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The Controlled Ecological Life Support System Antarctic Analog Project: Analysis of Wastewater from the South Pole Station, Antarctica—Volume 1

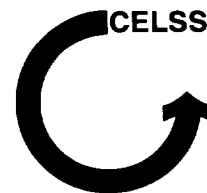
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Summary

The Controlled Ecological Life Support system (CELSS) Antarctic Analog Project (CAAP) is a joint National Science Foundation (NSF) and NASA project for the development, deployment and operation of CELSS technologies at the Amundsen-Scott South Pole Station. NASA goals are operational testing of CELSS technologies and the conduct of scientific studies to facilitate technology selection and system design. The NSF goals are that the food production, water purification, and waste treatment capabilities which will be provided by CAAP will improve the quality of life for the South Pole inhabitants, reduce logistics dependence, and minimize environmental impacts associated with human presence on the polar plateau.

This report presents an analysis of wastewater samples taken from the Amundsen-Scott South Pole Station, Antarctica. The purpose of the work is to develop a quantitative understanding of the characteristics of domestic sewage streams at the South Pole Station. This information will contribute to the design of a proposed plant growth/waste treatment system which is part of the CELSS Antarctic Analog Project (CAAP).

Wastewater samples were taken over a period of two days in January 1993. Sampling times were selected to roughly profile the daily characteristic variations in sewage production. The results of the wastewater analysis indicate that the station's sewage is extremely concentrated, a result of the effective water conservation practices employed by the inhabitants of the station. In addition to providing a detailed characterization, the analysis provides a basis from which an experimental program can be developed to examine the applicability of using South Pole Station sewage to supply water to a plant growth chamber's hydroponics system and the eventual use of water generated from plant transpiration to supplement the station's water supply.

Introduction

This report presents an analysis of wastewater samples taken from the United States Antarctic Program (USAP)

Amundsen-Scott South Pole Station, Antarctica. This station is located near the Geographical South Pole, latitude 90° S, longitude 0° W. The purpose of the work was to develop a preliminary quantitative understanding of the characteristics of aqueous sewage wastes at the South Pole Station. The result of this work will serve as the basis for the conduct of additional analyses and the eventual design and implementation of an advanced wastewater processing system under the Controlled Ecological Life Support System (CELSS) Antarctic Analog Project (CAAP).

CAAP is a joint endeavor between the National Science Foundation, Office of Polar Programs (NSF-OPP) and the National Aeronautics and Space Administration (NASA). Its fundamental objective is to develop, deploy and operate a testbed of NASA CELSS technologies and life support approaches at the Amundsen-Scott South Pole Station.

In order to support the development of this testbed, a program has been initiated to determine the critical characteristics of the South Pole Station's wastewater. To this end, a NASA CAAP team visited the South Pole Station, during the austral summer 1992–1993. The purpose of this trip was to observe the waste handling practices and collect waste stream samples for analysis. This paper provides a brief description of CAAP and a summary of the results of the wastewater analysis.

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Background

The National Science Foundation has been tasked with conducting and managing the research and support activities of the United States Antarctic Program (USAP). The USAP encompasses all activities undertaken by U.S. agencies on the Antarctic continent and assures compliance with the Antarctic Treaty and other applicable agreements. The US has maintained a presence at the South Pole since November 1956. Named after the two Antarctic explorers, Roald Amundsen (Norway) and Robert F. Scott (United Kingdom), who were the first to reach the South Pole, the current Amundsen-Scott South Pole Station has been in extensive service for over seventeen years and is close to the end of its life cycle (ref. 1). In consideration of this, the NSF has undertaken an initiative to rebuild the station. Recognizing significant technological and political changes and the ecological sensitivities that have come to pass since the initial U.S. presence at the pole, the NSF has sought to rebuild this station with the following vision in mind:

Create and implement a design that will serve the most complex frontiers of science, with technologies yet to be developed, while maintaining the essential pristine character of the vast polar plateau on which it will be situated. (ref. 1)

Concurrent with this rebuilding initiative, a NASA/NSF Memorandum of Agreement (MOA) was signed into effect in November 1993 (ref. 2). The purpose of this MOA is to establish cooperative projects between NASA and the NSF on the Antarctic continent. This MOA recognizes the value in viewing the Antarctic continent as an Earth-based space analog. This analog is seen in the similarities with the types of human activity, the remoteness, the extreme environments, the isolation, and the problems associated with the complicated and expensive resupply system needed to support humans in both space and on the Antarctic continent. Having assessed the needs of the NSF and the needs of NASA under this MOA, CAAP was initiated as a logical approach to meeting the multiple objectives of both agencies.

The Antarctic Analog Experience

The establishment of a CAAP Life Support testbed at the South Pole will provide NASA with a remote operational facility where the technologies which will enable the development of future Lunar or Martian habitats may be evaluated. The Antarctic analog of a future planetary base, while not exact, is as close as can be attained on Earth.

Environmental conditions at the South Pole represent some of the most challenging conditions for human habitation on Earth. Some of these conditions—the severe cold temperature (maximum -14°C , minimum -83°C , mean -50°C) (ref. 3), the remoteness, the isolation, and the scientific nature of South Pole operations—represent very similar conditions as a surface habitat on Mars. The size of the crew (up to 35) is favorable for scaling to future space missions. Duration of closure is another important scaling parameter. This duration (9 months or so) is long enough for the inhabitants to be affected by the psychological strain of living in a closed environment. Other factors that contribute to the analog experience include the need to conserve resources and a concern for reducing environmental impacts on the polar plateau (ref. 1).

From an operational perspective the South Pole presents additional interesting analogies. The complex logistics, methods, and practices there place a realistic demand on both the system and the crew member/users—the system must be highly effective, robust, and dependable. Because of the extreme environmental conditions a life support system designed for the South Pole Station will require an analogous level of attention to the issues of reliability and maintainability as would be required in space because the crew will be as dependent on its operation as a space crew would be. In addition, the proposed CAAP system must be fully integrated into the South Pole Station. The system must be designed to ensure that its operation does not introduce an unacceptable burden upon existing facilities such as power production and maintenance.

There are also unusual site specific constraints such as the four month construction window with the year-long deployment dwell time, the physical envelope of the LC-130 aircraft (South Pole Station is completely resupplied by air) and the difficulty of construction in the inhospitable climate (ref. 1).

Finally, an important factor is that for the NSF there is a distinct and real need for what CAAP would provide. This element includes improving the quality of life at the station, reducing the overall dependence on logistics, and minimizing impacts to the polar environment. This consideration also involves maximizing and leveraging the goals and expenditures of both NASA and the NSF.

The CELSS Antarctic Analog Program

CAAP consists of a deployed hardware system and a research activity. The hardware system will be installed at the New South Pole Station (NSPS). Initially the CAAP Facility will combine food production and an integrated waste processing system. Food production will be

provided by a crop growth chamber and an aquaculture system sufficient to provide fresh food for a winter crew of 35 persons. The waste processing system will likewise be capable of processing the human waste loading rate for the same number of people. All elements will be self-integrated in varying degrees to minimize energy consumption and dependence on the difficult logistics train now employed at the Antarctic. All subsystems will be designed to minimize maintenance, repair, and downtime. Conventional station life support methods, namely shipped and stored foods and sewage outfall into the polar plateau, will be used as a backup to the CAAP Facility.

