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THE ENGINEERING BIOTECHNOLOGY OF HANDLING WASTES RESULTING FROM A CLOSED ECOLOGICAL SYSTEM

Research Division
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FOREWORD

Less than 20 years ago the establishment of man in an environment consisting of a hermetically sealed container in which he might work for as much as a year and continue a normal living process was a scientist's dream.

Parameters of such environment include partial vacuum within the living space, a total conservation of mass balance, and a self-contained system providing water, food and air without recourse to any form of aid beyond the walls of the container.

In such an environment the waste products of living assume an unusual importance. Not only must the wastes be so handled that they do not harm man, but they must also become a continuing source of supply of those essentials for the maintenance of life, the water, the food, and the air required by man.

In this report an attempt has been made to present the multitude of problems involved in providing an environment, safe for man, and to suggest areas of research that should be helpful to those who are now engaged in the task of preparing the closed space in which man is expected to work and survive.

Preservation of the health of the occupants and the development of methods whereby the closed space will remain safe for extended periods of time is truly a challenge in sanitary engineering. New engineering concepts of waste handling are required. Treatment and recovery processes must be minimized in both weight and volume and yet be completely dependable at all times.

This report is concerned with that phase in which knowledge of engineering biotechnology of waste handling is directed toward the problems of closed space ecology and in which there are many areas requiring further investigation.

We trust that this contribution may speed research on many fronts and assist in bringing the occupancy of closed space closer to reality.

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ABSTRACT

This report is directed to an examination of the status of existing information and the areas of research requiring attention in connection with the handling of wastes resulting from human occupancy of a closed ecological system.

Probable wastes to be handled are classified. The problems related to handling and treatment and to cycling and reuse of treated end products in liquid, solid, and gaseous form are discussed.

Five detailed reports discussing the present status of knowledge of wastes handling in closed systems are included as appendices. Areas of research and development are suggested with respect to skin excretions, algae culture, carbon dioxide conversion to oxygen, the handling of closed space air, and the handling of bodily and other wastes.

A master file of 174 annotated references and an alphabetical author index to those references are included.

Report

THE ENGINEERING BIOTECHNOLOGY OF HANDLING WASTES RESULTING FROM A CLOSED ECOLOGICAL SYSTEM

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GENERAL INFORMATION

The work [redacted] is directed to an examination of the status of existing information and the areas of research requiring attention in connection with the handling of wastes resulting from human occupancy of a closed ecological system. STAT

The contract instructions were:

> The contractor will bring together by library study, field visits and conference information on biology, physics, chemistry and engineering as it relates to the handling and treatment of bodily wastes in closed spaces. Emphasis will be placed on a search for data that suggests the handling of waste without health hazard to personnel occupying a closed space and the possible conversion of waste material to products that may be utilized in supplying oxygen nutrients and other useful products while at the same time eliminating or controlling products that may be harmful or otherwise undesirable.
>
> The above data will be carefully analyzed and recommendations for specific research on methods of handling waste in a closed ecological system will be prepared.

The special study of the Air University Command and staff school class of 1956[148] has well summarized a number of the physical and physiological problems that must be faced. The following extracts from that report are repeated here.

> "It is anticipated that this brief investigation and study into problems with which we have lived and fought for fifteen years—and in some instances not yet solved—will lead to a better understanding of the problems yet to come."

"Providing the crew with the proper mixture of oxygen and eliminating waste gases from the sealed cabin pose major technological problems. Breathing air must closely approximate in composition that found in our atmosphere. One hundred percent oxygen will not satisfy the need. Over extended periods of time pure oxygen, under the required pressure, will produce toxic effects. Therefore, it will be necessary to add certain diluents such as a few dust particles, a little moisture and an inert gas in nearly the same proportions as found on earth. To minimize the effects and possibility of gas bubbles forming in the tissues, helium should probably substitute for nitrogen as the inert gas. The exchange and removal of waste gases such as carbon dioxide and methane are of extreme importance. Sodium hydroxide absorbs carbon dioxide readily but it has a saturation point which precludes its use over periods of long duration. Research continues on the feasibility of utilizing gas exchangers involving suspensions of chlorella algae under light. By process of photosynthesis, the 'green algae' takes in carbon dioxide and in return gives off oxygen in a cycle opposite to that performed by man. The limiting factor in this system would be the space requirement for an algae 'garden' large enough to provide oxygen for the entire crew."

"The problem of elimination of human body wastes can be broken into three separate categories: disposal of gases, liquids and solids. The suggested handling of these products is essentially different in each instance and some ingenious ideas for the manner of doing this have been propounded. The gases to be considered are carbon dioxide, the methane family and the mercaptan group. Work is presently in progress on the development of efficient gas exchangers, improving on the present reliable soda-lime apparatus. This approach appears to hold more promise than photo-synthesis, the property of the chlorophyll to convert carbon dioxide to oxygen in the presence of light. The human body excretes approximately two pounds or one quart of water, as water vapor daily. This occurs during respiration or by evaporation from the skin. This moisture must be absorbed or disposed of. The most feasible solution proposed is to utilize this water in the cabin air conditioning system. The air must be dehumidified then later humidified during the air exchange cycle. Proposed solutions for the solid waste elimination problem are even more ingenious and are limited only by the imagination and ingenuity of the space ship designer. A total of four pounds of solid waste per man per day is estimated. This total included food scraps, refuse and other sewage. One solution is to store the material in containers and return them to earth with the vehicle, similar to the chemical toilets in use today. Another means is to throw or expel the material

> from the vehicle into space. This, although the easiest and the cheapest, would play havoc with any visual observation in progress and would not be without danger, since clouds of micrometeors would be formed. A third solution visualizes the shooting of the material in a container, into outer space, propelled by a small, short-lived rocket engine. If the rocket were fired toward the earth and in the opposite direction of that of the space vehicle, it would quickly reach 'burnout'--and fall toward the earth, being completely incinerated as it entered the atmosphere."

This point of departure may be elaborated.

Men living in a closed space for an extended period of time must continue to function normally while performing whatever task is at hand. Men must eat, drink, breathe and live. Metabolism and body function continue while occupants work, rest, exercise and sleep.

In a tightly closed space there is no other supply of air, no other supply of water. Food is limited by space, storage and weight limitations. Bathing facilities are minimal. Cleansing operations applied to body, clothing, and equipment and premises are severely limited.

Is it possible to treat and recycle air, liquid, and solids so that no mass is lost from the closed space? Can the CO_2-O_2 balance be maintained without carrying an independent supply of oxygen? Is it necessary to recycle at all? Can excess water in closed space air be handled properly to avoid inclusion of soluble toxic end products evolving from human use of such space?

Some of these wastes that may result from closed space occupancy would cause no problem in normal environment, hence not much information appears in the current literature about them. It is in fact necessary to consider many questions of seemingly trivial nature now in order to be reasonably certain that nothing has been overlooked in establishing what may be expected as the environment of closed space. The experience to date is that questions under investigation compound as the studies lead toward tentative answers.

The probable wastes may be classified to include feces, urine, sebaceous gland excretions, perspiration, respiratory end products, washings containing soil from clothing, and washings containing food particles as a result of food preparation and service. In addition there probably is a series of wastes that will result from working operations. For example, the process of centrifuging, extracting, drying or otherwise recovering algae that has been under investigation as a means of maintaining CO_2-O_2 balance will itself produce debris, either solid, liquid or gaseous, that will require further handling. The actual working operations that force the closed space circumstances may produce waste materials that require controls.

A further complication is introduced by the fact that physiological data applicable to individuals living in normal environment at normal atmospheric pressure, eating the usual food, and consuming the usual amount of liquid may be altered by changes in the closed space mechanism for living.

Water reclamation from air and liquid and solid wastes has complications. Wastes reused for drinking purposes will require careful treatment. High salts equilibrium must be avoided as well as the inclusion of traces of soluble toxic materials.

In each approach these factors are always important:

1. The process must treat without failure.
2. The process wastes resulting from treatment must be adequately handled; and
3. The equipment and materials must not introduce excessive cubage and weight. The term "excessive" in this instance has not yet been defined.

A study of the research needs associated with the environment of closed spaces has been made by Professor Ingram and his colleagues, Dr. William E. Dobbins, Dr. Gail P. Edwards, Mr. Elmer R. Kaiser, Dean Henry J. Masson, Dr.

Bernard Newman, Mr. Gerald Palevsky, and Mr. Lawrence Slote. The discussion that follows represents the consensus of thinking on the part of the entire staff after review of literature and conferences and field visits to other locations where research on the closed space ecology and its problems has been in progress.

In the course of the literature search some articles have been sufficiently informative to justify preparation of briefs on content. From the information thus obtained an assessment and review of present knowledge has been developed on such essentials as CO_2-O_2 conversion; treatment of bodily wastes; recovery of usable water from contained air, urine, and other sources; removal of pollutants from contained air; and purification or disposal of various liquid wastes.

The conditions applicable to the need for any or several of these essentials are related to the duration of extra-terrestrial flight. Such flight may be (1) of short duration, amounting to hours; (2) of intermediate duration, amounting to days; and (3) of long term, amounting to weeks and months. This discussion deals almost entirely with the third problem, but the orientation of research needs emphasizes that careful study should be made of factors affecting weight and volume of equipment required to process and maintain an environment with total conservation of mass balance and recycle of matter, as opposed to the principle of replacement of essentials such as oxygen and water by withdrawl from storage while polluted matter is ejected from the closed system environment.

For conditions introduced by flight of short or intermediate duration, engineering economics may justify provision for partial or even total replacement of environmental constituents. Long term operations seem impractical

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without plans for cyclic use of the contained matter. Commentary and discussion of research needs related to the environmental complex will demonstrate the possible areas of research which may lead progressively to a healthful working space under a closed ecology.

BODILY WASTES

Feces, Urine and Flatulence

The handling of feces and urine, normally a matter causing little concern, can become a serious problem in a closed ecology. Gradwohl[69] has listed the more important products present in feces:

Indole	C_8H_7N	Odorous
Skatole	C_9H_9N	Odorous
Paracresol	C_7H_8O	
Para-oxyphenyl-propionic		Acid
Hydrogen sulphide	H_2S	Odorous
Methane	CH_4	
Methylmercaptan		Odorous
Hydrogen	H_2	
Carbon dioxide	CO_2	
Protheoses		
Peptones		
Peptides		
Ammonia	CH_3	Odorous
Amino acids		
Some raw vegetables, unchanged, such as radishes, cole slaw, pickles, onion, skin of fruit, nuts, berries		
Mucus		
Tissue remnants, epithelial cells, muscle fibers, connective tissue		
Crystals, phosphates and many others		
Detritus		
Fats, neutral, free fatty acids or soaps, approx. 2 gm. daily		
Starch granules		
Bacteria, a great variety		

Mattice[105] has indicated that feces contains 74-79% water and the dry solids developed amount to 20-40 gm/24 hrs. per capita. Information from a number of sources is such that for estimating purposes it would be safe to assume a 75% moisture content and 25% dry solids basis.

The quantity of feces per person is, of course, related to diet, and from both literature and studies by Ingram[84] it appears that a range of 100 to 150 grams per day per person is to be expected. Gradwohl[69] suggests an average of 102.8 grams per person per day. It may be estimated that dehydrated fecal material would amount to 20-25 grams per person per day. This quantity is small, but the difficulties in handling are many. At reduced atmospheric pressure outgassing may be anticipated. Hence, there is the need for rapid transfer to a closed system of handling so that the gases do not enter the atmosphere of the occupied closed space. Much of the water in feces is bound water and its recovery by extraction needs to be considered only for emergency. The basic problem appears to be one of handling and storage.

Heat followed by freezing or even freezing alone will suffice to inactivate the material and permit its storage at -20°C or lower. It is believed that the cubage required for storage of even as much as 0.5 lbs. per day would not be above 0.02 cubic feet per day, and might be considerably less. It is a matter of conjecture at the moment as to the cubage that might be required for equipment to inactivate and freeze material for storage. Initial research on this matter should be directed toward determination of methods suitable for sealing off the material after evacuation and preparing it for storage. Later when more is known of the diet and the probable characteristics of the metabolic end products further research on possible utilization of feces in a cyclic system should be undertaken.

Flatulence will, of course, contribute unwanted gases to the closed space. Flatulence will mingle with the room air and must be considered among the items to be treated in connection with purification of the closed space atmosphere.

Urine also is variable in quantity and composition. Hawk and Bergeim[78] report the following:

Composition of Average Normal Urine

Constituent	Daily Excretion Amt.-grams
Water	1200
Solids	60
Urea	30
Hippuric Acid	0.7
Uric Acid	0.7
Creatinine	1.2
Indican (Indoxyl Potassium Sulfate)	0.01
Oxalic Acid	0.02
Allantoin	0.04
Amino Acid Nitrogen	0.2
Purine Basis	0.01
Phenols	0.2
Cl as NaCl	12.0
Na	4.0
K	2.0
Ca	0.2
Mg	0.15
S as SO_2	2.5
Inorganic Sulfates as SO_3	2.0
Neutral Sulfur SO_3	0.3
Conjugated Sulfates as SO_3	0.2

Urine is a possible source of usable water and may be a source of nutrients to be used in connection with algae culture. However, it contains substances that may be toxic and therefore its possible treatment to recover usable water requires careful and extensive exploration.

Exploratory studies on distilled urine were carried out by Dr. Newman of the project staff. The urine was distilled at atmospheric pressure and had a urinous odor. It was passed through activated charcoal and then no odor or taste was apparent. In a toxicity series of 10, testing toxicity of distiled Zeolite treated samples to HeLa cells no growth was observed.

Assays of raw untreated urine gave the following analyses:

	Run 1	Run 2	Run 3
Total Solids mgm/l	25,400	34,100	28,000
pH	6.6	6.4	6.5
Ash mgm/l	16,200	24,400	
NaCl mgm/l	6,800	6,760	6,920
Nitrogen mgm/l			
Total N		5,950	6,700
Urea N	2,980		3,010

After distillation of one run total solids in the distillate were 160 mgm/l and total N was 114 mgm/l. Another run containing 125 mgm/l total N after distillation was passed through a Zeolite column and the total N remaining was 14 mgm/l.

Fractional distillation on two runs gave the following results for total N in the distillate.

Fraction	Total N mgm/l Run 1	Total N mgm/l Run 2
12 1/2%	219	184
12 1/2%	196	174
12 1/2%	155	120
12 1/2%	116	121
12 1/2%	120	160
12 1/2%	124	174
12 1/2%	326	280

We find that distillation of a sample delivers unsuitable water at the beginning and end of the action. Approximately one-half of the sample delivered is of such quality that it might be subjected to further treatment in ion exchange beds and with activated carbon and possibly additional filtration. However, the present thinking is that freezing techniques may offer a better quality of recovered water. It seems essential that research on the recovery of usable water from urine be explored fully.

