allow for replicate analysis (if required), and minimize waste disposal.

- 8.2 No chemical preservation required. Cool sample to 4°C.
- 8.3 Samples should be analyzed as soon as possible after collection. If storage is required, samples maintained at 4°C may be held for up to 28 days.

9.0 QUALITY CONTROL

9.1 Each laboratory using this method is required to operate a formal quality control (QC) program. The minimum requirements of this program consist of an initial demonstration of laboratory capability, and the periodic analysis of laboratory reagent blanks, fortified blanks and other laboratory solutions as a continuing check on performance. The laboratory is required to maintain performance records that define the quality of the data that are generated.

9.2 INITIAL DEMONSTRATION OF PERFORMANCE

9.2.1 The initial demonstration of performance is used to characterize instrument performance (determination of LCRs and analysis of QCS) and laboratory performance (determination of MDLs) prior to performing analyses by this method.

9.2.2 Linear Calibration Range (LCR) -- The LCR must be determined initially and verified every six months or whenever a significant change in instrument response is observed or expected. The initial demonstration of linearity must use sufficient standards to insure that the resulting curve is linear. The verification of linearity must use a minimum of a blank and three standards. If any verification data exceeds the initial values by $\pm 10\%$, linearity must be reestablished. If any portion of the range is shown to be nonlinear, sufficient standards must be used to clearly define the nonlinear portion.

9.2.3 Quality Control Sample (QCS) -- When beginning the use of this method, on a quarterly basis or as required to meet data-quality needs, verify the calibration standards and acceptable instrument performance with the preparation and analyses of a QCS. If the determined concentrations are not within $\pm 10\%$ of the stated values, performance of the determinative step of the method is unacceptable. The source of the problem must be identified and corrected before either proceeding with the initial determination of MDLs or continuing with on-going analyses.

9.2.4 Method Detection Limit (MDL) -- MDLs must be established for all analytes, using reagent water (blank) fortified at a concentration of two to three times the estimated instrument detection limit.⁽³⁾ To determine MDL values, take seven replicate aliquots of the fortified reagent water and process through the entire analytical method. Perform all calculations defined in the method and report the concentration values in the appropriate units. Calculate the MDL as follows:

$$\text{MDL} = (t) \times (S)$$

where, t = Student's t value for a 99% confidence level and a standard deviation estimate with $n-1$ degrees of freedom [$t = 3.14$ for seven replicates]
 S = standard deviation of the replicate analyses

MDLs should be determined every six months, when a new operator begins work, or whenever there is a significant change in the background or instrument response.

9.3 ASSESSING LABORATORY PERFORMANCE

- 9.3.1 Laboratory Reagent Blank (LRB) -- The laboratory must analyze at least one LRB with each batch of samples. Data produced are used to assess contamination from the laboratory environment. Values that exceed the MDL indicate laboratory or reagent contamination should be suspected and corrective actions must be taken before continuing the analysis.
- 9.3.2 Laboratory Fortified Blank (LFB) -- The laboratory must analyze at least one IFB with each batch of samples. Calculate accuracy as percent recovery (Section 9.4.2). If the recovery of any analyte falls outside the required control limits of 90-110%, that analyte is judged out of control, and the source of the problem should be identified and resolved before continuing analyses.
- 9.3.3 The laboratory must use LFB analyses data to assess laboratory performance against the required control limits of 90-110%. When sufficient internal performance data become available (usually a minimum of 20-30 analyses), optional control limits can be developed from the percent mean recovery (\bar{x}) and the standard deviation (S) of the mean recovery. These data can be used to establish the upper and lower control limits as follows:

$$\begin{aligned}\text{UPPER CONTROL LIMIT} &= \bar{x} + 3S \\ \text{LOWER CONTROL LIMIT} &= \bar{x} - 3S\end{aligned}$$

The optional control limits must be equal to or better than the required control limits of 90-110%. After each five to 10 new recovery measurements, new control limits can be calculated using only the most recent 20-30 data points. Also, the standard deviation (S) data should be used to establish an on-going precision statement for the level of concentrations included in the LFB. These data must be kept on file and be available for review.