CAAP will be implemented in phases marked by periods of hardware testing, the optimization of methods and techniques, and the deployment of evolutionary hardware to the South Pole. All CAAP subsystems will be phased to coincide with the construction phases of the NSPS.

Phase I– The Phase I system will result in the development of a plant growth chamber. This system will be deployed to the South Pole before the final crop growth facility is installed in the NSPS. The details of this deployment are provided in reference 4. In addition, a Phase I pre-prototype engineering facility will be constructed to support the development of the deployed systems. The pre-prototype facility will be constructed and operated at Ames Research Center. The pre-prototype unit will be used to evaluate a variety of design issues such as the use of wastewater to feed plants, crop yields, the development of automated hydroponics systems and harvesting systems, CO₂ concentration systems, and system optimizations to control energy usage such as highly energy efficient lighting systems and climate control systems.

Phase II– This phase will combine waste processing capabilities with the plant growth chamber. One potential system is being developed under the Small Business Innovative Research (SBIR) Program. Through this program NASA Ames Research Center is acquiring a unique wiped-film rotating-disk (WFRD) evaporator which will be evaluated for use in CAAP. This system will utilize waste heat, from the plant growth chamber lights, in a multi-effect evaporation mode for the purification of water. It is expected that this system will be capable of achieving water recovery rates ranging from 95% to 99% (ref. 5).

Phase Final– CAAP Phase Final will be designed to accommodate the life support requirements of up to 35 people. This is based on specifications defined by the NSF and appropriate margins will be included as required to mitigate uncertainties. This final version will include a vegetable food production chamber, a microenvironment (park), an aquaculture system, and waste processing.

The hydroponics center: The hydroponics center is planned to be a crop growth chamber optimized for food production. The system is being developed to provide 100% of the vegetable food requirements for a winter-over crew of 35 people. This facility will replace the original Phase I system.

The aquaculture system: The aquaculture component of CAAP should be capable of producing several fish fillets per person per week. The primary choice organism is the fish tilapia.

The park: The miniature park for the South Pole Station will be a microenvironment with an edible landscape. The park will contain a variety of edible ornamental plants grown in a hydroponics technique using a soilless medium. This facility will not be optimized for food production but will function more as an element of aesthetics (refs. 3 and 6).

CAAP waste processing: CAAP's wastewater processing system is expected to be capable of processing an estimated 113 liters person⁻¹ day⁻¹ (30 gal person⁻¹ day⁻¹) based on a station design requirement for water consumption rate (ref. 1). This water treatment system will be combined with a solid waste processing system to provide a complete waste management system.

CAAP Power Consumption

It is expected that the Phase Final system will demonstrate, through its operation, how energy can be managed efficiently in life support systems. CAAP will attempt to accomplish this by developing a CELSS system which will function in an energy starved environment without imposing an unacceptable logistical burden upon existing or future power generation facilities. This will be accomplished as follows:

All systems will be designed to use energy efficient lighting and environmental control components– The plant growth chamber will utilize state-of-the-art technologies such as solid state electronic ballast controllers, high efficiency lamps and reflectors, advanced temperature and humidity control systems, and carbon dioxide concentration techniques. These components will be utilized in order to directly reduce the net electrical draw on the station power grid while increasing plant growth rates.

Implement methods for energy leveraging– The plant growth systems of CAAP will consume electrical energy. Most of this energy will be converted into heat by the inefficiencies of the plant lighting system. This energy is considered low grade, i.e., low temperature (~50°C), but

work can still be extracted from it. This waste energy will be used by a wastewater treatment system to treat station sewage. The partially purified water will then be used to supply the plant growth systems. The plants will consume this water and through the process of transpiration produce potable water. This water will then be used in the station to supplement existing water supplies.

The use of the low grade heat generated by the inefficiencies of the plant growth chamber's lighting to perform tasks which currently consume high grade energy, such as providing for water supplies, will increase the availability of high temperature waste heat for other uses. The high temperature energy can then be used to perform functions which consume electrical energy, such as heating structures not currently on the glycol loop. This approach will increase the thermal efficiency of the station by extracting the maximum useful work from a limited supply of energy.

Explore and implement the enhancement of power production through utilization of in situ energy resources— CAAP is working with the NSF and other applicable government agencies and industrial representatives to investigate several in situ energy generation technologies. These technologies would be developed to provide nonfossil fuel based energy to power both the CAAP facility and station operations.

Solar power: Solar power conversion at the South Pole has been investigated and found to be viable during five months of the austral summer when there is ample sunlight (ref. 7). Unfortunately the time of greatest need for power is in the winter months when scientific equipment is at full power and when there is no sunlight available.

Wind power: The wind blows constantly at the South Pole (an average of 5.5 m s^{-1}) (ref. 8). In addition, the low temperatures somewhat offset the reduced air pressure (the effective altitude at the South Pole is approximately 3,237 m or 10,621 ft above sea level) (ref. 1). Wind power could offer a potentially viable alternative to the existing fossil fuel based power production facilities which are currently in use at the station. The CAAP program will incorporate and support the development of wind turbines for use at the South Pole Station.

Wastewater Analysis

In order to support the development of CAAP, a program has been initiated to evaluate the environmental factors and operational characteristics of the South Pole Station. This initial step will define the operating envelope within which the technologies selected for inclusion into CAAP

must function. To this end, a NASA CAAP team (Event No. T-339) visited the South Pole Station during the austral summer 1992–1993. The purpose of this trip was to observe existing plant growth facilities, station operations, logistical requirements, power generation techniques and capabilities, and waste handling practices, and to collect wastewater samples for analysis. The following sections of this paper provide a summary of the results of the wastewater analysis and waste handling practices employed at the station.

Wastewater Sample Collection

Waste Handling at the South Pole

The flow of sewage within the main South Pole Station is a combined single pipe gravity flow system. The sewage from each building flows through these conventional sewer lines into a subsurface utilidor. A utilidor is a system of tunnels located beneath the station which contains the utility lines for the station's primary structures. All sewer lines are heat traced and well insulated to prevent freezing.

In the utilidor the sewer lines join together and flow into one primary discharge line. This primary line flows down the main utilidor, away from the station, to a sump located approximately halfway down its length. This point is located outside the dome approximately 30 ft beneath the surface of the ice (see appendix A). At this point, the sewage discharges into a small tank from where it is pumped up to the surface by a sump pump. From the sump pump the sewage flows into a surface-level heat-traced discharge line which runs the rest of the way out to the sewage outfall.