Skin Excretions

Excretions from sebaceous glands and sweat glands contribute impurities to the contained air in the form of water, salts, and detritus. These are discussed in Appendix 1. Howell,[81] reporting on quantity of water loss, indicates that 25 to 40 grams per hour are lost through insensible perspiration with 1/3 to 1/2 of that being given off from lungs. Approximately 600 ml. of water is released from skin per 24 hours. However, the quantity may reach 2500 ml. per hour with strenuous muscular work. CO_2 release is estimated at 7 to 8 grams per 24 hours and increasing with sweating.

The skin surface usually has an acid reaction and may exert a bactericidal effect. Dirt and fat may interfere with this reaction. The water vapor loss from epithelial evaporation (insensible perspiration) does not carry over solutes. However, the sweat glands do release many electrolytes, organic acids and compounds, and inorganic salts in minute quantities. Sebaceous gland secretions are mixed with sweat, and the composition is not exactly known. The fatty, oily material does contain in small quantities cholesterol, some simpler fatty acids, fatty acid esters, albumins, and inorganic salts. The sebum may spread over the skin in a protective layer or may pack in the gland-cutaneous surface as a cheese-like mass. Organic constituents of what is thought to be a mixture of sebaceous and sweat gland excretion are believed to include small quantities of urea, uric acid, creatinine, lactic acid, ethereal sulphates of phenol and skatol, amino acids, sugar in traces, and albumin.

A review of the chemical composition of sweat by Robinson and Robinson[136] offers a range of values reported by various research studies. The components are here summarized:

1. <u>Sodium Chloride</u>

   NaCl and water are the principal substances whose loss by sweating may affect the homeostasis of the individual to a serious degree. Concentration of NaCl is variable. Individual values as low as 5 mEq/l to as high as 100 or 148 mEq/l have been reported. Average values ranging from 18-97 mEq/l have been reported in at least 86 separate studies. Normal output from skin (no sweating) is ca. 0.2 mEq/hr. of Cl^-. Sodium runs somewhat higher because of other sources of Na.

2. Potassium

Lower than Na averages about 4.5 mEq/l with range from 1 to 15 mEq/l. Potassium concentration varies inversely with the Na concentration and the Na/K ratio varies directly with the Na concentration. Na/K = 15 in unacclimatized men, dropping to 5 after a five-day adaptation period.

3. Calcium

Ranges from 1 to 8 mgm per 100 ml.

4. Magnesium

0.04 to 0.4 mgm/100 ml.

5. Copper

4.4 to 7.5 mcg/100 ml.

6. Manganese

3.2 to 7.4 mcg/100 ml.

7. Sulphates

4 to 17 mgm/100 ml.

8. Iron

0.1 to 0.2 mgm/100 ml.

9. I_2, F_2, Br_2 have been reported.

10. Lactic Acid

Values reported range from 4 to 40 mEq/l.

11. pH

Most observers found between 4 and 6.8.

12. Glucose

Extremely low. Reported from 0.1 mgm/100 ml. to 9 mgm/100 ml.

13. Nitrogen

Much more dilute than corresponding values in urine. Average values range from 23 mgm/100 ml. (tot. N) to 140 mgm/100 ml.

14. Urea N

Averages ranged from 12 to 39 mgm/100 ml. in several studies.

15. NH_3N

Most investigators report in range of 5 to 9 mgm per cent.

16. Creatinine

Ranges from 0.1 to 1.3 and averages 0.4 mgm/100 ml.

17. Uric Acid

Reports range from 0 to 1.5 mgm/100 ml.

18. Amino N

Extremely low, but 18 different amino acids have been identified.

19. Phenol and Histamine reported.

More should be known about the sebum, both quantitatively and as to deterioration. Study of determination of sweat gland excretions is also indicated. The wastes resulting from personal ablutions containing skin excretions should be investigated to determine means of safe disposal or recovery for reuse.

WASTES HANDLING AND TREATMENT

The wastes of a closed ecology occur as liquids, solids, and gases. Gaseous components are associated with both liquid and solid phase waste and are a principal consideration in the closed space air. Solids in quantity result from feces, but are also to be considered as a small but important constituent of urine. Personal and other cleansing operations and room air.

Algae Culture

Attention has been given the idea that liquid wastes might contribute a source of nutrient in algae culture. If so, the dual problems of waste treatment and CO_2-O_2 balance might have common solution. The green algae, Chlorella and Scenedesmus, have been used in studies of photosynthesis. Chlorella has a high rate of photosynthesis and low (by comparison) rate of respiration. Hence use of algae has offered seeming advantages in the establishment of CO_2-O_2 balance. An extensive review of the literature and an analysis thereof is contained in Appendix 2. There are certain desirable characteristics which an alga suitable for use in a confined space should have. The species of algae developed should:

1. Grow efficiently at a high temperature, say 40-50°C.
2. Give a high growth rate with higher rates of evolution of oxygen.
3. Derive part of its CO_2 needs from bicarbonate ion (danger of high pH resulting would need phosphate buffer - perhaps).
4. Grow in mass culture without change over long periods by recirculation of media.
5. Be very hardy - resist contaminating agents and inhibiting substances.
6. Have a pleasant flavor.
7. Be free from toxic substances.
8. Produce no substances which would inhibit its own growth.
9. Have good food value - as complete as possible - easily digestible.
10. Be able to utilize the nitrogen from urine.

It does not appear at the moment that algae can be utilized as a means of waste treatment, since the waste would have to be treated extensively before admission to the culture. There are many problems requiring further study before algae culture can be accepted as a means of obtaining CO_2-O_2 balance under closed space conditions.

In addition to the development of more suitable strains of organism, consideration whould be given to possible mutation effects, the establishment of suitable and easily supplied sources of nutrient, possibly from chemicals, urine and wastes, toxicity of the developed algae if used over extended time periods as part of human diet, the control of growth of biological contaminating agents, and the development of processing and harvesting equipment that will meet both cubage and weight requirements.

CO_2-O_2 Conversion

Since there are some possible limitations of growth of algae for maintaining CO_2-O_2 balance, it has been necessary to examine other possible methods of attaining CO_2 conversion. Appendix 3 contains a detailed discussion of the potential of chemical conversion.

The treatment which has been occurring in nature is the process of photosynthesis. In simplified form the reaction may be written:

$$\text{Light} + CO_2 + H_2O \longrightarrow CH_2O + O_2 + Q$$

Another possible form of the reaction might be:

$$CO_2 + H_2O \longrightarrow (C_6H_{10}O_6)_n + O_2 + Q$$

If this reaction can be made to take place in a non-living system (artificial photosynthesis), one might anticipate that oxygen would be made available and that a carbohydrate would be formed that might be made available for food or fuel or auxiliary energy. CO_2 would be removed as part of the reaction. Matters of materials balance and energy balance are involved here. A catalyst of some type is required. In nature the catalyst is chlorophyll.

When carbon dioxide is heated to higher temperatures it breaks down in one of two reactions, or possibly both:

$$2\ CO_2 \longrightarrow 2\ CO + O_2 - Q \qquad (a)$$

$$2\ CO \longrightarrow 2\ C + O_2 - Q_1 \qquad (b)$$

The temperatures required for the reactions are high.

Reaction (b) in all probability does not take place at least under conditions ordinarily attainable, and even for reaction (a) the temperatures required are very high (3000°C - app. 5400°F). At these temperatures the amount of molecular dissociation is only 18%. Higher temperatures serve only to dissociate the molecular oxygen into atomic oxygen. If the oxygen is to be recovered from the equilibrium mixture it would have to be cooled very quickly to prevent the reverse reaction taking place. It would be unusual if the recovery was more than 10%. The production of such high temperatures is a difficult one attainable probably only by means of an electric arc or sparks or solar furnace. The carbon monoxide produced is very poisonous but could be converted to a harmless and perhaps ecologically useful product. In the foregoing reaction the form of energy to bring about the dissociation is thermal. It might be fruitful to combine this with other forms of energy.

The following are actual or potential reactions of CO_2 with other substances.

(a) $CO_2 + H_2O \longrightarrow H_2CO_3$

This is the normal reaction with water at room temperatures, but the product is unstable and is easily decomposed by a modest rise in temperature. This reaction should not be confused with that of photosynthesis.

(b) $CO_2 + NaOH \longrightarrow NaHCO_3$

$2\ NaHCO_3 \longrightarrow CO_2 + Na_2CO_3 + H_2O$

These reactions may be used to remove the CO_2 from the enclosure but the use of $Ca(OH)_2$ is superior.

$CO_2 + Ca(OH)_2 \longrightarrow CaCO_3 + H_2O$

The $CaCO_3$ is insoluble.

(c) The reactions between carbon dioxide and hydrogen are interesting. They are:

$$CO_2 + 4H_2 \longrightarrow CH_4 + 2H_2O \qquad (a)$$

$$CO_2 + 2H_2 \longrightarrow \underset{\text{(graphite)}}{C} + 2H_2O \qquad (b)$$

related reactions are:

$$CO_2 + H_2 \longrightarrow CO + H_2O \qquad (c)$$

$$CO + 3H_2 \longrightarrow CH_4 + H_2O \qquad (d)$$

$$C + CO_2 \longrightarrow 2\,CO \qquad (e)$$

The foregoing reactions can be carried out under the environmental conditions existing in the closed system. H_2 may be obtained by the electrolysis of water.

In addition to the above reactions there is a vast spectrum of reactions by means of which many useful compounds may be produced. For example, the methane can be converted C_2H_4 and C_2H_2 which in turn can be converted to C_6H_6 and other cyclic compounds. Or the following catalytic reaction may be used to produce methyl alcohol:

$$CO + 2H_2 \longrightarrow CH_3OH$$

Depending upon the choice of catalyst ethyl alcohol, acids and esters may be produced.(132, 133)

(d) Excreta, etc. can be decomposed to form NH_3 or the ammonia may be formed from other sources. In any case there is a significant reaction between CO_2 and NH_3.

$$CO_2 + 2NH_3 \longrightarrow NH_4CO_2NH_2$$

$$NH_4CO_2NH_2 \longrightarrow NH_2CO\ NH_2 + H_2O$$

(e) If concern is for the production of O_2 there are the reactions of water with alkali peroxides, i.e.:

$$2\ Na_2O_2 + 2H_2O \longrightarrow 4\ NaOH + O_2$$

1 lb. Na_2O_2 produces 2.3 cu. ft. of O_2

1 lb. Li_2O_2 produces 3.9 cu. ft. of O_2

or by the electrolysis of water:

$$2H_2O \longrightarrow 2H_2 + O_2$$

Explorations and more intensive research into CO_2-O_2 conversion may be productive in the following channels of effort:

1. Induce greater efficiency in natural photosynthesis by acceleration of growth, using substances such as gibberellic acid.

2. Investigate means for creating a synthetic cell using organic dyes and enzymes as chloroplasts.

3. Study of the effect of various forms of energy on the decomposition of carbon dioxide.

4. Study the effect of the bombardment by electrons on carbon dioxide in various physical states.

Closed Space Air

The closed space air must be maintained in such condition that men can live and work in it. Consideration of the hazards and possible means of control is presented in Appendix 4. The control of temperature, humidity, air motion, foreign matter, microorganisms, and the balancing of the CO_2-O_2 ratio are all major factors to be considered in making the environment acceptable for habitation. The ventilation of the confining space is not merely the supplying of fresh air, or the replacement of spent O_2, but encompasses the exhausting of heat, dust, toxic gases, fumes and noxious odors which may be present in the sealed space, while returning a usable, uncontaminated air. An examination of each of the above mentioned, singly and in relationship with each other, is necessary for an understanding of the problems of ventilation and air conditioning.

There are three general methods of reducing the moisture content of the air: by compression, by adsorption, and by cooling. Cooling below the dew point and condensing or freezing out the moisture is the most common method of dehumidifying. For this purpose the concepts employed in present day commercial equipment may be utilized to produce the desired effects within the closed ecological system. Modifications with respect to size and weight may have to be investigated.

Another possibility is the utilization of the temperature gradient across the hull of the cabin. Exploratory investigations of the temperatures (see Appendix 5) suggest that at some location the cabin structure will have temperatures low enough to allow the use of freeze-out techniques. The engineering design of such a system requires more thorough investigation to determine its feasibility.

That dehumidification is necessary for comfort control is elementary, but more important is the fact that condensed water vapor from the enclosed atmosphere is one of the probable sources of water supply within the closed ecological system.

The water vapor that is condensed out of the contained atmosphere probably may be a purer and less contaminated source of water than any bodily waste.

Normally the air surrounding a living and breathing body is carried up by its own warmth and consequent lightness, thus allowing fresh air to take its place. But in a gravitationless system neither fresh nor foul air has weight, and there can be no convection currents. Without air circulation, heat discharged from the body would hang against the body causing intense perspiration, which in a saturated atmosphere would not evaporate. Body cooling effect would therefore be minimal. Non-circulation effects would also hold for the expired air. In a non-circulating atmosphere a motionless body would soon become enveloped in expired air, rich in CO_2 and water vapor.

Air motion imparted mechanically by a fan or other stirring mechanism to maintain the entire enclosed atmosphere in a state of turbulence or agitation is necessary.

In any confined area in which activities transpire there are always to be found impurities or foreign matter in the air. These materials are usually particles of organic matter which come from nose, mouth, and skin, and particles derived from the attrition of surfaces. These particles tend to produce odors. The organic particles produce normal body odors which are usually perceived in unventilated or even poorly ventilated areas. Within the contained atmosphere these body odors are to be anticipated and others which are not normally considered must be added.

Although odors as such are not injurious to health, they may affect health indirectly. As odors become extremely noxious, shallow breathing may induce O_2 deficiency and its sequelae. Odors may also be indicators of the presence of toxic substances.

At this time too little is known about the breakdown products and subsequent gasification of body oils, gland secretions, flatulence, and bodily waste products to be certain of their non-toxic effects when accumulated in an atmosphere after cycles of reuse.

The air purification system is envisioned as a train of absorbents and adsorbents which will remove the contaminants from the air by physical processes, chemical reaction or electrostatic attraction. Solid state rather than liquid phase materials should be employed in order to prevent as much as possible additional pollutant carry-over in the air stream and subsequent condensation in the water supply.

H. L. Barneby,[20] in a paper discussing the activity of activated charcoal required for air purification, offers a table which gives some rough idea of the quantity of charcoal required per year for odor concentrations of difficult intensity. As a guess, an odor index of 2, 3, or 4 might be anticipated in the closed space. This corresponds to 0.1, 1.0, and 10 pounds of odor per million cubic feet. One pound per year of charcoal is required to treat 100, 10 or 1 cubic feet of space at the respective levels of concentration. Accordingly, for a space of 1,000 cubic feet the amount of charcoal required may be between 10 and 1,000 pounds. It should be noted here that this amount is only enough to provide for odor removal and is predicated on the assumption that some fresh air is available due to building leakage. It is also important that activated charcoal is not provided for CO_2 adsorption. Barneby points out that activated charcoal is relatively inefficient in removing CO_2 and should not be depended on for that action.