9.3.4 Instrument Performance Check Solution (IPC) -- For all determinations the laboratory must analyze the IPC (a mid-range check standard) and a calibration blank immediately following daily calibration, after every tenth sample (or more frequently, if required) and at the end of the sample run. Analysis of the IPC solution and calibration blank immediately following calibration must verify that the instrument is within $\pm 10\%$ of calibration. Subsequent analyses of the IPC solution must verify the calibration is still within $\pm 10\%$. If the calibration cannot be verified within the specified limits, reanalyze the IPC solution. If the second analysis of the IPC solution confirms calibration to be outside the limits, sample analysis must be discontinued, the cause determined and/or in the case of drift the instrument recalibrated. All samples following the last acceptable IPC solution must be reanalyzed. The analysis data of the calibration blank and IPC solution must be kept on file with the sample analyses data.

9.4 ASSESSING ANALYTE RECOVERY AND DATA QUALITY

9.4.1 Laboratory Fortified Sample Matrix (LFM) -- The laboratory must add a known amount of analyte to a minimum of 10% of the routine samples. In each case, the LFM aliquot must be a duplicate of the aliquot used for sample analysis. The analyte concentration must be high enough to be detected above the original sample and should not be less than four times the MDL. The added analyte concentration should be the same as that used in the laboratory fortified blank.

9.4.2 Calculate the percent recovery for each analyte, corrected for concentrations measured in the unfortified sample, and compare these values to the designated LFM recovery range 90-110%. Percent recovery may be calculate using the following equation:

$$R = \frac{C_s - C}{s} \times 100$$

where, R = percent recovery

C = fortified sample concentration

C_s = sample background concentration

s = concentration equivalent of analyte added to sample

9.4.3 If the recovery of any analyte falls outside the designated LFM recovery range and the laboratory performance for that analyte is shown to be in control (Section 9.3), the recovery problem encountered with the LFM is judged to be either matrix or solution related, not system related.

9.4.4 Where reference materials are available, they should be analyzed to provide additional performance data. The analysis of reference samples

is a valuable tool for demonstrating the ability to perform the method acceptably.

10.0 CALIBRATION AND STANDARDIZATION

10.1 Set up the manifold for high (0-300 mg SO₄/L) or low (0-30 mg SQ /L) level samples as described in Figure 1.

10.1.1 High level working standards, 10-300 mg/L: As a minimum, prepare high level working standards by diluting the following volumes of stock standard (Section 7.10) to 100 mL.

<u>mL Stock</u>	<u>mg/L SO₄</u>
1	10
5	50
10	100
15	150
25	250
30	300

10.1.2 Low level working standards, 1-30 mg/L: Prepare at least this number of low level working standards by diluting the following volumes of dilute sulfate solution (Section 7.11) to 100 mL.

<u>mL Stock</u>	<u>mg/L SO₄</u>
1	1.0
5	5.0
10	10.0
15	15.0
25	25.0
30	30.0

10.2 The ion exchange column is prepared by pulling a slurry of the resin into a piece of glass tubing 7.5 inches long, 2.0 mm ID and 3.6 mm OD. This is conveniently done by using a pipet and a loose fitting glass wool plug in the tubing. Care should be taken to avoid allowing air bubbles to enter the column. If air bubbles become trapped, the column should be prepared over again. The column can exchange the equivalent of 35 mg of calcium. For the high level manifold this corresponds to about 900 samples with 200 mg/L Ca. The column should be prepared as often as necessary to assure that no more than 50% of its capacity is used up.