At the outfall the raw untreated sewage is deposited into the ice cap where it forms a large subsurface sewage plume. This plume was originally a 3 to 6 in. diameter hole which extended approximately 100 ft down below the surface of the ice. The sewage which has been discharged into this hole has melted the surrounding ice to form a large sewage plume. It is estimated that the diameter of this plume may grow as large as 100 ft (personal communication, J. Parland, 1993–94 South Pole Station Manager). There have been four of these discharge plumes in use over the last 15 to 17 years of the station operations (ref. 1). Three of the plumes are full and the fourth is half full (sewage level is approximately 50 ft from the surface (personal communication, J. Parland).

Sample Collection

Waste stream samples were collected at the South Pole Station during the 1992–93 austral summer season. The samples were collected at the station's sewage sump lift station. Three sets of samples were collected. The first sample set (sample A) was collected during a period of food preparation and dishwashing on 1/20/93 at 1:00 PM. The second sample set (sample B) was collected during a period of personal hygiene use on 1/20/93 at 9:00 PM, and the third sample set (sample C) was collected during a period of low water use on 1/21/93 at 9:00 AM. Approximately 7 liters of sewage was collected for each sample set.

Sample Analysis

The analysis of the samples was performed at four locations: the South Pole Station, the Crary Science and Engineering Laboratory–McMurdo Station, the NASA Ames Analytical Laboratory, and the Laboratory of Biomedical and Environmental Sciences–University of California, Los Angeles (UCLA).

A preliminary analysis of temperature, pH, density, conductivity, and volumetric settleable solids was performed on site at the South Pole Station. These parameters were evaluated at the station in order to maintain compliance with accepted analytical protocols dealing with sample preservation and handling as described in reference (ref. 9). Additional analysis of total solids, dissolved solids, suspended solids, and gravimetric settleable solids was performed at McMurdo Station. This analysis was performed in order to provide a basis from which to evaluate the effect of freezing and transporting the remaining waste samples to the continental United

States (CONUS). Analysis for metal content was performed at the UCLA Laboratory and the analysis of the remaining parameters and verification of field experimentation was performed at the NASA Laboratory.

Sample Preservation

The analytical work performed at the South Pole Station was completed within 1 hour of collection. The samples which were analyzed at the Crary Laboratory were refrigerated and transported from the South Pole on 1/23/93 and analyzed on 1/25/93. The samples which were analyzed at the NASA and UCLA laboratories were frozen at the time of collection and transported back to CONUS via New Zealand. The NASA Laboratory analysis was initiated on 2/11/93 and completed on 2/25/93.

Results

Tables 1 and 2 present the results of the analysis of the South Pole wastewater samples. Table 1 presents an analysis of the physical and chemical characteristics of the wastewater samples. This table combines all the data taken at the South Pole Station, the Crary Science and Engineering Laboratory, the NASA Ames Analytical Laboratory, and UCLA's Environmental Biology Biomedical and Environmental Laboratory. All experimental protocols conform to those outlined in reference 9. Table 2 provides a qualitative analysis of the volatile organic contaminants which were found in the wastewater samples. These data forecast the types of problematic volatile contaminants which are present in the South Pole wastewater. It is expected that these compounds will be design drivers for the proposed CAAP facility.

Table 1. Analysis of wastewater samples taken from the South Pole Station

Analysis— Parameter and site of analysis	Wastewater samples		
	Sample A, ^a Food preparation period	Sample B, ^b Hygiene period	Sample C, ^c Low water use period
pH (ARC ^d)	6.70	6.58	6.42
pH (Pole ^e)	7.04	7.61	8.14
Density (ARC), g/ml	0.9970	0.9974	0.9965
Density (Pole), g/ml	0.9930	0.9882	0.9903
Conductivity (Pole), sec	1,253	900	825
Total solids (ARC), %	0.221	0.170	0.165
Dissolved solids (ARC), %	0.123	0.077	0.089
Suspended solids (ARC), %	0.098	0.093	0.076
Noncombustible (as is), %	0.071	0.042	0.051
Noncombustible (on solids), %	31.95	24.47	31.15
Total solids (McM ^f), %	0.255	0.172	0.189
Dissolved solids (McM), %	0.185	0.122	0.131
Suspended solids (McM), %	0.070	0.050	0.058
Settleable solids (g) (McM), %	<0.2	<0.2	<0.2
Settleable solids (v) (Pole), %	<0.2	<0.2	<0.2
Alkalinity (as CaCO ₃), mg/L	502	1057	1045
Nonpurgable organic carbon, ppm	584	603	762
Ammonium, ppm	75	87	119
Lithium	ND ^g	ND	ND
Sodium, ppm	338	116	123
Potassium, ppm	77	83	80
Magnesium, ppm	10	10	10
Calcium, ppm	21	25	24
Fluoride, ppm	4	27	21
Chloride, ppm	14	112	80
Nitrate, ppm	27	ND	ND
Nitrite	ND	ND	ND
Sulfate, ppm	31	35	35
Phosphate, ppm	80	66	68
Iron, ppm	0.4	0.2	0.3
Copper, ppm	2.9	2.0	2.5
Lead, ppm	0.004	0.012	0.001
Boron, ppm	1.1	3.1	2.0
Other semivolatile compounds	See table 2		
Phenol, ppb	ND	150	1,650
Calcium carbonate saturation ^h	-1.1/-0.7	-0.8/0.2	-1.0/0.7
Oil and grease, mg/L	192	179	133
Floatables, %	5.67	4.21	5.81

^aSample A – Collected during a period of heavy food preparation and dishwashing on 1/20/93 at 1:00 PM.

^bSample B – Collected during a period of heavy personal hygiene use on 1/20/93 at 9:00 PM.

^cSample C – Collected during a period of low water use on 1/21/93 at 9:00 AM.

^dARC – Analysis performed at Ames Research Center.

^ePole – Analysis performed at South Pole.

^fMcM – Analysis performed at McMurdo Crary Laboratory.

^gND – Not detected.

^hCalculated data pairs are: Ames Research Center data/South Pole data.

Table 2. Analysis of semivolatile compounds in wastewater samples taken from the South Pole Station

Semivolatile compound	Wastewater samples		
	Sample A, ^a Food preparation	Sample B, ^b Hygiene	Sample C, ^c Low water use
Phenol	ND ^d	X ^e	X ^f
Hexanal	X*	X	X
Indole	ND	X*	X*
Caffeine	X*	X*	X*
Methylpentane	X	ND	ND
Ethylbenzene	X	ND	ND
Heptanal	X	ND	ND
Nonadienal	X	ND	ND
Octanal	X	ND	ND
Propylheptene	X	ND	ND
Undecanol	X	ND	ND
Benzene acetonitrile	X	ND	ND
Decanal	X	ND	ND
Dodecanal	X	ND	ND
Decadienal	X	ND	ND
Octadecene	X	ND	ND
Chloroindole	X	ND	ND
Hexadecanoic acid	X	X*	X*
Dimethyl disulfide	ND	X*	X*
Methylbutanoic ethyl ester	ND	X	X
Dimethyl trisulfide	ND	X	X
Methyl indole	ND	X	X
Decanoic acid	ND	X	ND
Dodecanoic acid	ND	X	ND
Tetradecanoic acid	ND	X	ND
Butanoic acid	ND	ND	X
Unedecyne	ND	ND	X
Octadecanoic acid	ND	ND	X
Squanene	X	ND	X

^aSample A – Collected during a period of heavy food preparation and dishwashing on 1/20/93 at 1:00 PM.