Experiments[174] conducted in 1942 have shown that recycling of air in a closed room through air filters does little to change the overall room microorganism concentration, even though a large number of organisms are caught on the filter. Newer types of air filters of the millipore type, or the impregnated resin deep filters are capable of removing over 99% of the organisms from air drawn through the filter,[5, 82] but the residual concentration of microorganisms in the enclosed atmosphere may still be high.

Germicides, glycol sprays and other similar airborne materials may have a beneficial effect in reducing bacterial numbers, but their effect on humans under confined conditions with continuous inhalation and ingestion would require thorough study before they could be considered safe for use.

In summary it appears that temperature control, air motion development, removal of particulate matter, elimination of odors and control of micro-organism populations seem feasible with modifications of present day commercial equipment. A train of materials can be established such that turbulent air from the confined cabin would be drawn through an activated carbon filter, a millipore, or deep bed filter, and chemical train for specific materials such as CH_4, H_2S, and any others that may become apparent as more analyses of breakdown products are conducted.

By the time the air has passed through the train most of the gross impurities have been removed. This leads to the assumption that the room air may provide the purest source of water available in the confined ecological system. This supply of water developed from the water vapor would undoubtedly contain small amounts of entrained or dissolved gases. What the effect of these small amounts might be on the human system is not known, nor did any of the library references examined indicate study in this field.

It is conceivable that the human body, which is a well-organized purification unit, can receive these materials through inhalation, skin, or oral intake, and detoxify them, if necessary, passing them out as waste products. If this be the case, many problems of train contaminant removal are simplified by having the human body act as its own purification plant.

Further research is much needed in conjunction with the problem of air conditioning for a closed ecological system to ascertain the chronic toxic limits for humans of the several material exposures by ingestion, by inhalation, and by skin absorption. This is opposed to the problem of acute toxicity about which much has been written. Spector[149] offers information on lethal dosages of many compounds, gases, vapors, and fumes.

Other Wastes

The following tabulation sets forth the types of waste and their probable sources:

Type of Waste		Sources
Liquids	Human closed space occupancy	Bodily wastes including urine, feces.
		Room air including products of respiration and perspiration.
		Personal cleansing.
Solids		Clothes washing.
		Food preparation.
		Utensil cleansing.
		Cabin cleansing.
Gases		Process operations.

It will be observed that there are a number of sources of waste other than those related to body metabolism. In the area of personal cleansing, clothes washing, food preparation, utensil cleansing, cabin cleansing and process operations there is almost total lack of knowledge of the probable character and quantity of such wastes.

Waste liquids from all sources will contain organic solids in suspension, in solution or both. Waste solids will contain water within the mass, or be suspended in water or air. Wastes gases will be mixed with room air or will be trapped and become part of an air purification train.

Waste solids in a more complex system may be developed directly, i.e., from feces and food preparation wastes; or indirectly, i.e., from residues from the recovery of water from urine, room air, and various cleansing operations. In either case the composition of the wastes is not now known.

The composition and quantity of feces are related to the diet. The composition and quantity of food preparation wastes are related to the food supply and its characteristics. Direct wastes from dehydrated foods preparation will probably be minimal. The amount and character of waste that may

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come from the use of algae or some other food product of the closed system is pure conjecture until more is discovered about the condition of the food product and the useable amounts recoverable within the cycle.

Indirect wastes will be end products of a treatment process. Other than the immediate knowledge that such wastes will be both organic and mineral in composition and will be of variable moisture content depending on the process, little can be predicted without definitive knowledge of a particular process.

Literature on sewage treatment processes is voluminous. The journal of the Federation of Sewage and Industrial Wastes Associations, Sewage and Industrial Wastes, is perhaps the most complete single source of information on sewage treatment.

Methods normally used include screening to remove larger solids, sedimentation to remove settleable suspended material, and a form of biological treatment to remove dissolved organic materials. The use of algae as a means of sewage purification is not feasible (see Appendix 2, part VI).

The remaining biological processes used in present treatment practice are the activated sludge process and the trickling filter process. Both of these require the maintenance of a culture of a complex of microorganisms including bacteria and protozoa. The problems of maintenance appear to be even more involved than those related to the mass culture of algae. In this area of treatment an entirely new concept must be evolved to meet the parameters of weight and cubage permissible for a closed space ecology. It is conceivable that all liquid and semi-liquid wastes, with the exception of urine, and room air water condensate would have to be combined for further treatment. Recycling of water seems inevitable and to satisfy the daily requirement between 90 and 95% of available water (not including that in feces) should be recovered in a degree of purity compatible with the end use.

Obviously, water for drinking purposes would need to be entirely potable, psychologically acceptable, and physiologically useable.

There are complexities that require step by step screening and involve consideration of a number of hypothetical combinations of recovery for use. Concurrently the possible usefulness of anticipated end products of treatment must be considered. For example, fibrous materials might be used as filter aids, and mineral matter, such as nitrates or phosphates, may have a nutrient value for another process such as algae growth. Vitamins may be recoverable as a diet supplement. (Domestic sewage sludge is a potential source of Vitamin B-12.) Even inert matter may have some value and its usefulness should be given attention.

Research effort is required along the following lines in relation to the handling of other wastes:

1. Establishment of the elements of food supply suitable for maintaining man in a closed space ecology, including information on use of concentrated, dehydrated, precooked, cooked in place, and synthesized food products.

2. Exploration of food preservation procedures that will minimize spoilage and waste which, in order, would merely add to the non-productive shipping weight support and increase the need for equipment weight to reprocess or treat spoiled products. Preservation techniques include deep freezing, irradiation and suitable protective packaging.

3. Extimation of food losses that may be anticipated within the handling cycles and subcycles as they may affect the quantity and composition of wastes to be recycled. These include direct spoilage, loss due to physical damage and contamination, preparation loss, uneaten food, and cleansing losses.

4. Projection of treatment processes applicable to the treatment of water-carried wastes and the solids resulting therefrom into treatment processes that may have feasibility and practicability aboard space vehicles when useability of end products is the objective.

COMMENT

From the foregoing discussion it is obvious that there are many environmental factors that require research. Not until closed space air is maintained at safe and healthful levels, polluted liquids and objectionable solids are treated or safe practice in handling and disposal is devised, will it be possible to maintain human life for weeks or months in a closed space. The processes that are employed must not fail, since the environment will be totally dependent on the continuous and proper functioning of reclamation and conversion operations.

It is to be anticipated that research directed along paths suggested here and in more detail in appendices will permit early development of methods, processes, and equipment required.

ANNOTATED REFERENCES

The following references have been prepared to assist those who wish to search more deeply into various aspects of the closed ecological system with special consideration of the handling, recovery, collection, conversion, storage and reuse of waste products of closed space occupancy.

Since the ASTIA established a codification system having a classification that is in wide use among military agencies and contractors dealing with military agencies, the references set up here are in general conformance with ASTIA classification. That is, the category, Medical Sciences, is ASTIA No. 16. The section, Anatomy and Physiology, under Medical Sciences is No. 1. That category and subdivision is expressed as 16-1. Within each category and subdivision thereof the references have been listed alphabetically and a number assigned to each. That is, the first reference under 16-1 has a Master File No. 16-1-1; the second reference is 16-1-2.

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An author cross reference system has been established so that if one is searching for an author's works among these references it is possible to search the Author Index alphabetically and find both the Author Index No. and the Master File No.

For example, S. Robinson has conducted studies on composition of sweat. In the Author Index under Robinson the Master File No. is 16-1-11. The Author Index No. is 136. Both identifying numbers appear in these references and in the author listings. Multiple writings of one author may be found easily in the Author Index, and the references, being shown by Master File No., can be found quickly in these pages.

The ASTIA categories and subdivisions under which references have been prepared are listed below. ASTIA categories not shown herein have no annotated references in this listing.

1. AIRCRAFT & FLIGHT EQUIPMENT
    2. Aircraft Design
    4. Flight Operating problems
    5. Flight Safety

2. ASTRONOMY, GEOPHYSICS & GEOGRAPHY
    7. Meteorology

4. CHEMISTRY
    1. Chemical Engineering
    2. Inorganic Chemistry
    3. Organic Chemistry
    4. Physical Chemistry

13. INSTALLATIONS & CONSTRUCTION
    1. Air Conditioning & Refrigeration Equipment
    3. Sanitation Engineering

16. MEDICAL SCIENCES
    1. Anatomy & Physiology
    2. Bacteriology
    3. Biochemistry
    4. Biology
    6. Hygiene & Sanitation
    9. Nutrition
    11. Pharmacology & Toxicology

25. PHYSICS
   8. Thermodynamics

29. QUARTERMASTER EQUIPMENT & SUPPLIES
   2. Food & Containers

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Author Index No.		Master File No.
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163	Thompson, T.G. and Nelson, K.H., "Desalting Sea Water by Freezing," Refrigerating Engineering, 62, 7, 44 (July, 1954).	4-1-20
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166	Van Heuvelen, W. and Svore, J.H., "Sewage Lagoons in North Dakota," Sewage and Ind. Wastes, 26, 6, 771 (June, 1954).	13-3-7
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170	White, C.S. and Benson, O.O., Jr. (Editors), "Physics and Medicine of the Upper Atmosphere," Univ. of New Mexico Press, Albuquerque, N.M. (1952).	16-0-5
171	Winslow, C.E.A., et al, "Ventilation," Report of the New York State Commission on Ventilation, Milbank Memorial Fund, E.P. Dutton & Co., New York, N.Y. (1923).	13-1-16
172	von Witsch, H. and Harder, R., Production of Organic Material by Green Algae and Diatoms, "Algal Culture from Laboratory to Pilot Plant," p. 154, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953).	16-4-58
173	Yaglou, C.P., Riley, E.C. and Coggins, D.I., "Ventilation Requirements," Paper 1031, Trans. A.S.H.&V.E., 42, 133 (1936); also, Heating, Piping and Air Conditioning, 8, 1, 65 (Jan., 1936).	16-6-5
174	Yaglou, C.P. and Wilson, U., Disinfection of Air by Air Conditioning Processes, "Aerobiology," Publication No. 17 (edited by F.R. Moulton), p. 129, American Association for the Advancement of Science, Washington, D.C. (1942).	13-1-17

MASTER INDEX

Author Index No.		Master File No.
	1-0, AIRCRAFT & FLIGHT EQUIPMENT	
74	Haber, H., "Space Satellites, Tools of Earth Research," National Geographic, CIX, 4, 486 (Apr., 1956). Discusses historical background leading to space flight. Presents the type of scientific research which will be conducted in connection with the International Geophysical Year.	1-0-1
138	Ross, M.D. and Lewis, M.L., "To 76,000 Feet by Strato-Lab Balloon," National Geographic, CXI, 2, 269 (Feb., 1957). Review of problems. Suggests data from General Mills, Minneapolis, Minn.	1-0-2
151	Stevens, A.W., "Man's Farthest Aloft," National Geographic, LXIX, 1, 59 (Jan., 1936). Rising to 13.71 miles, the National Geographic Society-U.S. Army Air Corps Stratosphere Expedition gathers scientific data at record altitude.	1-0-3

Author Index No.		Master File No.

1-2, AIRCRAFT DESIGN

119 Nicoll, N.R., "Design of the Life Compartment Necessary for Space Travel," Journal of the British Interplanetary Society, 13, 5, 277 (Sept., 1954). 1-2-1

The author describes a parabolic housing with a saucer-shaped base as the life compartment. The atmospheric control is through adsorption of CO_2 by Lithium Oxide, liquid oxygen being used as make-up. Special attention is called to the fact that the ship will rotate to develop a gravitational field.

Calculation of weights of life compartment in which three men will live for up to 15 days.

Structure	1,220#
Air locks	150
Coelostate apparatus	52
Chaise longue and rails	84
Catwalk and supports	196
Refrigeration plant	56
Food, O_2 & apparatus	168
Water	112
Total	2,038#

144 Slote, L. and Murray, W.D., "A Method of Predicting Skin, Compartment, and Equipment Temperatures for Aircraft," Final Report, New York Univ. Contract No. AF 33(616)-122, ASTIA No. AD-19722, WADC Technical Report 53-119 (July, 1953). 1-2-2

This report presents a method for the calculation of the equilibrium skin temperature of aerodynamic shapes in steady flight. Graphical methods are presented for the calculation of equipment temperature and compartment air temperature. The numerical and graphical solutions are presented for aircraft flying at speeds to Mach number 5 and for altitudes from 0 to 100,000 feet in the proposed USAF Hot and Cold Atmospheres.

In this report an attempt is made toward simplification of the empirical formulae by graphic presentation of calculations upon typical aerodynamic shapes. Analysis is based upon consideration of a flat plate and the case of an isothermal surface and constant free stream velocity. Methods for applying the graphs to other surfaces are presented.

Author Index No.		Master File No.
	1-4, FLIGHT OPERATING PROBLEMS	
140	Sandorff, P.E. and Prigge, J.S., Jr., "Thermal Control in a Space Vehicle," Journal of Astronautics, III, 1, 4 (Spring, 1956). A mathematical analysis of the probable temperature of the surface of a space vehicle under various flight conditions. The formula which the authors develop is: T mean = 796°R where T mean = Aver. Temp. in °R and R is radius in inches. One rpm would cause stabilization of hull temperature at 705° R ± 10° R. Some means of maintaining low temperatures inside the ship must be designed. Discusses insulation, use of double hull construction heat pump, radiation shields and use of heat stops in the hull itself.	1-4-1

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Author Index No.	1-5, FLIGHT SAFETY	Master File No.
108	McFarland, R.A., "Human Factors in Air Transport Design," 1st Ed., McGraw-Hill Book Co., New York, N.Y. (1946).	1-5-1

Text book of 670 pages with 13 chapters and 3 appendices.

Book outlines interaction of human and physical variables in flight which are important in the operation of aircraft.

Book covers safety and efficiency of operation as well as comfort and well being of passengers during all stages of flight.

Author Index No.		Master File No.
	2-7, METEOROLOGY	
30	Brooks, C.E.P. and Evans, G.J., "Part II. Annotated Bibliography on the Climate of Enclosed Spaces (Cryptoclimates)," Meteorological Abstracts, 7, 2, 211 (Feb., 1956).	2-7-1

Good reference for finding additional reference material. 282 abstracts given. Covers 1868 to date.

Includes some information on: (1) Devices for modifying indoor climate; (2) Controlled laboratories for simulating weather or climatic conditions; (3) Measurement methods for meteorological elements affecting indoor climate.

Note references: 7B-40, 7B-45, 7B-49, 7B-55, 7B-58, 7B-66, 7B-67, 7B-71, 7B-72, 7B-74, 7B-89, 7B-154, 7B-165, 7B-192, 7B-195, 7B-215, 7B-222, 7B-232, 7B-238.