10.3 Allow the instrument to warm up as required. Pump all reagents until a stable baseline is achieved.

- 10.4 Analyze all working standards in duplicate at the beginning of a run to develop a standard curve. Control standards are analyzed every hour to assure that the system remains properly calibrated. Since the chemistry is non-linear, data recording devices should be adjusted accordingly.
- 10.5 Prepare standard curve by plotting instrument response against concentration values. A calibration curve may be fitted to the calibration solutions concentration/response data using computer or calculator based on regression curve fitting techniques. Acceptance or control limits should be established using the difference the measured value of the calibration solution and the "true value" concentration.
- 10.6 After the calibration has been established, it must be verified by the analysis of a suitable quality control sample (QCS). If measurements exceed a 10% of the established QCS value, the analysis should be terminated and the instrument recalibrated. The new calibration must be verified before continuing analysis. Periodic reanalysis of the QCS is recommended as a continuing calibration check.

11.0 PROCEDURE

- 11.1 Set up instrument as specified under calibration and standardization (Section 10.0).
- 11.2 Fill and connect reagent containers and start system. Allow the system to equilibrate as required. Pump all reagents until a stable baseline is achieved.
- 11.3 Place standards and samples in sampler tray. Calibrate instrument, and begin analysis.
- 11.4 At the end of each day, the system should be washed with the buffered EDTA solution (Section 7.5). This is done by placing the methylthymol blue line and the sodium hydroxide line in reagent water for a few minutes and then in the buffered EDTA solution for 10 minutes. Wash the system with reagent water for 15 minutes before shutting down.

12.0 DATA ANALYSIS AND CALCULATIONS

- 12.1 Prepare a calibration curve by plotting instrument response against standard concentration. Compute sample concentration by comparing sample response with the standard curve. Multiply answer by appropriate dilution factor.
- 12.2 Report only those values that fall between the lowest and the highest calibration standards. Samples exceeding the highest standard should be diluted and reanalyzed.
- 12.3 Report results in mg/L.

13.0 METHOD PERFORMANCE

- 13.1 In a single laboratory, the estimated standard deviation, calculated from duplicate analyses of 26 surface and wastewaters at a mean concentration of 100 mg/L was ± 1.6 mg/L.
- 13.2 The mean recovery from 24 surface and wastewaters was 102%.

14.0 POLLUTION PREVENTION

- 14.1 Pollution prevention encompasses any technique that reduces or eliminates the quantity or toxicity of waste at the point of generation. Numerous opportunities for pollution prevention exist in laboratory operation. The EPA has established a preferred hierarchy of environmental management techniques that places pollution prevention as the management option of first choice. Whenever feasible, laboratory personnel should use pollution prevention techniques to address their waste generation. When wastes cannot be feasibly reduced at the source, the Agency recommends recycling as the next best option.
- 14.2 The quantity of chemicals purchased should be based on expected usage during its shelf life and disposal cost of unused material. Actual reagent preparation volumes should reflect anticipated usage and reagent stability.
- 14.3 For information about pollution prevention that may be applicable to laboratories and research institutions, consult "Less is Better: Laboratory Chemical Management for Waste Reduction", available from the American Chemical Society's Department of Government Regulations and Science Policy, 1155 16th Street N.W., Washington, D.C. 20036, (202) 872-4477.