^bSample B – Collected during a period of heavy personal hygiene use on 1/20/93 at 9:00 PM.

^cSample C – Collected during a period of low water use on 1/21/93 at 9:00 AM.

^dND – Not detected.

^eX – Present.

^f* – Found in substantial quantities.

Temperature and Appearance of Waste Streams During Sampling

Sump lift station– The sewage appears to be well macerated before it enters the sump. However, several large floating bodies were apparent. These appear to be the result of some type of precipitation or flocculation. It appears that this material builds up near the high water mark of the sump. Eventually it breaks off and floats in the sump. No samples of this material were taken. The

sump tank is corroded but seems to be in relatively good shape overall.

Sample A—Food preparation and dishwashing period– The temperature of the fluid in the sump was 26°C. The samples which were collected were yellow-brown in color. They appeared to have quite a bit of suspended material. The samples did not have a strong odor and minimal foam or floating material was apparent.

Sample B—Human hygiene period— The temperature of the fluid in the sump was 26°C. The samples were yellow-brown in color and darker than sample A. They also appeared to have quite a bit of suspended material and some small floating chunks of what appeared to be feces. The samples had a stronger odor than sample A but were still relatively mild and contained little foam.

Sample C—Low water use period (flush water)— The temperature of the fluid in the sump was 27°C. The samples were yellow-brown in color and darker than sample A. They also appeared to have quite a bit of suspended material and some small floating chunks of what appeared to be feces. The samples had a strong odor and contained no foam.

Wastewater Characteristics

Analysis of the waste samples collected at the South Pole Station indicates that the sewage produced there can be classified as “strong” (ref. 10). This classification is characteristic of wastewater which has been generated in a water rationed environment. Table 3 is a comparison of the results of the analysis of the samples and a collection of data used to classify domestic sewage as weak, medium, or strong. In almost every category, the South Pole data are above the referenced data for strong sewage.

Total solids— The total solids measurement represents the total amount of material, primarily nonvolatile material, which must be removed from the waste stream. Analytically, the total solids content of wastewater is defined as all matter that remains as a residue upon evaporation at 103–105°C (ref. 9). Use of this technique dictates that any contaminants which have significant vapor pressures at this temperature will volatilize and will, therefore, not be measured as a solid.

Total solids measurements are useful in determining how much solid material will be produced as a by-product of a separation based wastewater treatment process. For the South Pole application, this number gives an indication of the amount of material which would have to be disposed of as a by-product of the water treatment system. In the samples which were analyzed, approximately 0.20% (w/w) of the waste stream is solids, or 99.8% of the waste stream is water. Based upon these data a person will produce 0.2 kg (dry weight) of solid waste per day (assuming the total effluent waste stream flow is approximately 30 gal/person-day (113 kg/person-day)).

Dissolved solids— Dissolved solids represent the portion of the total solids which cannot be removed by either sedimentation or filtration. Analytically, the dissolved solids are defined as that material which will pass through

Table 3. Comparison of composition of South Pole wastewater to typical composition of untreated domestic wastewater (ref. 10)

Contaminants	South Pole samples, mg/L			Referenced concentration data (ref. 10), mg/L		
	A	B	C	Weak	Medium	Strong
Total solids	2210	1700	1650	350	720	1200
Dissolved solids	1230	770	890	250	500	850
Suspended solids	980	930	760	100	220	350
Settleable solids ^a	<2000	<2000	<2000	5	10	20
Noncombustible solids	710	420	510	125	355	600
TOC	584	603	762	80	160	290
Ammonia	79	92	126	12	25	50
Nitrate	27	0	0	0	0	0
Nitrite	0	0	0	0	0	0
Phosphorus	26	22	22	4	8	15
Sulfate	31	35	35	20	30	50
Alkalinity	502.0	1057	1045	50	100	200
Chlorides	14	112	80	30	50	100

^aMeasurement did not give accurate value due to the presence of emulsions.

a glass-fiber filter (such as Whatman GF/C) with a pore size of about 1.2 micrometers (ref. 9). The dissolved solids consist of both organic and inorganic molecules and ions that are present in true solution with water. These contaminants will likely pass through the pre-treatment process and impact the primary treatment process. In the South Pole waste stream, dissolved solids account for approximately 52% of the total solids.

Suspended solids– Suspended solids represent the portion of the total solids which can potentially be removed by filtering the sample. Analytically, the suspended solids are defined as that material which will not pass through a glass-fiber filter (such as Whatman GF/C) with a pore size of about 1.2 micrometers (ref. 9). The suspended solids represent the contaminants which could potentially be removed through filtration and sedimentation. In the South Pole waste stream, suspended solids account for approximately 48% of the total solids.

Settleable solids– The settleable solids category represents the portion of the suspended solids which can be removed by sedimentation. Settleable solids are defined as the amount of solids which will settle to the bottom of an Imhoff cone in a 60-minute period (ref. 9). The settleable solids values reported in this paper provide only an upper limit. The data are presented in this way because the standard deviation of the experimental data was quite high (average volumetric settleable solids value is 0.097% (V) and the standard deviation is 20%).

Noncombustible solids– Noncombustible solids represent that fraction of the total solids which cannot be incinerated. In this procedure the sample is evaporated and combusted at 550°C (ref. 9). At this temperature the organic fraction of the sample will be oxidized and driven off as a gas. The inorganic fraction will remain as an ash. Approximately 0.054% of the South Pole wastewater solids samples are noncombustible (inorganic). Therefore, approximately 30% of the total solids are inorganic.

Nitrogen/phosphorus– Nitrogen and phosphorus content is used to indicate the tendency for cultural eutrophication of the wastewater. These compounds are critically important nutrients that, along with other elements such as iron, are required for biological growth. The level of nitrogen in a waste stream will to some extent determine its treatability through biological means. In the South Pole wastewater samples, nitrogen is primarily bound up as ammonia and ammonium ions. The average ammonium level is 93 ppm. There is also a trace amount of nitrogen bound up as nitrates, 27 ppm. Phosphorus, analyzed as phosphate, is also present at an average level of 71 ppm.

Sulfur– Sulfur is required in the synthesis of proteins and is released in their degradation. Sulfate can be biologically converted to sulfite and combined with hydrogen to form hydrogen sulfide (H₂S). As a gas this compound can be biologically oxidized to form sulfuric acid, an extremely corrosive compound (ref. 9). In addition, concentrations above 200 ppm can upset biological processes (ref. 10). The South Pole wastewater samples show moderate sulfate levels, 34 ppm.