Underlined references appear to justify immediate follow up.

Author Index No.		Master File No.
	4-1, CHEMICAL ENGINEERING	
8	___________, "More from the Bottom of the Barrel," Oil and Gas Journal, 52, 46, 123 (Mar. 22, 1954).	4-1-1

A discussion (with flow diagrams) of seven different processes newly developed or revised to help reduce the bottom of barrel stocks of crude oil.

The processes discussed are all primarily useful in converting portions of the residue into suitable feeds for catalytic cracking units.

25	Berliner, J.J. and Staff, "Freeze Drying," Report No. 7066, J.J. Berliner, New York, N.Y. (undated).	4-1-2

Freeze drying was used early in France during the 1900's through 1930 as a process for preserving labile biological products. The process in the beginning consisted of freezing the material and placing it in a desiccator over P_2O_5 and applying a vacuum until dried.

In the U.S. patents were issued in 1934 and 1938 for freeze drying in thin layers with refrigerator coils under high vacuum. External radiant heat was supplied.

A paper by Greaves and Adair is cited, but the reference is not given. This paper describes the thermodynamic relationships involved in heat transfer to control drying rates without melting the frozen material.

A discussion is presented giving the mechanism of freeze drying according to the principles based on the phase diagram of the watery solution being concentrated. Actually, the process involved should be one consisting of sublimation without any liquid phase being present at any time after freezing has taken place, so that instead of distilling water, the solid ice can be vaporized at a much lower temperature which is well below the eutectic.

In order to reduce the partial pressure over the solid being sublimed high vacuums are necessary. Energy to satisfy vaporization requirements are supplied by outside heat, and vapors are removed continuously by means of a pump.

Diagrams are presented showing the simple sublimation procedure, the equilibrium diagram for the water-solute system, and a phase diagram for pure water.

Author Index No.		Master File No.
	4-1, CHEMICAL ENGINEERING	4-1-2

25 (cont'd)

Calculations are given showing the effect of air leakage into the system on the efficiency of vapor condensation when the condenser temperature is at about -40°C and the still temperature at -20°C.

The authors point out that in the low micron pressure ranges gaseous flow does not follow ordinary fluid flow principles. Instead, Knudson's molecular flow formula is obeyed. This is: $Q = \frac{4}{3} \sqrt{2n} \sqrt{\frac{RT}{M}} \frac{r^3}{L} (P_1 - P_2)$

Q = flow in liters/sec. measured at the average pressure
R = gas constant
T = absolute temperature (scale not stated; probably Cent.)
M = molecular weight of the gas
r = radius of the tube through which the gas flows in centimeters
L = length of the tube in centimeters
P_1 and P_2 are the upstream and downstream pressures in micron (n = not stated by the authors).

After a discussion of the freeze-drying mechanism in very general terms, an estimated cost of drying foods on a production scale is given as about $0.03/lb. of water removed.

The conditions under which a given volume of material at a specified temperature will freeze-dry or sublime at a maximum rate are summarized as follows:

1. The vapor pressure of the ice sublimed on the condenser is negligible in comparison with that of the frozen material.
2. The surfaces of condenser and frozen material have a uniform and minimum separation.
3. The partial pressure of the permanent gas (usually air) in the interspace is a minimum.
4. Mechanical obstruction to vapor transfer by radiation shields and sterile caps is a minimum.
5. The frozen material is of uniform and minimum thickness.

26 Bowman, N.J., "The Food and Atmosphere Control Problem on Space Vessels, Part I. Chemical Purification of Air," Journal of the British Interplanetary Society, 12, 3, 118 (May, 1953). 4-1-3

The removal of water from the air may be readily carried out by refrigeration. The removal of CO_2 by combined refrigeration and compression is not attractive because of large quantities of air that must be processed to keep CO_2 concentration below 0.2%. For short trips use of Lithium Oxide is recommended for absorption, while for longer trips (over 8 days) use of CaO and regeneration in a muffle furnace is recommended.

Author Index No.	4-1, CHEMICAL ENGINEERING	Master File No.
26 (cont'd)	Various values for water exhaled, CO_2 produced and O_2 utilized. An estimate:	4-1-3

1 pint of water/man/day exhaled
1 kg of CO_2/man/day for moderate activity
O_2 consumption varies from 300 to 750 ml/min.

The fact is pointed out that it would be necessary to carry liquid O_2 to replace that consumed by the body.

29 Bradish, C.J., Brain, C.M. and McFarlane, A.S., "Vacuum Sublimation of Ice in Bulk," Nature, 159, 4027, 28 (Jan. 4, 1947). 4-1-4

A discussion of the theory and equipment used for freeze drying of biological materials for the maximum rate of vaporization per unit exposed area of frozen product at a specified temperature.

43 Calvin, M. and Sogo, P.B., "Primary Quantum Conversion Process in Photosynthesis; Electron Spin Resonance," Science, 125, 3246, 499 (Mar. 15, 1957). 4-1-5

A possible explanation of an age old mystery--how plants build sunlight into the food compounds that maintain life on earth--was proposed in Washington.

44 Cheasley, T.C., Forrester, J.D. and Sarapuu, E., "Underground Electrocarbonization of Coal and Related Hydrocarbons," Mining Engineering, 6, 9, 908 (Sept., 1954). 4-1-6

The process described is the gasification of coal or oil by passing an electric current through the beds beneath the ground. It is essentially a coke oven below ground being heated by electrical energy.

Explains problems and costs of operation as well as results from pilot unit at Hume, Mo.

46 Curran, H.M., "Fresh Water Extracted from Salt Water: Is the Freezing Method the Best?," Refrigerating Engineering, 63, 9, 45 (Sept., 1955). 4-1-7

The freezing method of extracting fresh water from salt water and the distillation method are similar in that both involve the formation of a pure water phase by the application of suitable heat transfer processes. The methods differ in that the ice phase remains in contact with residual brine, whereas in distillation the vapor phase requires a suitable process subsequent to freezing in order to separate the ice and brine. Difficulties in handling the solid phase are disadvantageous at present.

Author Index No.	4-1, CHEMICAL ENGINEERING	Master File No.
		4-1-7

46 (cont'd)

No process has been discovered as yet by which all the ice found can be made available as a source of water. Whether the separation of ice and brine is accomplished by gravitational draining, centrifuge draining, washing or a combination, some ice must be lost by melting to reduce the concentration of brine adhering to crystal faces.

Processes for rapid freezing of thin layers of ice and subsequent centrifuging of ice are explained. Techniques and apparatus described and results tabulated.

47 Daniels, F., "Atomic and Solar Energy," American Scientist, 38, 4, 521 (Oct., 1950). 4-1-8

The author states, "Is there any chance of beating nature at her own game and developing artificial photosynthesis with organic dyes and enzyme substances? Might not these cause the combination of carbon dioxide and water using reactions somewhat different from those occurring in the growth of green plants?" He then states that there doesn't seem to be any theoretical reason for such a development to be unsuccessful in the distant future. He believes, "It would be interesting to see what might be done with two million dollars in three years for the greater utilization of solar energy for peaceful purposes under conditions of decentralization and independent initiative, aided by rapid publication of results."

52 Echols, L.M., "Evaluation of Methods of Generating Oxygen from Solid Chemicals for Aircraft Breathing Systems," ASTIA No. AD-10360, Technical Memorandum Report WCRD 53-10 (Feb. 11, 1953). 4-1-9

The purpose of this report is to evaluate the work already done in the field of chemical oxygen, and to estimate the work which lies ahead. Comparisons made herein deal with the gaseous, liquid and chemical means of supply of oxygen to aircraft breathing systems. The points for consideration are:

1. Weight
2. Volume
3. Performance
4. Hazards
5. Handling and Storage

4-1, CHEMICAL ENGINEERING

Author Index No.		Master File No.
52a	Rehling, H.R. and Leser, T., "Determination of the True Composition of the Products of the Theoretical Combustion with Oxygen and Oxygen/Nitrogen Mixtures at Temperatures Up to 2500°C. at Atmospheric Pressures," p. 634, Third Symposium on Combustion and Flame and Explosion Phenomenon, Standing Committee on Combustion Symposia, The Williams and Wilkins Co., Baltimore, Md. (1949). No chemical reaction can be fully understood without complete knowledge of the reaction products. In combustion with air it is possible to calculate the approximate gas composition since flame temperatures normally do not reach beyond 2000°C. and dissociation is relatively small. The authors show how it is possible to calculate the amount of atomic hydrogen and oxygen formed in the simplest cases where the gas contains only CO_2 and H_2O.	4-1-10
58	Flosdorf, E.W., "Freeze Drying as Applied to Penicillin, Blood Plasma and Orange Juice," Chemical Engineering Progress, 43, 7, 343 (July, 1947). Discussion of reasons for freeze drying and equipment used. The advantages and disadvantages of batch operation vs. continuous operation are discussed.	4-1-11
66	Gerster, J.A., "Advances in Distillation Separation," Ind. and Eng. Chem., 47, 2, 253 (Feb., 1955). The article discusses distillation and its advances to permit greater accuracy in design of fractionating columns. Some new techniques in azeotropic and extractive distillation are summarized.	4-1-12
70	Greaves, R.I.N., "Centrifugal Vacuum Freezing," Nature, 153, 3886, 485 (Apr. 22, 1944). Describes the application of centrifugation to the drying of biological materials from the frozen state. Centrifuging the material as the temperature is lowered prevents frothing. Axis of spinning permits variation in shape of final frozen material.	4-1-13
92	Kirk, R.E. and Othmer, D.F. (Editors), Section on Drying, Drying Agents and Drying Oils, "Encyclopaedia of Chemical Technology," Vol. 5, p. 232, Interscience Publishers, Inc., New York, N.Y. (1950). Sections of encyclopedia cited above list methods, equipment and theory of action of drying, drying agents and drying oils.	4-1-14

Author Index No.	4-1, CHEMICAL ENGINEERING	Master File No.

100 Liimatainen, R.C. and Mecham, W.J., "Removal of Halogens, Carbon Dioxide, and Aerosols from Air in a Spray Tower," ASTIA No. AD-69324, ANL-5429 Eng. (Feb. 28, 1955). 4-1-15

Tests were made of the removal from air of Bromine, Fluoride and Iodine vapors, of atmospheric Carbon Dioxide, and of two aerosols (of 0.5 and 0.10 micron mean diameter) from a multiple nozzle caustic spray tower with gas flow rates up to 6000 cu. ft./min. The halogen absorption efficiencies ranged from 60 to 100 per cent, with an average K_Ga of 13 lb.-mol./(hr.)(cu. ft.)(atm.). The corresponding average gas rate was 1442 lb./(hr.)(sq. ft.) and the average liquid rate was 112 lb./(hr.)(cu. ft.). The average concentration of Potassium Hydroxide used was 6 weight per cent. Carbon Dioxide runs over a range of gas rates, liquid rates, Carbon Dioxide concentrations, and Potassium Hydroxide concentrations showed values of K_Ga as high as 3.74 lb.-mol./(hr.)(cu. ft.)(atm.), which is comparable to those obtained in packed towers. The K_Ga was independent of the gas rate, but increased with liquid rate, Carbon Dioxide concentration, and Potassium Hydroxide concentration. Aerosol absorption efficiencies were between 35 and 57 per cent in the tests made. Analysis of the spray contacting mechanism was developed for the purpose of aiding in the design of highly efficient spray scrubbers.

104 Mair, B.J., Pignocco, A.J. and Rossini, F.D., "A 50 Stage Apparatus for Distillation at Very Low Pressures," Anal. Chem., 27, 2, 190 (Feb., 1955). 4-1-16

Paper describes design and assembly of a 50 stage apparatus for distillation at very low pressures.

Operation and tests are described in conjunction with petroleum paraffins.

Materials for report from doctoral thesis and American Petroleum Institute Research Project No. 6, Carnegie Institute.

141 Schroeder, A.L. and Schwarz, H.W., "Low Temperature Vacuum Dehydration," Chemical Engineering Progress, 45, 6, 370 (June, 1949). 4-1-17

A general review of high vacuum dehydration is presented. Equipment and operation costs are discussed.

The problems of drying rate, final moisture content, concentration and mechanism of release of water are mentioned as requiring further study.

Two general types of high vacuum dehydration are considered; namely, sublimation drying and liquid film drying.

Author Index No.	4-1, CHEMICAL ENGINEERING	Master File No.

155 Stutzman, L.F., Tri-Monthly Report, Project NR 266-001 (N6-ori-158), ASTIA No. AD-6741, Chem. Eng. Dept., Northwestern Technological Inst., Evanston, Ill. (July 1-Sept. 30, 1952). 4-1-18

One of the most promising regenerative chemical methods for removal of CO_2 from air is by reaction with Silver Oxide to form Silver Carbonate, which can later be regenerated to the original Silver Oxide. This method, along with many others, was listed in the complete survey of CO_2-removal methods presented in a recent report of Project NR 266-001, dated March 31, 1952. The same general reaction will occur with many metal oxides, but Silver Oxide seems to offer the best possibility of easy reversibility, thus making possible a regenerative process for CO_2 removal.

156 Stutzman, L.F., "Operation Hideout," Report, Project NR 266-001 (N6-ori-158-03), ASTIA No. AD-19360, Chem. Eng. Dept., Northwestern Technological Inst., Evanston, Ill. (Sept. 30, 1953). 4-1-19

Report gives data of a trial installation utilizing a Sodium Hydroxide scrubber to remove CO_2 from a closed environment.

The scrubber removed CO_2 at an average rate of 9.77#/hr. at an average caustic utilization of 90.3%.

Operating characteristics for the caustic unit:

Air rate 600 cfm at 80°F. and 750 mm Hg.
Caustic (28.5%) feed rate. 59.6#/hr.
Water feed rate--theoretical--127.1#/hr.
CO_2 removed from air 7.5#/hr.
Caustic utilization 80%.

Foul air is blown through a packed column over which the caustic is permitted to drain downward. The spent caustic could be pumped directly to the sea.

The equipment, with no attempt for compactness, covered an area approximately 9' x 2'. The caustic feed was outside the ship.

CO_2 levels were checked and scrubber cut in or out electronically through a Gow Mac analyzer, a Brown potentiometer, and a Liston Becker Carbon Dioxide analyzer.

Men were sealed in on January 27 and released on March 10, 1953, for a total of 42 days. CO_2 levels were maintained between 1% and 1.5%. Smoke and odors were also removed to a remarkable degree.

Author Index No.	4-1, CHEMICAL ENGINEERING	Master File No.
156(cont'd)	Medical aspects of the test pertaining to physiological, psychological and sociological, as well as medical examinations, are not reported. These were by Medical Research Laboratory at New London Submarine Base.	4-1-19
163	Thompson, T.G. and Nelson, K.H., "Desalting Sea Water by Freezing," Refrigerating Engineering, 62, 7, 44 (July, 1954).	4-1-20

Report of experimental procedure for freeze-out of desalted water from sea water. Various arrangements are noted and description of techniques employed.