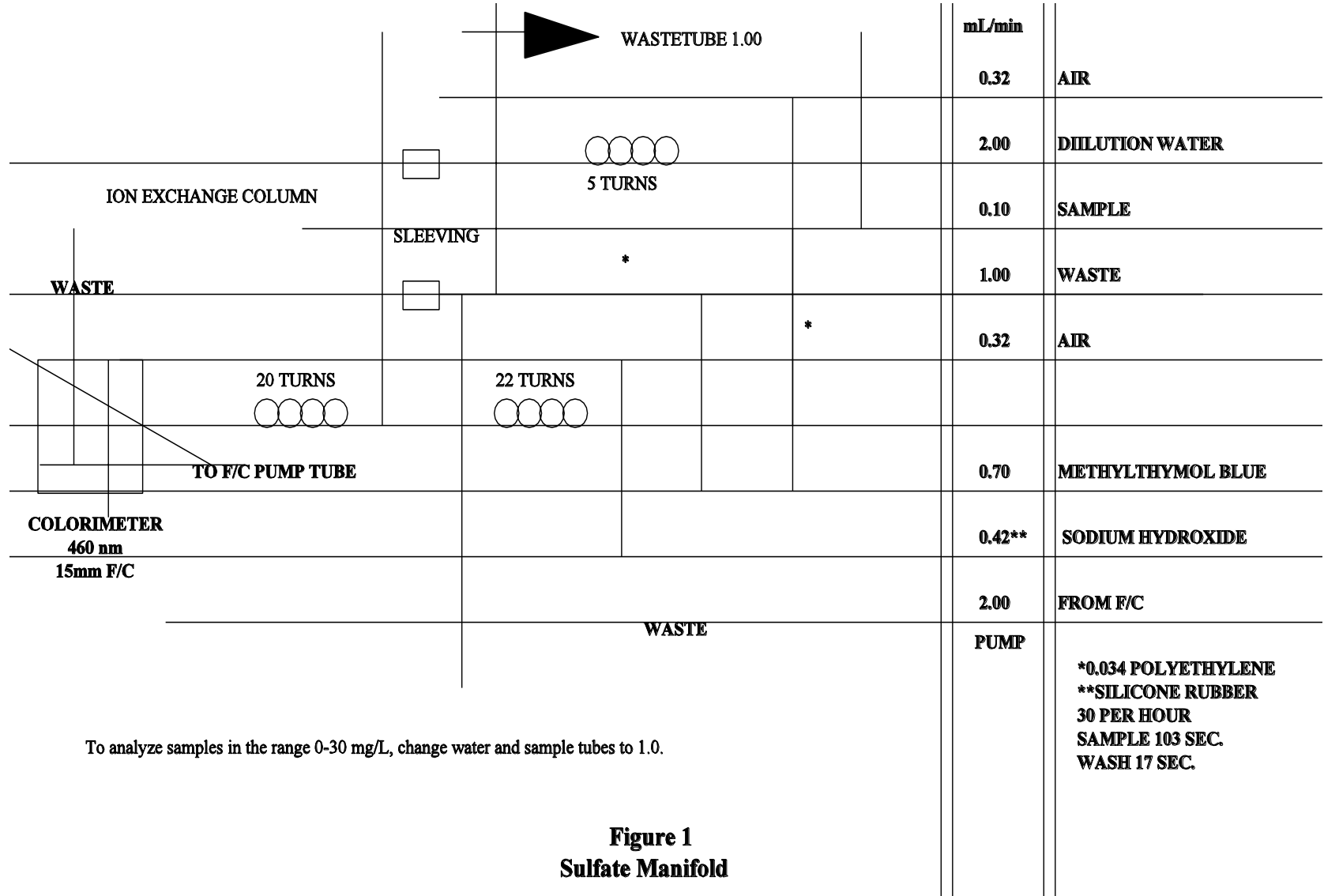
15.0 WASTE MANAGEMENT

- 15.1 The Environmental Protection Agency requires that laboratory waste management practices be conducted consistent with all applicable rules and regulations. Excess reagents and samples and method process wastes should be characterized and disposed of in an acceptable manner. The Agency urges laboratories to protect the air, water, and land by minimizing and controlling all releases from hoods and bench operations, complying with the letter and spirit of any waste discharge permit and regulations, and by complying with all solid and hazardous waste regulations, particularly the hazardous waste identification rules and land disposal restrictions. For further information on waste management consult the "Waste Management Manual for Laboratory Personnel", available from the American Chemical Society at the address listed in Section 14.3.

16.0 REFERENCES

1. Lazrus, A.L., Hill, K.C. and Lodge, J.P., "Automation in Analytical Chemistry", Technicon Symposia, 1965.
2. Coloros, E., Panesar, M.R. and Parry, F.P., "Linearizing the Calibration Curve in Determination of Sulfate by the Methylthymol Blue Method", Anal. Chem. 48, 1693 (1976).
3. Code of Federal Regulations 40, Ch. 1, Pt. 136, Appendix B.

375.2-13



To analyze samples in the range 0-30 mg/L, change water and sample tubes to 1.0.

Figure 1
Sulfate Manifold