Alkalinity– Alkalinity results from the presence of hydroxides, carbonates, and bicarbonates of elements such as calcium, magnesium, sodium, potassium, or ammonia. Wastewater is normally alkaline, meaning basic. The concentration of alkalinity is important when chemical treatment is to be used, in biological nutrient removal process, and when ammonia is to be removed by air stripping.

Calcium carbonate saturation (calculated)– Calcium Carbonate Saturation Index (SI) is used to evaluate the scale forming and scale dissolving tendencies of water. Assessing these tendencies is useful in corrosion control programs and in preventing CaCO₃ scaling in piping and equipment such as heat exchangers. A positive SI connotes an over-saturated water with respect to CaCO₃. A negative SI signifies an under-saturated water. An SI of zero represent a water in equilibrium with CaCO₃. The South Pole wastewater samples SI values are both positive and negative. The negative values are associated with pH measurements taken at Ames Research Center. The positive SI values, with the exception of sample A, are associated with the South Pole pH measurements. However, the positive values are small and the data taken as a whole are indicative of a solution in equilibrium with CaCO₃.

Variations due to freezing and transporting samples– The analysis of the waste samples which was performed at the Crary Laboratory provides a basis from which to evaluate the effect of freezing and transporting waste samples to CONUS for analysis at the NASA Laboratory. The samples which were analyzed at the Crary Laboratory were refrigerated after collection and then transported to the laboratory. The samples which were analyzed at the NASA Laboratory were frozen at the time of collection and then transported. A comparison of the two data sets demonstrates that the refrigerated samples had higher total solids levels (approximately 5%), higher dissolved solids (approximately 34%), and lower suspended solids values (approximately 33%).

Comparison of samples A, B, and C— Three sets of South Pole wastewater samples were collected. The first sample set (sample A) was collected at 1:00 PM. The second sample set (sample B) was collected at 9:00 PM, and the third sample set (sample C) was collected at 9:00 AM on the following day. Sample A was collected near the end of the station's lunch break. This sample is representative of wastes derived from the food preparation and dishwashing. Sample B was collected during the time when station personnel most often use showers and washbasins. Sample C was collected during a period when water use at the station was at a minimum and the primary source of waste can be assumed to be toilet flush.

This sample collection schedule was performed in order to evaluate the daily variations in wastewater characteristics and to evaluate the usefulness of segregating the potentially more dilute food preparation and hygiene wastes from the less dilute toilet flush wastes. The analysis has shown, however, that the opposite is true, namely the food and hygiene wastes are, in general, more contaminated than the toilet wastes. For example, the total solids level for sample A, as recorded at the Ames Laboratory, is 0.221%. The total solids level for sample B is 0.170%, and for sample C is 0.165%. The volatile organic analysis, table 2, demonstrates that the organic volatile contaminants in sample A differs significantly from samples B and C.

Discussion

System Design Issues

The wastewater analysis presented in this report provides an indicator of the potential effects of utilizing the station's waste stream to supply the plant growth chamber. As previously stated the station's sewage is extremely strong. The high solids levels and generally high contamination levels observed in the samples will prohibit the direct introduction of sewage into the chamber. For example, the wastewater analysis has shown that the South Pole effluent has an average boron level of 2.1 ppm. The maximum allowable level of boron for use in a plant system is 1 ppm (ref. 11). Copper, which is present in the South Pole samples at 2.5 ppm, has a maximum allowable level of 0.5 ppm (ref. 11). In addition the South Pole effluent is heavily contaminated with organic compounds. Some of these organic compounds can prove to be phytotoxic. A complete understanding of the effects of these potentially toxicological compounds must be developed to ensure that the final wastewater treatment system addresses the presence of these and other problematic compounds.

Another issue which influences the design of the waste treatment system deals with how the water which is produced through plant transpiration is used. In the proposed CAAP system this transpired water will be provided to the station for hygiene or potable use. The level of contamination in this water will be a function of the types and quantities of contaminants in the chambers feed stream and the effectiveness of the plants at removing them.

The types of contaminants which were found in the station's wastewater samples can be loosely grouped into three categories. They are inorganic compounds, non-volatile organic compounds and volatile organic compounds. The contaminants which are of primary concern in analyzing the water produced in a crop growth chamber are the volatile organic compounds. In a plant system, condensed water is generated by transpiration of water at the stomata on the leaf surface. Contamination of this water can come from three potential sources:

1. Volatile compounds which exist in solution with the water at the stomata on the plant's leaf surface
2. Direct evaporation of volatile contaminants in the hydroponics solution
3. Evolution of volatile compounds directly from plant tissue

Nonvolatile compounds, such as inorganics, will only appear in the condensed water if they are entrained in water droplets and carried to the point of condensation. Table 4 list the elemental analysis of transpired water condensed from a growth chamber using a noncontaminated hydroponics solution (ref. 11). As shown, the contamination of condensed water due to the entrainment of nonvolatile compounds is minimal. In addition, the low TOC measurement indicates that contamination due to evolution of organic compounds from plant tissues is not a significant problem. There is, however, no good data on transpired water quality as a function of the contamination of hydroponics fluids with volatile organic compounds of the types identified in table 2.

The proposed CAAP experimental program will evaluate the efficiency of the waste treatment system in removing the volatile compounds identified in table 2 and the ability of the selected species of plants to accommodate these compounds. In addition, contamination of condensed water due to direct volatilization of organic compounds from the chamber's hydroponics fluid and the evolution of compounds directly from plant tissue will also be investigated.

Table 4. Transpiration water analysis compared with EPA and Space Station Freedom (SSF) potable water specifications (ref. 11)

Element	Transpired water, ppm	SSF limits for potable water, ppm	EPA limits for potable water, ppm (ref. 12)
P	0.049	NA ^a	NA
Na	0.363	NA	NA
K	0.004	340	NA
Ca	0.232	30	NA
Mg	0.085	50	NA
Zn	ND ^b	NA	5
Cu	ND	1	1
Fe	0.001	0.3	0.3
Mn	0.003	0.05	0.05
B	ND	NA	NA
Mo	0.009	NA	NA
Al	ND	NA	NA
Si	ND	NA	NA
V	ND	NA	NA
Co	ND	NA	NA
Ni	0.016	0.05	0.1
Cr	0.004	0.05	0.1
TOC	<1.5	0.5	NA

^aNA – Not applicable.

^bND – Not detected.

The data provided in this paper will support the development of the CAAP experimental program. This will be accomplished by using the waste stream analysis to create a solution which is analogous to the South Pole Station's effluent. This analog waste stream will then be used experimentally to define the effectiveness of the CAAP system at removing any harmful compounds from the plant chamber feed and condensed product water.

Another important issue addressed by this analytical work deals with whether or not a solid waste treatment facility is needed in the proposed system. Initial design calculations indicate that as much as 130 kg/day of solid waste could be produced as a by-product of the water treatment system alone, assuming that this solid material is 95% water by weight. If a 55 gallon drum holds approximately 200 kg of this by-product material, 180 drums of waste would be collected over a 9 month period of operation. The inclusion of a dewatering system into the proposed CAAP design could reduce the water content of this by-product to as low as 50%. This would reduce the number of barrels of waste produced over a 9 month period to 18. Clearly the inclusion of a dewatering system, or other solid waste treatment system, would result in a substantial reduction in the logistics of disposing of this material.