The authors state that hot brines are very corrosive and that severe encrustation occurs during distillation so that only about 30% recovery is achieved.

Additional references cited:

Hampel, C.A., "Fresh Water from the Sea," Chem. Eng. News, 26, 1982 (1948).
Telkes, M., "Fresh Water from Sea Water by Solar Distillation," Ind. Eng. Chem., 45, 1108 (1953).
Howe, D., "Fresh Water from Salt Water," Trans. Am. Geophys. Union, 33, 417 (1952).

Author Index No.	4-2, INORGANIC CHEMISTRY	Master File No.
128	Quinn, E.L. and Jones, C.L., "Carbon Dioxide," A.C.S. Monograph No. 72, Reinhold Publishing Co., New York, N.Y. (1936).	4-2-1

Extensive data on the properties of CO_2 in gaseous, liquid and solid forms.

Critical Temp.	-31.0°C.
Critical Pressure	-72.8 atmospheres
Triple Point	-56.6° C. and 5.1 atmospheres

Specific Volumes (liters/Kilogram)

Temp. °C.	Saturated Vapor	Saturated Liquid	Solid
31	2.156	2.156	
30	2.990	1.6768	
20	5.258	1.2976	
10	7.519	1.1655	
0	10.383	1.0813	
-10	14.194	1.019	
-20	19.466	0.971	
-30	27.001	0.931	
-40	38.164	0.897	
-50	55.407	0.867	
-56.6	72.220	0.849	0.661
-60		0.840	0.657
-80			0.639
-100			0.627
-183			0.599

Extensive data given on the adsorption of CO_2 gas by Silica Gel and Charcoal; also on the solubility in water and various other liquids and solutions.

Chemical Properties of CO_2

Hydrolysis of starch (in saturated solution of CO_2 at high pressures) to dextrose.
100% conversion of the starch accomplished in:
1.5 hours at 216° C. and 100 atmospheres
and 5 hours at 180° C. and 100 atmospheres

Reference: Dewey & Krase; Ind. Eng. Chem., 23, 1436-7 (1931).

Reduction of CO_2 by Hydrogen

Most usual reaction: $CO_2 + H_2 \rightleftharpoons CO + H_2O$
Other products may be formed under certain conditions, especially under influence of catalytic agents.

Complete reduction to C may possibly take place according to reaction: $CO_2 + 2H_2 \rightleftharpoons C + 2H_2O$

Reference: Randall, et al; Ind. Eng.Chem., 21, 941 (1929).

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128(cont'd) 4-2-1

Note: This last looks intriguing:

$$CO_2 + 2H_2 \rightleftharpoons C + 2H_2O$$

$$2H_2O + \xrightarrow[\text{decomp.}]{\text{electrolytic}} 2H_2 + O_2$$

Overall reaction is:

$$CO_2 \longrightarrow C + O_2$$

CO_2 Reduction by Metals

ex $Sn + 2\ CO_2 = SnO_2 + 2\ CO$

also $2\ CO_2 + 2\ K = K_2C_2O_4$ (Potassium Oxalate)

CO_2 with NH_3 Produces Urea

$CO_2 + 2NH_3 \longrightarrow (NH_3)_2\ CO_2 \longrightarrow (NH_2)_2\ CO + H_2O$

urea

Reduction with Carbon

$CO_2 + C \longrightarrow 2\ CO$

132 Randall, M. and Gerard, F.W., "Synthesis of Methane from Carbon Dioxide and Hydrogen," Ind. & Eng. Chem., 20, 12, 1335 (Dec., 1928). 4-2-2

The equilibrium in the formation of methane and water vapor from CO_2 and H_2 and the reverse reaction have been determined. The free energy of methane calculated from these experiments is in agreement with the value found from the direct synthesis from graphites and hydrogen in the same temperature range. The cause of the deposition of carbon in the catalysts has been discussed.

133 Randall, M. and Shiffler, W.H., "Deposition of Carbon in Reaction Between Carbon Dioxide and Hydrogen," Ind. & Eng. Chem., 21, 10, 941 (Oct., 1929). 4-2-3

The authors show that the reaction:

$$CO_2(g) + 2H_2(g) = C\ (graph.) + 2H_2O(g)$$

is the sum of Reactions 12 and 13 in the previous reference (Author Index No. 132, Master File No. 4-2-2) by M. Randall and F.W. Gerard, and can largely explain the experimental results.

Author Index No.	4-3, ORGANIC CHEMISTRY	Master File No.

14 ___________, Report, 126th National A.C.S. Meeting, Division of Gas and Fuel Chemistry, Chemical and Engineering News, 32, 40, 3955 (Oct. 4, 1954). 4-3-1

R.S. Montgomery of Dow Chemical reported on methods of developing and then separating various aromatic acids from coal.

Three methods were used:

1. Solvent fractionation - use of a different solvent to extract portions.
2. pH Separation - separation according to change in pH.
3. Vacuum Sublimation - here new material formed that was not present in original coal acid mixture. New products are caused by thermal decomposition of some components in original mixture.

61 Gaffron, H., "The Development of Organic Photochemistry Concomitant with the Production of Organic and Living Matter on Earth," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 4-3-2

Investigations of photosynthesis in the past were guided mainly by the assumption that within the green plant carbon dioxide, or a derivative of it, is more or less directly converted into sugar when in contact with light-activated chlorophyll. The solution of the problem was looked for in the specific photochemistry of carbon compounds. The author states that today, as a result of numerous investigations, we know that the main riddle in photosynthesis consists in the highly efficient interaction between an excited pigment-enzyme complex and the molecules of water. The reduction of Carbon Dioxide is one of several possible consequences of this photochemical process. It just happens to be greatly favored under the conditions found in green plants as they exist today.

71 Greaves, R.I.N., "The Preservation of Proteins by Drying," Special Report No. 258, Medical Research Council, H.M. Stationery Office, London, England (1946). 4-3-3

A discussion of techniques of freeze drying with particular reference to proteinaceous material.

Author Index No.	4-3, ORGANIC CHEMISTRY	Master File No.

103 Mair, B.J., Montjar, M.J. and Rossini, F.D., "Fractionation of Hydrocarbons by Adsorption with Added Components," Anal. Chem., 28, 1, 56 (Jan., 1956). 4-3-4

A method is described for separating hydrocarbon by adsorption and then fractionation.

Method is considered effective for separating branched paraffins from cycloparaffin.

164 Turk, A., "Catalytic Reactivation of Activated Carbon in Air Purification Systems," Ind. and Eng. Chem., 47, 5, 966 (May, 1955). 4-3-5

Activated carbon is used for the absorption of organic vapors. This process suffers from the necessity of frequent reactivations of the carbon. This is usually accomplished by the use of superheated steam being passed over the carbon.

To reduce the cost and increase efficiency the carbon is impregnated with a catalyst of moderate activity which does not impair the absorption properties of the carbon.

Then when the carbon is saturated, reactivation is effected by passing a warm air stream over the combined carbon-catalyst. The adsorbate is completely oxidized in the catalyst-carbon surfaces.

The activated carbon must have a high kindling point. Successive reaction reactivations do not alter the adsorption capacity of the carbon.

Chromic Oxide is one of the catalytic agents mentioned.

The problem of disposal of the oxidized desorbed gases remains.

Author Index No.	4-4, PHYSICAL CHEMISTRY	Master File No.
6	__________, "Freeze Drying of Foodstuffs," Modern Refrigeration, XLVI, 540, 55 (Mar. 18, 1943). Excerpts from the address of A.S. McFarlane outlining history of development of dehydration of foodstuffs and a description of procedure and theory with discussion of pan type freezing unit.	4-4-1
23	Bassham, J.A. and Calvin, M., Photosynthesis, "Currents in Biochemical Research," (edited by D.E. Green), p. 29, Interscience Publishers, Inc., New York, N.Y. (1956). The authors attempt to present some current opinions regarding selected aspects of photosynthesis, together with some speculations in areas that may be expected to prove fruitful in the near future. These areas are: Function of Chloroplast; The Carbon-Reducing Enzymes; The Light Reaction; and Intermediate Transfer Systems.	4-4-2
28	Bradish, C.J., "Freeze Drying," Chemical Products, 10, 9-10, 60 (July-Aug., 1947). A discussion of theory of freeze drying as well as a description of apparatus for vacuum sublimation of ice. The freeze drying cycle and mechanism of freeze drying with particular discussion of the tray drier is reported.	4-4-3
36	Burk, D., Cornfield, J. and Schwartz, M., "The Efficient Transformation of Light into Chemical Energy in Photosynthesis," Scientific Monthly, LXXIII, 4, 213 (Oct., 1951). Presents an application of the Einstein Law of Photochemical Equivalence to living organisms.	4-4-4
45	Commoner, B. and co-workers, "Free Radicals Power Life," Science News Letter, 71, 16, 243 (Apr. 20, 1957). Free radicals, which contain unpaired electrons, have been found associated with life processes by a team of Washington University scientists.	4-4-5
51	Duysens, L.N.M., "Energy Transfer Within the Chloroplast," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). Plants have solved the problem of using air, water and light as sole raw materials to produce sugar or other	4-4-6

Author Index No.	4-4, PHYSICAL CHEMISTRY	Master File No.
51(cont'd)	carbohydrates, an achievement, the author states, you would not believe if you had not heard about it in school. He also states that anybody who intends to find out a way for using light energy in order to drive chemical reactions may find it worthwhile to acquaint himself with what is known about the mechanism of sugar production by plants. The author then goes on to discuss a few aspects of photosynthesis that held interest for him.	4-4-6
120	Nord, M., "Principles of Freeze Drying," <u>Food Manufacture</u>, <u>XXVII</u>, 11, 452 (Nov., 1952). Elaboration of principles and mechanisms of freeze drying. Discussion of operational principles and costs.	4-4-7
129	Rabinowitch, E.I., "Photosynthesis and Related Processes," Vol. I, Interscience Publishers, Inc., New York, N.Y. (1945). Volume I deals with the chemistry of photosynthesis, chemosynthesis and related processes in vitro and in vivo..	4-4-8
130	Rabinowitch, E.I., "Photosynthesis and Related Processes," Vol. II, Pt. 1, Interscience Publishers, Inc., New York, N.Y. (1951) Volume II, Part 1, deals with the spectroscopy and fluorescence of photosynthetic pigments; kinetics of photosynthesis.	4-4-9
131	Rabinowitch, E.I., "Photosynthesis and Related Processes," Vol. II, Pt. 2, Interscience Publishers, Inc., New York, N.Y. (1956). Volume II, Part 2, deals with the kinetics of photosynthesis; addenda to Volume I and Volume II, Part 1.	4-4-10
161	Thomas, J.B., "The Chloroplast as a Photoreceptive Mechanism in Photosynthesis," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). The author states that though the photosynthetically active organelles may differ in different species, the photoreceptive part of these structures always consists of lamellae. Lamellae are also encountered in other photoreceptors, such as the outer segments of the retinal rod. However, a layered structure is not restricted to such organelles. It is encountered in various centers of intense chemical activity, such as nerves. Actually, this can also be said of chloroplasts.	4-4-11

Author Index No.	13-1, AIR CONDITIONING & REFRIGERATION EQUIPMENT	Master File No.
1	__________, "Air Cleaner," Iron Age, 175, 14, 152 (Apr. 7, 1955).	13-1-1
	Article describes new type of air scrubber devised by National Dust Collector Corp. and National Engineering Co. to filter out all foundry shakeout room dust as well as bentonite and polishing agents.	
	The dust laden air passes through a water bath, a water fog and through horizontal bed of glass spheres which are kept hot.	
	The sludge drops to bottom of pool and water is reused.	
3	__________, "Control Toxic or Combustible Gases, Dusts or Vapors," Rock Products, 57, 10, 73 (Oct., 1954).	13-1-2
	The article explains the necessity and use of portable safety equipment for boiler, kiln and other equipment in and around a cement plant as needed for intermittent use by repair and maintenance crews.	
5	__________, "Filtration of Very Fine Dusts," Engineering, 179, 4659, 607 (May 13, 1955).	13-1-3
	Taken from an article by G. H. Vokes.	
	Discusses "absolute" air filtration, or removal of all contaminants.	
	Describes the asbestos-wool depth filter, the resin impregnated filter and the Vokes '55 paper. This paper is a type of millipore made of asbestos fibers in Esparto grass based paper.	
	Paper unit is capable of 99.95% removal of Di-octyl Phthalate dust cloud initially, and removal improves as the filter clogs.	
	The filter is made of the paper accordion pleated in a box 24"x24"x11¼" and permits 1000 cu. ft. per min. of air to be drawn through the unit with less than 1.5" water pressure initially. The entire filter unit with its wood frame can be incinerated to eliminate the fouled filters when used with contaminated aerosols.	

Author Index No.	13-1, AIR CONDITIONING & REFRIGERATION EQUIPMENT	Master File No.
7	____________, "Laundering Foul Air for Reuse," Factory Management and Maintenance, 114, 2, 128 (Feb., 1956).	13-1-4
	Plant described is a metal finishing plant having sanders, polishers, buffers and plating operations. Factory is windowless and fully air controlled.	
	Found more economical to reuse the internal air rather than exhausting. Reuse saves heat in winter, refrigeration in summer, prevents damage to outside from fumes and mist.	
9	____________, "New Air Cleaner," SAE Journal, 63, 7, 54 (July, 1955).	13-1-5
	Based on paper by E. Blackburne and C.R. Denton.	
	New type of felt element filter for use on tanks and other combat vehicles to replace oil bath filter for motor is described.	
	Felt unit is self cleaning because of vibrations from motor.	
10	____________, "New Atomic Powered Submarines Equipped with Heavy Duty Cooling Systems," Industrial Refrigeration, 132, 2, 21 (Feb., 1957).	13-1-6
	Report of design of air conditioning system for atomic powered submarines.	
	Cooling system used for humidity control. Activated coconut shell charcoal used for absorbing odors from kitchen, lavatory, as well as machinery.	
	Stale air freshened without admixture of outside air, but process not elaborated.	
11	____________, "New Device Enters Dust War," Electrical Journal, CLIV, 20, 1636 (May 20, 1955).	13-1-7
	Article discusses home and industrial unit newly designed and introduced by Air Control Installations, Ltd. This unit is a compact electrostatic precipitator working on 25 W.	
19	Bacarella, A.L., Dever, D.F. and Grunwald, E., "Absorption of Organic Vapors by Anhydrous Magnesium Perchlorate," Anal. Chem., 27, 11, 1833 (Nov., 1955).	13-1-8
	Anhydrous Magnesium Perchlorate has been used as an absorbent for various organic vapors. Gas flow rates of approximately two liters per hour at one atmosphere were passed through a Nesbitt absorber containing ca. 50 grams of Magnesium Perchlorate.	

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19(cont'd) 13-1-8

From data of authors it is reasonable to suppose that Magnesium Perchlorate could be a general reagent for absorbing vapors of alcohols, aldehydes, ketones, amines, nitriles and nitro compounds--or more generally--polar rather than non-polar compounds.

Caution must be taken as Magnesium Perchlorate is known to give explosive mixtures with organic materials, although the authors report no explosion in four years of work.

20 Barnebey, H.L., "Quantity of Activated Charcoal Required for Air Purification," unpublished paper, Barnebey-Cheney Co., Columbus, O. (May, 1957). 13-1-9

Discusses the quantity of activated charcoal required for air purification and offers a table which gives some rough idea of the quantity of charcoal required per year for odor combinations of different intensity. As a guess an odor index of 2, 3, or 4 might be anticipated in the closed space. This corresponds to 0.1, 1.0, and 10 pounds of odor per million cubic feet. One pound per year of charcoal is required to treat 100, 10 or 1 cu. ft. of space at the respective levels of concentration. Accordingly, for a space of 1000 cu. ft. the amount of charcoal required may be between 10 and 1000 pounds. It should be noted here that this amount is only enough to provide for odor removal and is predicated on the assumption that some fresh air is available due to building leakage. It is also important that activated charcoal is not provided for CO_2 adsorption. Barnebey points out that activated charcoal is relatively inefficient in removing CO_2 and should not be depended on for that action.

Many useful tables of odor level, activated charcoal capacity and odor index included in this paper.

77 Hasinger, S., "Water-Mist Separation in Cabin Air-Conditioning Systems," WADC Technical Report 53-324, ASTIA No. AD-61815 (Nov., 1953). 13-1-10

Tests were conducted by personnel of the Equipment Laboratory, Wright-Patterson Air Force Base, Ohio, between May, 1951 and June, 1952 to determine the most practical method of removing water mist from aircraft cabins. Three separation systems were tested: (1) cyclone separation, (2) filter separation, and (3) electrical precipitation. Cyclones

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77(cont'd) 13-1-10

proved to be impractical because of their size and pressure drop. Filters were found to require very little space but tended to be very sensitive to droplet size; in addition, they clogged rapidly with ice under freezing conditions. Experiments with electrical precipitation showed that this system eliminated many of the drawbacks of the other two systems; however, it was inferior to the filter in regard to size and complexity.

82 Humphrey, A.E. and Gaden, E.L., Jr., "Air Sterilization by Fibrous Media," Ind. and Eng. Chem., 47, 5, 924 (May, 1955). 13-1-11

A filter to be used for the removal of bacteria and spores must satisfy two standards: high efficiency of removal of the organism and a low pressure drop.

The filters, when said to sterilize the air, do so only in a practical sense; that is, the filters develop a commercially acceptable standard of sterility. The air filter is designed for the probability of penetration by a minimum number of organisms during the operating period. Since this number is so small, the unit is considered commercially sterile.

Millipore filters prepared from sterilized dry cellulose ester gel membranes, 120 to 160 micron thick, are reported to retain 100% of all bacterial cells on thin surface when filtering air. Pores in the filter are less than $\frac{1}{2}$ micron in diameter and then are from 10^6 to 10^8 pores per square centimeter. However, the delicate mechanical structure of the millipore filters limits their use in industry. They are an essential assay tool and are used in research.

Work was undertaken using glass wool pads with various binders. It was found that the penetration of bacteria through the fibrous filter was logarithmic, with maximum being on the surface. Bulk density and fiber distribution in the filter beds are more important to the collection action than is the kind of fibrous media used.

When the air stream containing the bacteria is wet the results are inconsistent pointing to some relationship between humidity and some aspects of filtration which at present are unknown.

Filters used for this experiment were commercial glass mats 0.02" thick and impregnated with resin binders. Mats were then layered to increase thickness. Filter density was observed at 2.29 lbs./cu.ft. Under best conditions pressure drop to remove 90% of spores used was 1.05" of water at start.

Author Index No.	13-1, AIR CONDITIONING & REFRIGERATION EQUIPMENT	Master File No.
101	Lodge, J.P., "Analysis of Micron Sized Particles," Anal. Chem., 26, 11, 1829 (Nov., 1954). Article is a summary of work done by Cloud Physics Project at Univ. of Chicago as part of work on ARDC Contract AF 19(604)-618 and Contract AF 33(038)-25913, Geophysics Research Directorate of A.F. Cambridge Research Center. The article describes a method of identifying particulate matter of ca. 0.2 micron. Membrane filters retain particles of ca. 0.2 micron quantitatively. The use of a gel on the filter causes the particles to react colorimetrically and thereby be identified.	13-1-12
102	Madison, R.D. (Editor), Part III, Fan Application, Section 2-Ventilation, "Fan Engineering," 5th Ed., p. 408, Buffalo Forge Co., Buffalo, N.Y. (1948). Handbook covering physics of air and fans. Section on ventilation gives information about air requirements, odors, ventilation requirements, temperature, humidity and air motion. Tables and charts included.	13-1-13
106	May, J.W., "Solving the Ink Mist Problem," Heating, Piping and Air Conditioning, 27, 7, 120 (July, 1955). A continuous two-ply paper filter carried on an endless steel wire mesh is used as the filter media to trap the ink mist in a newspaper press room. As the filter plugs, the increase in heat loss activates a motor to move new material into position. This causes a drop inpressure which also activates the motor to move new filter media into position.	13-1-14
142	Seely, B.K., "Detection of Certain Ions in 10^{-10} to 10^{-15} Gram Particles," Anal. Chem., 27, 1, 93 (Jan., 1955). The procedure for microscopic observation of the chemical reaction between dust particles and the surface of a filter agent coated with a gelatin medium sensitized with specific salts is described. The paper describes methods and means of identifying and counting various particles in impact collection of atmospheric particles.	13-1-15

Author Index No.	13-1, AIR CONDITIONING & REFRIGERATION EQUIPMENT	Master File No.

142(cont'd) 13-1-15

The procedures for iodides, copper, cobalt and nickel, Ferric and Ferrous Iron, Sodium, Potassium and Carbonates are provided.

171 Winslow, C.E.A., et al, "Ventilation," Report of the New York State Commission on Ventilation, Milbank Memorial Fund, E.P. Dutton & Co., New York, N.Y. (1923). 13-1-16

Winslow and other members of a Commission undertook comprehensive studies of ventilation for the New York State Commission on Ventilation and published a report in 1923. This report contains many interesting details concerning the physiological significance of the various factors in ventilation with special reference to the effects of air conditions on health, comfort and efficiency. Among the several comments it was noted that a disagreeable odor existed in the experimental room supplied only with recirculated air. Odors were associated with higher humidity created by air washing operations.

This report is most comprehensive and should be studied carefully in connection with research on air conditions in closed space. Many tables and references to physiological effect should be historically helpful.

174 Yaglou, C.P. and Wilson, U., Disinfection of Air by Air Conditioning Processes, "Aerobiology," Publication No. 17 (edited by F.R. Moulton), p. 129, American Association for the Advancement of Science, Washington, D.C. (1942). 13-1-17

In this paper the authors describe the results of their experiments on reducing bacterial populations by air conditioning.

Bacterial population in the air depends on the air distribution system, the source of air supply, the number and activity of the occupants and general methods of housekeeping. When the fresh air supply is directed downward and the air velocity across the floor is greater than 50 fpm, the number of organisms in the air increases out of proportion to just increased air velocity. This is because settled matter is resuspended.

When a room is congested there are proportionally more bacteria present in the air and ordinary amounts of ventilation do little to reduce the amounts.

Air filtration reduces the bacterial content substantially of fresh air, but recycling seems to have little effect on the general room concentration.

Author Index No.	13-1, AIR CONDITIONING & REFRIGERATION EQUIPMENT	Master File No.
174(cont'd)	Commercial air washers are effective in reducing micro-organism population, but again do not reduce room concentrations during recirculation. Gradual pollution of recirculated spray water not only reduces washing efficiency, but may eventually add organisms to the air. Use of germicides helped in reducing fungus growths and slime, but had no effect on bacterial population. Many common antiseptics are unsuitable as germicides because of toxicity, odor or corrosiveness to equipment under conditions of prolonged recirculation.	13-1-17

Author Index No.	13-3, SANITATION ENGINEERING	Master File No.
84	Ingram, W.T., "An Investigation of the Treatment of Cabin Cruiser Wastes," Sewage and Ind. Wastes, 28, 1, 93 (Jan., 1956).	13-3-1

Investigation of quantity of wastes produced by individuals in connection with coliform density studies indicated an average specimen discharge including feces, urine and paper, amounted to 154.1 gm with extreme range from 22 gm to 463 gm.

Average organisms recovered by plate count on nutrient agar was 62.4×10^{12} organism/gm feces.

Average coliform density was 30.5×10^{7} organisms/gm feces.

109	McNeil, W.J., "Aircraft-Toilet Servicing Unit," Aero Medical Lab., WADC Technical Report 54-296, Contract No. AF 33(600)-23308, ASTIA No. AD-44600 (June, 1954).	13-3-2

This report describes an aircraft toilet servicing unit that has been developed to provide ground crews with equipment suitable for servicing aircraft toilets. The unit consists of a tank for flush water, a waste collection tank, a hose and nozzle assembly, and a motor driven air pump.

(Developed by Wickland Manufacturing Company, Pasadena, Calif. under Contract No. AF 33(600)-23308).

110	McNeil, W.J., "Urine Evaporator," Aero Medical Lab., WADC Technical Report 54-94, ASTIA No. AD-29012 (Feb., 1954).	13-3-3

Laboratory and flight tests indicated that the use of deionization resins effectively removed the corrosive properties of urine. However, their use is considered to be impractical because large quantities were required for practical application. Tests further indicated that evaporation of urine does not remove its corrosiveness. Therefore, no benefits can be foreseen from the use of the urine evaporator, and there are no plans for the continuation of this project.

111	McNeil, W.J. and Suelter, C.H., "Aircraft Sewage Disposal," Aero Medical Lab., WADC Technical Report 54-504, ASTIA No. AD-75798 (Apr., 1955).	13-3-4

This report outlines a research and development program that will have the objective of acquiring data to guide an engineering program for the construction of an aircraft sewage system which will eliminate, as far as possible, the major problems of aircraft sanitation.

Author Index No.	13-3, SANITATION ENGINEERING	Master File No.
152	Stolley, R.H. and Fauth, E.H., "Treatment of Sewage Sludge by the McDonald Process," Public Works, 88, 3, 111 (Mar., 1957).	13-3-5

The treatment of sewage sludge to obtain usable by-products for sale, as well as rendering the residue sterile and decreasing costs of sludge digestion installation. Basically it is a solvent extraction process wherein extraction, dehydration and treatment of raw sludge are accomplished simultaneously.

The solvent used was C_2Cl_4 (Tetrachloroethylene).

The process calls for heating the settled sludge to 150° F. and then mixing with solvent. The mixture is then centrifuged to remove most of the water. The sludge and solvent is then heated to 215° F. Since the solvent has a boiling point of 250.2° F. there is little carryover. The extractable material is dissolved in the solvent. The meal, or non-extractable material is removed from the solvent and compacted and dried. The final meal is dry, fibrous and resembles the discharge from a vacuum cleaner.

The solvent is drawn off and filtered and the dissolved solids are increased from 2 to 95%. The concentrated material is then passed over a column of Raschig rings with a counter flow of live steam. The solvent is evaporated and a "black fat" is collected at the bottom.

Because of the importance of the by-products to the economies of the process, the materials were carefully analyzed.

The following are the more significant of the results in the fertilizer analysis:

Nitrogen	2.7%	Nickel	0.04%
Potash	0.1	Lead	0.075
Phosphorus	2.4	Silicon	6.6
Humus	48.0	Tin	0.01
Crude Fiber	20.6	Strontium	0.02
Al	0.56	Zinc	0.90
Ca	2.7	Cadmium	0.49
Cu	.09	Titanium	0.07
Fe	2.6	Barium	0.05
Mg	0.45	Cobalt	0.01
Manganese	0.02		

Author Index No.	13-3, SANITATION ENGINEERING	Master File No.
152(cont'd)	The results of bacterial tests indicate the material can be called sterile. Vitamin B-12 is present in the meal @ 0.3 microgram per gram. The analysis of the "black fat" is on a fuel oil analysis with 15935 Btu/pound. An interesting corollary of the study was that centrifuging cannot be accomplished without the premixing of solvent and for this reason cannot be operated for sludge dewatering only.	13-3-5
162	Thompson, T.G., "Fresh Water from the Sea," Technion Yearbook, 14, 96, American Technion Society, New York, N.Y. (1957). The distillation process for the recovery of salt free water from the sea is the process most thought of. However, the distillation process is costly in energy required, maintenance of equipment and usually about 2/3 of water has to be discarded in batch type operation. Relatively little attention has been given to the possibility of securing fresh water from sea water by freezing processes--yet natural ice formed in the sea has been used as a source of fresh water by Arctic area inhabitants since ancient times. To ascertain not only the extent of removal of salts from the ice, but also amount of fresh water found, experiments were conducted. The following conclusions may be drawn: (a) About 80% of total salts concentrated in approximately 20% volume; (b) 50% of water contained less than 20% original salinity; (c) remaining 50% of water contained from 125 to 235 ppm chlorides; (d) reduction of freezing point due to presence of salts permits self washing of ice; (e) potable water can be increased by reprocessing partially desalted water; (f) for equal volumes of fresh water about 1/6 energy required by freezing as compared to distillation. These are all based on late experiments. Commercial size units should be investigated and particularly possible utilization of residual brines.	13-3-6
166	Van Heuvelen, W. and Svore, J.H., "Sewage Lagoons in North Dakota," Sewage and Ind. Wastes, 26, 6, 771 (June, 1954). Experience in North Dakota indicates that lagoons should have a detention period of 120 to 200 days depending upon rate of percolation and evaporation. Usually there is no overflow. Generally a 10 acre lagoon should be provided for each 1000 population.	13-3-7

Author Index No.	13-3, SANITATION ENGINEERING	Master File No.
166(cont'd)	Construction of the lagoon is described. No sludge removal is required even when raw sewage is fed to pond. No advantage has been observed in using settling as pretreatment and lagoons receiving raw sewage operate as well or better than those receiving primary treatment. BOD removal averages 95% in the summer and 65% in the winter.	13-3-7
169	Wenzel, W.J., "Sewage Lagoons--Low Cost Treatment and Disposal Method," Engineering News Record, 151, 8, 48 (Aug. 20, 1953). Author recommends a lagoon area of ten acres per 1000 population, one-half mile or more out of town--preferably to leeward from the prevailing winds. Water depth should be 3-5 feet. Sewage should enter at the center of the lagoon, a foot or more above the bottom. Screening and grinding are not necessary and no objectionable floating material has been observed in North Dakota lagoons. Detention period of about 300 days with evaporation and seepage will approximately balance inflow and no effluent will be discharged, although level does rise in winter. Ice covers the ponds in winter; biological activity stops and sewage is held in storage until activity resumes in the spring.	13-3-8

Author Index No.	16-0, MEDICAL SCIENCES	Master File No.