Future Work (Analytical Wastewater Evaluations)

The data presented in this report provide an analysis of short-term (day cycle) variations in waste stream composition. In order to develop a complete characterization of the wastewater at the South Pole Station it will be necessary to analyze the long-term (year cycle) variations in contaminant loading. In addition, it will also be necessary to determine the effluent flow rates of wastes at the station.

Recommendations for future analytical work– Long-term variations in waste stream composition are required in order to determine maximum and minimum contamination levels (ref. 10). The South Pole Station is a seasonal facility and, as a result, variations in the waste stream composition between the summer and winter time periods can be expected. These maximum and minimum values must be determined to evaluate the contaminant loading ranges that the waste treatment system must be designed to accommodate.

The determination of the effluent flow rate of wastewater at the station is required to size the proposed treatment facility (ref. 10). Currently, daily water generation rates are monitored and recorded by station personnel. These data provide only an estimate of the effluent flow rate.

As such it does not take into account water loss due to transpiration, perspiration, and leakage. In the Antarctic environment, the loss of water through transpiration could be significant. Installation of an effluent flow rate monitoring system at the station would provide the data required to accurately size the proposed waste treatment facility.

Conclusions

The preliminary analysis of wastewater samples taken from the South Pole Station has provided the first set of data from which the design of an integrated waste management system can evolve. Several conclusions can be drawn from this work.

1. The wastewater generated at the station can be classified as very strong. This classification is based on comparisons with data provided by reference (ref. 10) (see table 3). This result was expected and is characteristic of facilities where strict water rationing is practiced.
2. The proposed waste treatment facility will require the use of a pretreatment filtration system. This requirement is derived from the high levels of suspended solids found in the waste stream. In the South Pole waste stream, suspended solids account for approximately 48% of the total solids and 0.09% of the total waste stream.
3. The proposed waste treatment facility will require the use of a pretreatment sedimentation bed. This requirement is derived from the high levels of settleable solids found in the waste stream. Although the sizing of this process cannot be completed until more data are collected, the need to provide some sedimentation capability is evident by the experimental results. (Note of caution: The settleable solids values reported in this paper provide only an upper limit. The data are presented in this way because the standard deviation of the experimental data was quite high). In the future, analytical procedures will be modified to ensure the generation of higher resolution data.
4. The high oil and grease values, averaging 169 mg/L, indicates that some sort of source reduction technique should be utilized. One such technique is the use of grease traps located at key generation points such as the galley sink.
5. The calcium carbonate Saturation Index (SI) indicates that the potential for calcium carbonate precipitation

is low. This condition offers an advantage in that there may not be a significant problem associated with calcium scaling on the heat transfer surfaces of process equipment.

6. Visual observations indicate that the sewage is not septic while in the collection and discharge system. This observation is made based on the light yellow-brown color of the sewage and its mild odor. Since the residence time of the sewage in the station is relatively short, little biological degradation of the organic content of the waste stream occurs. This is advantageous because low biological activity in the stream will reduce need for odor abatement equipment in the station's waste collection system.

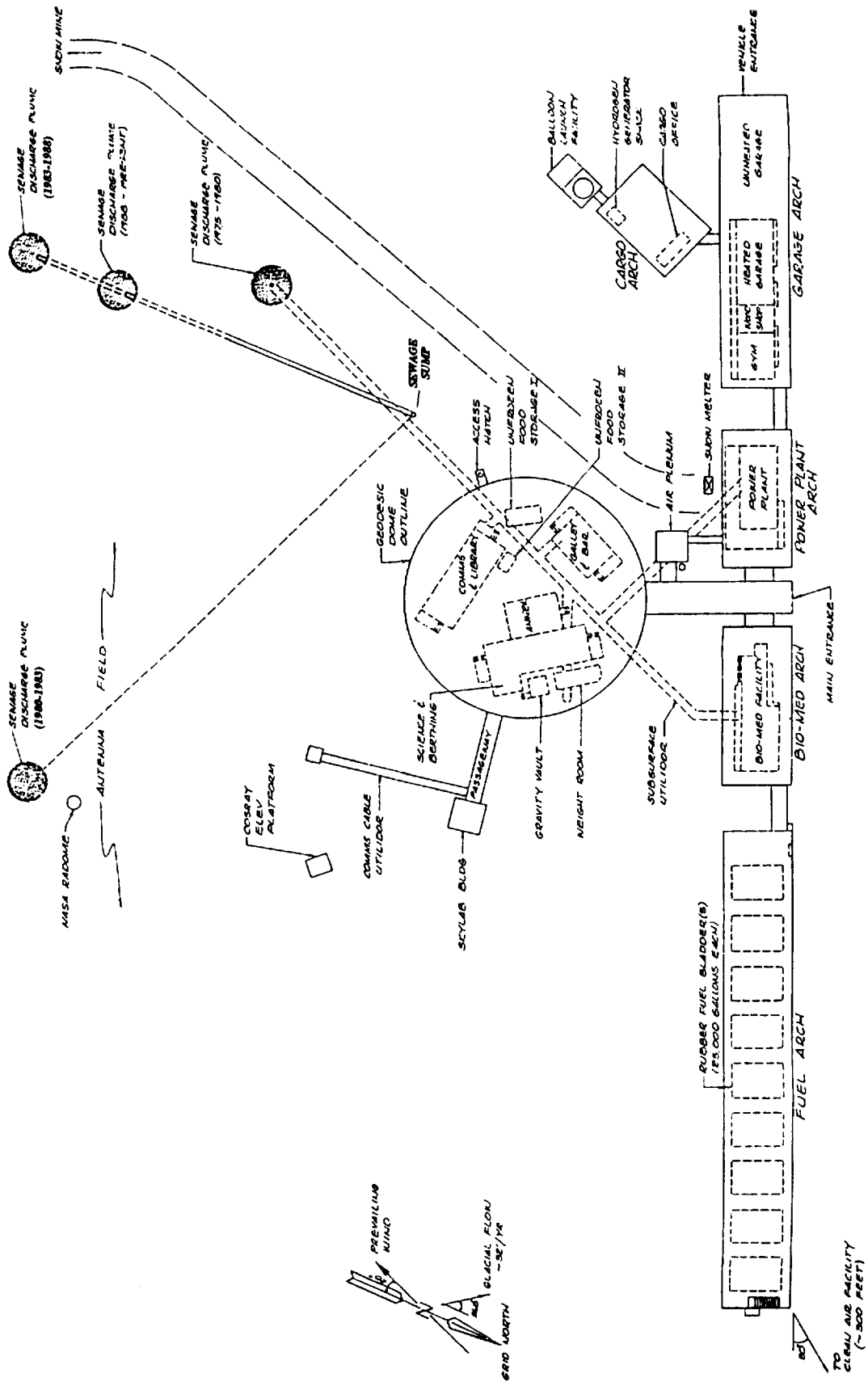
7. The low heavy metals content of the waste stream indicates that metal contamination is not a significant problem. This condition is characteristic of municipal systems where industrial activity is minimal.

8. The Crary Laboratory solids analysis provides a basis from which the effect of transporting samples to CONUS can be evaluated. The results seem to indicate that variations occurred; percent differences as high as 34% were calculated. Whether these effects are the result of factors related to sample transportation or are the result of normal experimental variation cannot yet be determined. However, it is evident that the solids analysis should again be duplicated at the Crary Laboratory during any future analytical programs to ensure that accurate data are obtained.

9. Variations between the composition of samples A, B, and C indicate that the common classifications of wastewater as gray, meaning more dilute, and black, meaning less dilute, do not apply to an environment, such as that which exists at the South pole, where strict water rationing is enforced. The samples indicate that the toilet flush water is the most dilute of the samples. The food preparation water had the highest solids levels and the hygiene water also contained relatively high levels of solids. As long as strict water rationing is enforced and high flow toilets are utilized, segregation of gray and black water sources may offer little benefit to the design of the initial waste processing system.

10. The work presented in this report represents the beginning of a complete waste stream analysis. The two elements which remain to be analyzed are the long-term variations in waste stream composition and the determination of effluent flow rates.

Appendix A—South Pole Station Site Plan



Appendix B—Experimental Protocol

Analytical Procedure for South Pole Samples

I. Purpose

This procedure gives a detailed description of the testing methodologies performed on water and wastewater samples collected at the South Pole.

II. Scope

This operating procedure gives detailed instructions for performing analytical tests on water and wastewater samples. The tests and methodologies were adapted from "Standard Methods for the Examination of Water and Waste Water," 17th edition. The selected tests were chosen to provide information to characterize the sample for further treatment using various waste purification systems. The tests include:

1. Appearance
2. Conductivity
3. Temperature
4. pH
5. Density
6. Methane*
7. Total solids
8. Settleable solids—volumetric
9. Settleable solids—gravimetric
10. Dissolved solids
11. Suspended solids
12. % Noncombustible material
13. % Floatable material
14. Total organic carbon
15. Biochemical oxygen demand*
16. Alkalinity
17. Sodium
18. Potassium
19. Calcium
20. Magnesium
21. Ammonia
22. Calcium carbonate saturation (calculation)
23. Chloride
24. Sulfate
25. Nitrate
26. Nitrite
27. Phosphate
28. Iron
29. Copper
30. Oil and grease
31. Surfactant*

32. Phenols
33. Other semivolatile organic compounds
34. Lead

*Not performed.

III. Sampling table

Analyte	Test location	Sample container
Appearance	South Pole	1
Temperature	South Pole	1
Conductivity	South Pole	1
Density	McMurdo and Ames	1 and 3
pH	South Pole and Ames	1 and 3
Total solids	McMurdo	1
Settleable solids (volumetric)	South Pole	1
Settleable solids (gravimetric)	McMurdo	1
Dissolved solids	McMurdo and Ames	1 and 3
Suspended solids	McMurdo and Ames	1 and 3
% Noncombustible	Ames—Analytical Lab	3
% Floatable material	South Pole	1
Total organic carbon	McMurdo and Ames	1 and 3
Alkalinity	Ames—Analytical Lab	2
Sodium	Ames—Analytical Lab	2
Potassium	Ames—Analytical Lab	2
Calcium	Ames—Analytical Lab	2
Magnesium	Ames—Analytical Lab	2
Ammonia	Ames—Analytical Lab	2
Calcium carbonate saturation	Ames—Analytical Lab	NA
Chloride	Ames—Analytical Lab	2
Sulfate	Ames—Analytical Lab	2
Nitrate	Ames—Analytical Lab	2
Nitrite	Ames—Analytical Lab	2
Phosphate	Ames—Analytical Lab	2
Oil and grease	Ames—Analytical Lab	3
Copper	Ames—Analytical Lab	2
Iron	Ames—Analytical Lab	2
Lead	Ames—Analytical Lab	2
Phenols	Ames—Analytical Lab	4
Other semivolatile organics	Ames—Analytical Lab	4

Sample container identification and storage conditions:
 1 – Freeze or refrigerate, 2 liter polypropylene containers
 2–4 – Freeze or refrigerate, 1 liter polypropylene containers

IV. Analysis

A. Appearance

Record the general physical appearance of the sample using any terms that briefly describe its visible characteristics (i.e., odor, color, turbidity, suspended material, sediment, floating material, particulate matter, and foreign material).

B. Temperature

1. Apparatus

Thermometer covering the temperature range of 5–20°C.

2. Procedure

Measure the temperature of the sample with a calibrated thermometer. Record the temperature to the nearest 0.1°C.

C. Conductivity

1. Apparatus

Conductivity electrode
Conductivity meter
Conductivity standards
Thermometer

2. Procedure

Calibrate the conductivity meter with a standard conductivity solution. Measure and record the conductivity of the sample. Record the temperature of the solution.

D. pH measurement

1. Apparatus

pH buffer standards
pH electrode
pH meter
Thermometer

2. Procedure

Calibrate the pH meter with a standard buffer solution. Measure and record the pH of the sample. Note: The temperature of the buffer and the sample should be between 50°F and 70°F. If it is not possible to obtain these temperatures, record the temperature and proceed.

E. Methane

Use instrumentation available at South Pole.
(Not performed.)

F. Density

1. Apparatus

Analytical balance capable of measuring at least 160 grams to the nearest 0.1 mg

50 ml volumetric flasks

Disposable transfer pipets

Water bath equilibrated to 20°C

2. Procedure (perform in at least duplicate)

(a) Ensure that the sample is homogeneous by shaking well.

(b) Adjust the temperature of a portion of the sample to $20 \pm 2^\circ\text{C}$.

(c) Zero the balance.

(d) Weigh an empty 50 ml volumetric flask and record the weight (W_0).

(e) Fill the flask to the mark (with the aid of the transfer pipets) with the temperature equilibrated sample.

(f) Weigh the filled volumetric flask and record the weight (W_1).

(g) Calculate the density as follows:

$$\text{Density (grams/ml)} = (W_1 - W_0)/50$$

(h) Average the multiple density measurements.

G. Total solids

1. Apparatus

Analytical balance capable of measuring at least 160 grams to the nearest 0.1 mg

Aluminum weighing dishes

Disposable transfer pipets

Forced air oven set at $105 \pm 5^\circ\text{C}$

2. Procedure (perform in at least duplicate)

(a) Zero the balance.

(b) Weigh an aluminum weighing dish and record the tare weight (W_T).

(c) Add 30–40 ml of sample to the dish.

(d) Weigh the dish with the sample and record the gross weight (W_G).

(e) Place the dishes in the oven which has equilibrated to $105 \pm 5^\circ\text{C}$ and dry to a constant weight.

(f) Remove the dishes from the oven and allow them to cool to room temperature.

(g) Weigh the dishes and record the final weight (W_F).