55 Fisher, A.C., "Aviation Medicine on the Threshold of Space," National Geographic, CVIII, 2, 241 (Aug., 1955). 16-0-1

Service doctors, facing medical problems unknown on earth, make possible man's exploration of the hostile heavens.

69 Gradwohl, R.B.H., Chapter VIII, Feces, "Clinical Laboratory Methods and Diagnosis," Vol. 2, p. 1261, C.V. Mosby Co., St. Louis, Mo. (1956). 16-0-2

This chapter describes the compositions of stools, physical chemical, etc.

The feces consist of the indigestible and undigested remnants of food, plus certain constituents such as material secreted by the intestinal wall, plus certain bacteria which may or may not belong to the group of normal intestinal flora. The food remnants, together with intestinal parasites and their eggs, are intimately mixed with bacteria and excretions from the intestinal mucosa. Strassburger claimed feces ordinarily are one-third bacteria.

Usual amount of stool is 100 to 200 grams a day, dependent on diet, varying from 30 to 282 gms., average 102.8 gms.

On a mixed diet weighing 150 gm., individuals ought to pass 30-37 gm. fecal material. Vegetable and starchy diet increases amount while proteins decrease amount.

Stools never show more than a bare trace of chlorides. Color of stools is due to presence of Hydrobilirubin from bile. Odor due to Indol and Skatol, from action of bacteria upon protein.

The most important products formed are:

Indole ($C_6H_4NHCH:CH$)) Odorous
Skatol (C_9,H_9,N))
Paracresol ($CH_3C_6H_4OH$)
Para-oxyphenyl-propionic Acid
Para-oxyphenylacetic Acid
Volatile Fatty Acid
H_2S (odor)
CH_4
Methylmercaptan (odor)
H_2
CO_2

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69(cont'd) 16-0-2

Proteoses
Peptones
Peptides
Ammonia
Amino Acids
Some raw vegetables pass unchanged (radishes, cole slaw, pickles, onion, skins of fruits, nuts, berries)
Mucus
Tissue remnants, epithelial cells, muscle fibers, connective tissues
Crystals, phosphates (many named)
Detritus
Fats, neutral, free fatty acids or soaps
Starch granules
Bacteria, great variety normally found. Normal discharge via stools 126 billion bacteria/day
Ancretions, limey (not in normal stools)

Fresh stools are neutral, or nearly so. They consist normally of 65-85 per cent watery parts and 15-35 per cent dry solids.

91 Kendricks, E.J., et al, "Medical Problems of Space Flight," Special Report from Instructors Journal, Air Training Command, USAF School of Aviation Medicine, Randolph Field, Tex. (Aug., 1955). 16-0-3

Series of articles dealing with physiology of man in trying to fly in space.

In the lead article, "Men Are Now Flying in Space," E.J. Kendricks states that men must take their own peculiar environment with them. The real task of aviation medicine is to show men how to live in space.

In his article, "Living Room in Space," H. Strughold states that flight above the range of 80,000 feet necessitates a sealed cabin pressurized from within and providing all the physiological necessities of a habitable climate on the ground without resort to outside environment. The sealed cabin must perform at least six vital functions--maintain pressure, furnish oxygen, remove CO_2, control moisture, keep down temperatures and control odors. There are other problems in a sealed cabin of a more or less routine character--disposal of body wastes, provision of food and drinking water.

Author Index No.	16-0, MEDICAL SCIENCES	Master File No.
91(cont'd)	A pilot uses 0.9 cu. ft. of O_2 per hour. A standard O_2 cylinder contains 240 cu. ft. of compressed O_2, enough for one man's consumption for 11 days.	16-0-3

CO_2 is exhaled at a rate of about 0.7 cu. ft./hr. Photosynthesis from "a mere 5 pounds of green algae suspended in a nutrient solution" yields as much O_2 as a man consumes. The weight and bulk of the necessary equipment for algae growth seems prohibitive for small craft.

Humans produce about 100 gram calories per hour, or enough to raise an ounce of water 6°F.

At the top of the atmosphere, solar constant is 1.94 gram calories per minute per square centimeter. Radiation on one side of the ship from the sun and loss to space on the other leaves the problem of retaining a physiological temperature within the cabin.

Above 25 miles, the ship is exposed to full cosmic ray bombardment.

The problem of meteor collision is discussed.

In addition, the article describes the effects of intense light and darkness and means of navigation.

In "Characteristics of the Earth's Atmosphere" the various concentric gaseous layers about the earth, winds and clouds, electrical phenomena and how each affects man in flight are discussed.

In "From High-Altitude Flight to Space Flight" H. Haber points out the problems of combining rocketry with aerodynamics. The problems of heat, skin friction, aerodynamic support, pressure changes, cosmic radiation, and sensation of weightlessness are briefly introduced.

In the article, "The Peculiar State of Weightlessness," S.J. Gerathewohl explains what loss of gravity means and how it will be attained. Experiments which have been conducted are described and the problems encountered are discussed.

153 Strughold, H., "The Medical Problems of Space Flight," International Record of Medicine and General Practice Clinics, 168, 9, 570 (Sept., 1955). 16-0-4

Paper discusses physiologic environmental questions of altitude regions and implications of speed and reduced gravitational influences.

Author Index No.	16-0, MEDICAL SCIENCES	Master File No.
170	White, C.S. and Benson, O.O., Jr. (editors), "Physics and Medicine of the Upper Atmosphere," Univ. of New Mexico Press, Albuquerque, N.M. (1952). Report of a symposium sponsored by the USAF School of Aviation Medicine and the Lovelace Foundation for Medical Education and Research.	16-0-5

Author Index No.	16-1, ANATOMY & PHYSIOLOGY	Master File No.

12 ________, "Odors and the Sense of Smell," Airkem, Inc., New York, N.Y. (1950). 16-1-1

An extensive bibliography of references dating from 320 B.C. to 1947. Covers the following subjects:

A. Anatomy of the Olfactory System
B. Physiology of the Olfactory Sense
C. Pathology and Perversion of Odor Perception
D. Body Odors
E. Aromatic Chemicals, Essential Oils and the Chemistry of Odors
F. Classification of Odors
G. Odor Detection, Tests and Measurements
H. Odors of Food and Water
I. Industrial and Miscellaneous Odors
J. Perfumes and Floral Odors
K. Odor Control
L. Theories of Odor Stimulation and General Treatment

35 Bulmer, M.G. and Forwell, G.D., "Sodium and Potassium in Thermal Sweat," Report, Flying Personnel Research Comm., ASTIA No. AD-59072, Institute of Aviation Medicine, RAF (England), (Nov., 1954). 16-1-2

The hypothesis is put forward that sweat is produced from a precursor fluid with the same sodium concentration as interstitial fluid and that the sweat glands, during its passage through them, retain an amount of sodium which is constant and independent of the sweat rate, provided the latter is sufficiently high.

Deductions from this hypothesis are shown to hold good when the sweat sodium is greater than about 50 mEq./l.; below this concentration sweat behaves as if sodium retention were less than maximal.

Sweat potassium concentration is independent of sweat rate.

Sweat potassium falls during acclimatization to a concentration just under 2 mEq./l. greater than serum potassium.

53 Fenno, R.M., "Man's Milieu in Space," Jnl. Aviation Medicine, 25, 6, 612 (June, 1954). 16-1-3

The author presents a summary of the physiologic requirements of man in a sealed cabin. The physiological requirements of oxygen supply, CO_2 removal, temperature, pressure,

Author Index No.	16-1, ANATOMY & PHYSIOLOGY	Master File No.
53(cont'd)	noxious gases, noise, and radiation are discussed in detail. The author states that a possible solution to a self-sustaining "balanced acquarium" in space lies in a chemical, mechanical or photosynthetic gas exchanger or combination of these for the maintenance of our gaseous environment.	16-1-3
72	Grollman, A. (Editor), Paragraph: Sensible and Insensible Perspiration, "Clinical Physiology," p. 192, McGraw-Hill Book Co., New York, N.Y. (1957). About 25% of heat produced by body is dissipated as insensible water. Equivalent to loss of about 800 ml daily divided equally between skin and lungs. Pulmonary loss is influenced by humidity of inspired air and magnitude of ventilatory exchange. Water lost by vaporization does not carry solutes with it. Sensible perspiration contains electrolytes and other solutes at hypotonic concentrations. Na concentration ranges from 10 to 80 mEq./l. Chloride present in slightly lower concentrations. K ranges from 1 to 15 mEq./l. Sweating results in loss of water in excess of salt. Both water and salt required to replenish deficit resulting from sweating. Concentration of NaCl falls when negative sodium balance exists.	16-1-4
81	Howell, W.H., Section: Functions of the Skin, "A Textbook of Physiology," 14th Ed., p. 869, W.B. Saunders Co., Philadelphia, Pa. (1940). Stratum corneum has an acid reaction (pH 5.5) and experimental work indicates some bacteria are destroyed when placed on skin. Dirt or fat upon skin interferes with property of self-disinfection. Excretions of skin formed in sweat glands and in the sebaceous glands. Estimated about 2 million sweat glands over the cutaneous surface. Amount of secretion varies; influenced by temperature and moisture content of atmosphere as well as by physical and psychical state of individual. Average production 500 to 600 gms. per 24 hrs. at rest; may reach 2500 gms. per hr. with strenuous muscular work. Water loss from skin by secretion from sweat glands and by evaporation from epithelial surface (insensible perspiration). Latter amounts to 25 to 40 gms. per hr. at rest with 1/3 to 1/2 given off from lungs. Estimated about 600 ml. water is given off from skin per 24 hrs.	16-1-5

Author Index No.	16-1, ANATOMY & PHYSIOLOGY	Master File No.
81(cont'd)		16-1-5

Estimated oral intake of water 1200 to 1300 ml. per day to supplement metabolic water obtained by diet and oxidation.

Sweat is mixed with sebaceous gland excretion.

Reaction acid due to lactic and volatile acids.

NaCl concentration 0.5 to 0.6%.

Organic constituents present in small amounts with profuse sweating include urea, uric acid, creatinine, lactic acid, ethereal sulphates of phenol and skatol, amino acids, sugar in traces, and albumin.

Sebaceous secretion from single or compound alveolar glands found over cutaneous surface usually in association with hairs. Alveoli are filled with epithelial cells, some filled with fatty material. Detritus of cells forms secretion, sebum, an oily semi-liquid. Exact composition unknown. Contains cholesterol, some simpler fatty acids, fatty acid esters of higher primary alcohols, such as octodecyl and cetyl alcohol, albumins, and inorganic salts. Forms layer on skin to prevent undue absorption of water and evaporation.

Skin also excretes slight amount of CO_2. Estimated at 7 to 8 gms. per 24 hrs., increasing with marked sweating.

85 Johnson, B.C., Hamilton, T.S. and Mitchell, H.H., "The Effect of Choline Intake and Environmental Temperature on Excretion of Choline from Human Body," J. Biol. Chem., 159, 1, 5 (June, 1945). 16-1-6

No difference in choline loss through sweat in a hot, moist atmosphere in comparison with the loss in normal air.

86 Johnson, B.C., Hamilton, T.S. and Mitchell, H.H., "The Excretion of Folic Acid Through the Skin and in Urine of Normal Individuals," J. Biol. Chem., 159, 2, 425 (July, 1945). 16-1-7

1. The human excretes Folic acid in the sweat.

2. More is excreted under conditions of profuse sweating.

Author Index No. | 16-1, ANATOMY & PHYSIOLOGY | Master File No.

87 Johnson, B.C., Hamilton, T.S. and Mitchell, H.H., "The Excretion of Nicotinic Acid, Nicotinamide, Nicotinuric Acid, and N^1-Methylnicotinamide by Normal Individuals," J. Biol. Chem., 159, 1, 231 (June, 1945). 16-1-8

The amounts of Nicotinic acid and its metabolites present in sweat are too small to have any significant influence on the Nicotinic acid requirements of persons subjected to profuse sweating throughout the day.

88 Johnson, B.C., Hamilton, T.S. and Mitchell, H.H., "The Excretion of Pyridoxine, 'Pseudopyridoxine' and 4-Pyridoxic Acid in the Urine and Sweat of Normal Individuals," J. Biol. Chem., 158, 3, 619 (May, 1945). 16-1-9

1. Study was made of the excretion of Pyridoxine, Pseudopyridoxine, and 4-Pyridoxic acid in the urine and sweat of four men subjected to a hot, moist environment.

2. Over 85% of the total Pyridoxine and metabolites excreted in the urine was in the form of 4-Pyridoxic acid; 4 to 5% was Pyridoxine, and 7 to 8% was Pseudopyridoxine.

3. The percentage composition of these 3 compounds in sweat was similar to that in urine.

4. The total amount of Pyridoxine and its metabolites present in sweat appears to be too small to have any significant influence on the Pyridoxine requirements of persons sweating profusely throughout the day.

98 Lee, M.F., Henry, J.P. and Ballinger, E.B., "Basic Requirements for Survival of Mice in a Sealed Atmosphere," Jnl. Aviation Medicine, 25, 4, 399 (Apr., 1954). 16-1-10

O_2 consumption of a mouse was determined in the resting place and during various states of activity for time periods from one hour to four weeks.

Basic requirements of food, water, O_2 and soda-lime for a thirty day period in a sealed container were established to be 200 gm. food, 150 cc. H_2O, 72,000 cc. O_2, and 1300 gm. of soda-lime.

136 Robinson, S. and Robinson, A.H., "Chemical Composition of Sweat," Physiological Rev., 34, 2, 202 (Apr., 1954). 16-1-11

Rate of Sweating

Maximal total sweat losses by men working in the desert reported as 10 to 12 liters.

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136(cont'd)

Coal miners (acclimatized) - 1.1 Kg/hr. during a 5.5 hr. period.
Soldiers carrying on moderate activity--2 to 8 1/24 hrs.

Methods of Sampling

1. Analyses on sweat collected directly from skin.
2. Analyses of sweat residues washed from the skin following periods of measuring rate of evaporation of sweat from the skin.
3. Estimation of sweat components by difference in material balance studies.

I. Sweat for analysis collected by:
   a) Scraping from the skin into a beaker or test tube.
   b) Absorbing on filter paper or absorbent cotton covering a skin area.
   c) Allowing it to accumulate in an impermeable glove, sock, or bag enveloping a skin region.
   d) Collection in capillary micro-pipettes from sweat droplets as they form at the sweat pores.