(h) Calculate the % total solids as follows:

$$\% \text{ total solids} = \frac{(W_F - W_T)}{(W_G - W_T)} \times 100$$

(i) Average the % total solid measurements.

H. Dissolved solids and suspended solids

1. Apparatus

Same as in IV.G.1 above plus:

Glass-fiber filter disks without organic binder such as Whatman grade 934AH, Gelman type A/E, Millipore type AP40 or equivalent

Filtration apparatus

2. Procedure

(a) Ensure that the sample is homogeneous by shaking the sample container.

(b) Vacuum filter 200 ml of the sample and collect the filtrate.

(c) Follow the procedure for total solids measurement on the samples in duplicate.

(d) Calculate the % dissolved solids using the equation in the total solids analysis.

(e) Record the average of the % dissolved solids determinations.

(f) Calculate the % suspended solids as follows:

$$\begin{aligned} \% \text{ suspended solids} \\ = \% \text{ total solids} - \% \text{ dissolved solids} \end{aligned}$$

I. Settleable solids—gravimetric and volumetric

1. Apparatus

Imhoff cones and stand

2. Procedure

(a) Ensure that the sample is homogeneous by shaking the sample container.

(b) Fill the Imhoff cone to the 1 liter mark with the sample.

(c) Allow the solids to settle for 45 minutes and gently stir the sides of the cone to remove any entrapped air. Allow the solids to settle for an additional 15 minutes.

(d) Record the settleable solids as ml per liter for the volumetric measurement.

(e) Remove the upper layer and place it in a separate container.

(f) Perform the total solids (section IV.G) on this sample in duplicate.

(g) Average the duplicate measurements and record the results as % supernatant solids.

(h) Calculate the % settleable solids—gravimetric as follows:

$$\begin{aligned} \% \text{ settleable solids—gravimetric} \\ = \% \text{ total solids} - \% \text{ supernatant solids} \end{aligned}$$

J. Percent noncombustible

1. Apparatus

Muffle furnace equilibrated at $550 \pm 50^\circ\text{C}$

Vycor dishes 60 ml size or equivalent

Analytical balance capable of measuring 160 grams to the nearest 0.1 mg

2. Procedure

(a) Ensure that the sample is homogeneous by shaking the sample container.

(b) Zero the balance.

(c) Weigh the empty dish and record the tare weight (W_T).

(d) Place the sample in the dish such that it occupies three-quarters of the volume of the dish.

(e) Weigh the dish with the sample and record the gross weight (W_G).

(f) Evaporate the water from the sample by placing the dish in an oven set at 105°C .

(g) Remove the dish from the oven and place it in a muffle furnace which is at room temperature.

(h) Raise the temperature of the muffle furnace to $550 \pm 50^\circ\text{C}$ and allow the sample to ash to a constant weight (usually results in a white residue, not black or brown).

(i) Remove the dish from the muffle furnace and allow it to cool to room temperature.

(j) Weigh the dish and record the final weight (W_F).

(k) Calculate the % noncombustible material in the sample as follows:

% noncombustible material

$$= \frac{(W_F - W_T)}{(W_G - W_T)} \times 100$$

(l) Average the duplicate results.

K. % Floatable material

1. Apparatus

1000 ml separatory funnel with Teflon stopcock

HCl 6N

1,1,2 Trichloro-1,2,2 Trifluoroethane

2. Procedure

(a) Place 1 liter of sample in a Nalgene separatory funnel and allow it to stand for 30 minutes without agitation.

(b) Discharge the first 900 ml of water through the Teflon stopcock stopping before any oil or other floating material escapes.

(c) Submit the funnel to the laboratory for the following analysis.

(1) Acidify the sample to pH 2 or lower with 6N HCl.

(2) Extract with 50 ml trichlorotrifluoroethane and collect the extract in a clean container.

(3) Repeat the extraction two more times combining the extracts.

(4) Transfer the extract to a tared evaporating dish (W_T) and carefully evaporate the solvent in the fume hood.

(5) Weigh the dish after evaporation (W_F).

(6) Calculate the % floatable material as follows:

% floatable material, mg/L

$$= (W_F - W_T) \times 1000$$

L. Alkalinity

Submit sample to Ames Analytical Chemistry Laboratory for analysis according to procedure ACL # 10014, "Alkalinity—Titration Method."

M. Biochemical oxygen demand (BOD)

Submit samples to McMurdo or other outside laboratory for analysis.

N. Total organic carbon

Submit the samples to McMurdo or Ames Central Analytical Chemistry Laboratory for analysis. Perform the analysis according to Ames Central Analytical Chemistry Laboratory document number ACL #10002.

O. Ammonia, sodium, potassium, calcium, and magnesium

Submit the samples to Ames Central Analytical Chemistry Laboratory for analysis. Perform the analysis according to Ames Central Analytical Chemistry Laboratory document number ACL #10001.

P. Chloride, nitrate, nitrite, sulfate, and phosphate

Submit the samples to Ames Central Analytical Chemistry Laboratory for analysis. Perform the analysis according to Ames Central Analytical Chemistry Laboratory document number ACL #10006.

Q. Iron, copper, and lead

Submit the samples to Ames Central Analytical Chemistry Laboratory for analysis by atomic absorption spectroscopy.

R. Oil and grease

Submit the samples to Ames Central Analytical Chemistry Laboratory for analysis according to the following procedure.

1. Apparatus

Separatory funnel – 1000 ml

HCl (6N)

Evaporation dishes

Beakers – 250 ml

2. Procedure

(a) Acidify 1 liter of sample with 5 ml HCl (6N) to reduce the pH to below 2.

(b) Transfer the sample to a separatory funnel and extract with 30 ml of trichlorotrifluoroethane.

(c) Allow the two layers to separate. Remove the organic layer (bottom) to a clean, dry beaker.

(d) Extract two more times with 30 ml of trichlorotrifluoroethane and combine the extracts.

(e) Place the beakers on a hot plate set at a low to moderate temperature. Reduce the volume of the extract to 20–30 ml.

(f) Tare an aluminum evaporation dish (W_T) and transfer the concentrated extract to the dish. Rinse the beaker with trichlorotrifluoroethane to complete the transfer.

(g) Evaporate the solvent in the weighing dish by passing air over the dish.

(h) Weigh the dish and record the weight (W_F).

(i) Calculate the oil and grease as follows:

$$\begin{aligned} \text{Oil and grease, mg/L} \\ = (W_F - W_T) \times 1000 \end{aligned}$$

S. Phenols

Submit the samples to Ames Central Analytical Chemistry Laboratory for analysis. Perform the analysis according to Ames Central Analytical Laboratory document number ACL #10012.

T. Other semivolatile organic compounds

Submit the samples to Ames Central Analytical Chemistry Laboratory for analysis. Perform the analysis utilizing a modified EPA 8270 procedure to identify and quantitate any semivolatile organic compounds.

U. Calcium carbonate saturation

Calculate the calcium carbonate saturation value according to standard methods for water and wastewater analysis.

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