Components

1. Sodium Chloride: NaCl and water are the principal substances whose loss by sweating may affect the homeostasis of the individual to a serious degree. Concentration of NaCl is variable. Individual values as low as 5 mEq./l. to as high as 100 or 148 mEq./l. have been reported. Average values ranging from 18-97 mEq./l. have been reported in at least 86 separate studies. Normal output from skin (no sweating) is ca. 0.2 mEq./hr. of Cl. Sodium runs somewhat higher because of other sources of Na.

2. Potassium: Lower than Na. Averages about 4.5 mEq./l. with range from 1 to 15 mEq./l. Potassium concentration varies inversely with the Na concentration and the Na/K ratio varies directly with the Na concentration. Na/K = 15 in unacclimatized men, dropping to 5 after a 5-day adaptation period.

3. Calcium: Ranges from 1 to 8 mgm. per 100 ml.

4. Magnesium: 0.04 to 0.4 mg./100 ml.

5. Copper: 4.4 to 7.5 mcg./100 ml.

6. Manganese: 3.2 to 7.4 mcg./100 ml.

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136(cont'd)		16-1-11

7. Sulphates: 4 to 17 mgm./100 ml.

8. Iron: 0.1 to 0.2 mgm./100 ml.

9. I_2, F_2, Br_2 have been reported.

10. Lactic acid: Values reported range from 4 to 40 mEq./l.

11. pH: Most observers found between 4 and 6.8.

12. Glucose: Extremely low. Reported from 0.1 mgm./100 ml. to 9 mgm./100 ml.

13. Nitrogen: Much more dilute than corresponding values in urine. Average values range from 23 mgm./100 ml. (tot. N) to 140 mgm./100 ml.

14. Urea N: Averages ranged from 12 to 39 mgm./100 ml. in several studies.

15. NH_3N: Most investigators report in range of 5 to 9 mgm. percent.

16. Creatinine: Ranges from 0.1 to 1.3 and averages 0.4 mgm./100 ml.

17. Uric acid: Reports range from 0 to 1.5 mgm./100 ml.

18. Amino N: Extremely low, but 18 different amino acids have been identified.

19. Phenol and Histamine reported.

154 Strughold, H., "The U.S. Air Force Experimental Sealed Cabin," Jnl. Aviation Medicine, 27, 2, 50 (Feb., 1956). 16-1-12

The experimentation program for this experimental sealed cabin is a combined research project of the space medicine and of physiology-biophysics. The project involves two main problems which warrant investigation: (1) To what extent, and in what direction, are the various climatic factors changed by the presence of occupants in the cabin. (2) How can these changes be counteracted by physical, technical, or biological means.

Author Index No.	16-1, ANATOMY & PHYSIOLOGY	Master File No.
154(cont'd)	This experimental chamber also can serve as a training device to indoctrinate the occupant with the problems encountered in a closed ecological system and to familiarize him with the procedures necessary to handle any emergency situations such as the failure of the automatic control systems and an eventual puncture of the cabin itself.	16-1-12

Author Index No.	16-2, BACTERIOLOGY	Master File No.
39	Buswell, A.M., "A Study of the Chemical Mechanism of Anaerobic Methane Production," Jnl. of Bacteriology, 29, 1, 81 (Jan., 1935).	16-2-1
	Study was made of the anaerobic fermentation of 91 pure compounds (carbohydrates, alcohols, acids, aldehydes, ketones--both aliphatic and aromatic). CO_2, CH_4 and H_2 appear to be primary products with the H_2 combining with CO_2 to give more methane.	
40	Butterfield, C.T., "The Purification of Sewage by Bacteria in Pure Culture," Jnl. of Bacteriology, 33, 1, 83 (Jan., 1937).	16-2-2
	Reports on oxidation of sewage by massed growths of pure culture of bacteria. Predominant bacteria from good activated sludge were isolated in pure culture. Results show that pure cultures can oxidize in five hours from 38 to 62% of the 5-day B.O.D. (140 to 345 ppm) of the substrate feeds.	
42	Callow, D.S. and Pirt, S.J., "Automatic Control of pH Values in Cultures of Microorganisms," Jnl. of General Microbiology, 14, 3, 661 (July, 1956).	16-2-3
	Equipment for the automatic control of pH value in cultures of microorganisms is described. The apparatus discussed was designed for a 2 liter scale continuous culture apparatus. The equipment will continuously control pH value with an accuracy of ± 0.05 pH units for periods of many hours. The pH value may be changed merely by turning a knob on the controller. It is sufficient to check the meter standardization every day or two. The main components are readily available commercial products. A sketch and description is given.	
59	Fox, N. and Szilard, L., "A Device for Growing Bacterial Populations Under Steady State Conditions," Jnl. Gen. Physiol., 39, 2, 261 (Nov. 20, 1955).	16-2-4
	A device called the "breeder" is described in which the turbidity of an exponentially growing population of bacteria is maintained at a preset value by controlling the rate of inflow of fresh nutrient solution while the total culture volume remains constant. The rate of influx of the nutrient solution is controlled by a photo-cell which responds to the turbidity of the culture and the culture volume is held constant by means of an overflow siphon from the growth tube. A technique is described for overcoming the difficulties presented by bacterial growth on the walls of the growth tube. A diagram is presented.	

Author Index No.	16-2, BACTERIOLOGY	Master File No.

76 Hall, I.C., "Review of Development and Application of Physical and Chemical Principles in the Cultivation of Obligately Anaerobic Bacteria," Jnl. of Bacteriology, 17, 4, 225 (Apr., 1929). 16-2-5

A description of methods of cultivation of obligate anaerobes in use up to 1929. A summary is as follows:

1. Reduction of Oxygen Tension

A. Biological Methods
Aerobe - anaerobe symbiosis
Symbiont in medium
Symbiont in air chamber
Use of animal and plant tissue

B. Physical Methods
Boiling
Evacuation
Use of Inert Gases

C. Chemical Reduction
Agent in air chamber
Catalytic ignition of hydrogen and residual
Reduction by Phosphorous and by iron compounds
Reduction by alkaline pyragallel

79 Herbert, D., Elsworth, R. and Telling, R.C., "The Continuous Culture of Bacteria; A Theoretical and Experimental Study," Jnl. of General Microbiology, 14, 3, 601 (July, 1956). 16-2-6

A theoretical treatment of continuous culture is given which allows quantitative prediction of the steady-state concentrations of bacteria and substrate in the culture, and how these may be expected to vary with change of medium, concentration and flow-rate. The layout and operation of a pilot plant for the continuous culture of bacteria are described. This plant has been operated continuously for as long as four months without breakdown or contamination of the culture. No alterations in the properties of the organisms have occurred during such periods of continuous culture. Results are given by a series of experiments on the continuous culture of Aerobacta cloaca in a chemically defined medium designed to allow quantitative comparison with results predicted by theory. Continuous culture methods are compared with batch methods and it is concluded that continuous process may be expected to show a five to tenfold increase in product as compared with batch methods.

Author Index No.	16-2, BACTERIOLOGY	Master File No.

96 Langlykke, A.F., Peterson, W.H. and McCoy, E., "Products from the Fermentation of Glucose and Arabinoses by Butyric Acid Anaerobes," Jnl. of Bacteriology, 29, 4, 333 (Apr., 1935). 16-2-7

1. Fifty-two Butyric acid-forming cultures were studied with relationship to fermentation of glucose and arabinose and production of neutral products.

2. Low yields of neutral products were associated with high yields of acid.

3. The formation of Ethanol in fermentation proceeds more readily than does Acetone or Butanol.

4. Isopropyl alcohol may be produced.

5. Acetone may be produced.

99 Levine, P.P., "The Effect of Atmosphere of Hydrogen, CO_2, and Oxygen, Respectively, and of Mixtures of These Gases on The Growth of Bacillus Subtilis," Jnl. of Bacteriology, 31, 2, 151 (Feb., 1936). 16-2-8

1. In an atmosphere of 100% H_2, spores of B. subtilis do not germinate and vegetative cells do not multiply.

2. In an atmosphere of 100% CO_2, spores of B. subtilis do not germinate.

3. In an atmosphere of CO_2, addition of 4% air permits germination of spores with subsequent growth to permit visible growth.

4. An atmosphere of 100% O_2 is not inhibitory to growth.

112 Mead, M.W., Jr. and King, C.G., "Proteolysis and the Selective Destruction of Amino Acids by Clostridium Sporogenes and Clostridium Histolyticum," Jnl. of Bacteriology, 17, 3, 151 (Mar., 1929). 16-2-9

1. Proteolytic action of Cl. histolyticum is greater than that of Cl. sporagenes.

2. In anaerobic cultures rich in proteins resulting pH is held at 7.5 to 8.2.

3. Degree of destruction of tyrosine and histidine depends on the particular protein utilized.

4. With Cl. histolyticum tyrosine crystals are formed in the medium whenever this amino acid is liberated during protein hydrolysis.

Author Index No.	16-2, BACTERIOLOGY	Master File No.
135	Roberts, R.S., "Bacteriological Problems Involved in the Use of B. Coli as a Food," Jnl. of Pathology and Bacteriology, LXIX, 1-2, 359 (Jan.-Apr., 1955).	16-2-10

Cultures of E. coli in a chemical medium, freed of culture fluid and heat-killed are innocuous in food and serve as an excellent source of animal protein.

Factors of importance in large-scale cultivation are:

1. Impure substrates, such as agricultural grades of ammonia; phosphate and molasses can be used if chelating agents are present.

2. Response to aeration is a strain characteristic.

3. Aeration does not mean oxygenation.

139	Ruchhoft, C.C., Kallas, J.G. and Edwards, G.P., "Studies of Bacterial Population During Sludge Digestion," Jnl. of Bacteriology, 19, 4, 269 (Apr., 1930).	16-2-11

1. Six types of sludges
   (a) Activated sludge alone; (b) fresh solids alone; and (c) four different mixtures of (a) and (b) were allowed to digest at 15°C. and at 25°C.

2. The following changes were followed: (a) reduction of organic acids; (b) pH changes; and (c) changes in bacterial population.

3. The greatest reduction in organic solids was found with 20% activated sludge. Digestion was more rapid at 25°C. than at 15°C.

4. Calculations were made of the rate of organic solids reduced per day per billion bacteria.

143	Skinner, C.E. and Gardner, C.G., "Utilization of Nitrogenous Organic Compounds and Sodium Salts of Organic Acids by Certain Soil Algae in Darkness and in the Light," Jnl. of Bacteriology, 19, 3, 161 (Mar., 1930).	16-2-12

1. Pure cultures of Pleurococcus, Cystococcus, Chlorella, Scenedesmus, and an unidentified strain of green algae were grown in liquid and semi-solid media in diffused sunlight or in total darkness.

Author Index No.	16-2, BACTERIOLOGY	Master File No.
143(cont'd)	2. Organic compounds, such as glucose, gelatin, peptone, egg albumin, casein, citric, lactic, malic, oxalic, succinic, and tartaric acids were added to the media at pH = 6. 3. The organic compounds, except oxalates, increased growth of some of the algae. 4. Glucose and some of the nitrogenous compounds served as sole energy sources for some species of algae.	16-2-12
168	Weinzirl, J. and Gerdeman, A., "The Bacterial Count of Ice Cream Held at Freezing Temperature," Jnl. of Bacteriology, 17, 1, 38 (Jan., 1929). Storage of ice-cream at minus 10°C. does not prevent bacterial multiplication.	16-2-13

Author Index No.	16-3, BIOCHEMISTRY	Master File No.

78 Hawk, P.B., Oser, B.L. and Summersen, W.H., Chapter, The Urine, "Practical Physiological Chemistry," 13th Ed., p. 788, Lea and Febiger, Philadelphia, Pa. (1956). 16-3-1

Urine

Composition of Average Normal Urine
Daily Excretion

Constituent	Amount (gms.)
Water	1200
Solids	60
Urea	30
Hippuric acid	0.7
Uric acid	0.7
Creatinine	1.2
Indican (Indoxyl potassium sulfate)	0.01
Oxalic acid	0.02
Allantoin	0.04
Amino acid nitrogen	0.2
Purine basis	0.01
Phenols	0.2
Cl as NaCl	12.0
Na	4.0
K	2.0
Ca	0.2
Mg	0.15
S as SO_2	2.5
Inorganic sulfates as SO_3	2.0
Neutral sulfur SO_3	0.3
Conjugated sulfates as SO_3	0.2

105 Mattice, M.R., Appendix--Resume of Normal Data, "Chemical Procedures for Clinical Laboratories," p. 403, Lea and Febiger, Philadelphia, Pa. (1936). 16-3-2

Analysis of Normal Sweat

Total Solids	0.04 - 0.86%
Total N	0.3 gm./day
NH_3-N	4.7 - 6.0 mg./100 ml.
Total volume	100 - 500 ml./day
NPN	32 - 67 mgm./100 ml.
Urea N	20 mgm./100 ml.
Amino N	6 - 8 mgm./100 ml.
Chlorides	4 - 6 mgm./ml.
pH	6.1 - 6.6
Sugar	12 - 20 mgm./100 ml.

Physical Characteristics of Urine and Feces

	Urine	Feces
% Water	90 - 95	74 - 79
pH	5.5 - 8.0	7.0 - 7.5
Total Solids		20 - 40 gm./24 hr.
Freezing Point	-1.0 to -2.5°C.	

Author Index No.	16-4, BIOLOGY	Master File No.
2	________, "Algae Hazard Found Facing Space Travel," Aviation Week, 67, 10, 65 (Sept. 9, 1957).	16-4-1

Ordinary flowers and vegetables can be poisonous, according to Air Force scientists, and space travelers could be menaced by their own food and air supply. It has recently been determined that the normal photosynthesis process can be disrupted so that the damaged plants produce carbon monoxide instead of oxygen. Dead plants also contain carbon monoxide.

This discovery has created the need for more study of one of the techniques for keeping crews alive for weeks or months in a space ship. This is to grow algae in the ship to replace the carbon dioxide given off by the flyers by oxygen.

4 ________, "Development of Chlorella Culture Process," Final Report, Stanford Research Institute Project No. 191, Stanford Research Institute, Stanford, Calif. (Mar., 1950). 16-4-2

Final report on S.R.I. Project No. 191 prepared for Research Corporation (Mar., 1950).

13 ________, Pilot-Plant Studies in the Production of Chlorella, "Algal Culture from Laboratory to Pilot Plant," (edited by J.S. Burlew) p. 235, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-3

Chapter based on report by A.D. Little, Inc., Cambridge, Mass., "Pilot Plant Studies and Economic Evaluation of Mass Culture of Algae."

The pilot-plant project begun at Arthur D. Little, Inc. in 1951 had four purposes: (1) to achieve the continuous production of high-protein Chlorella on a larger scale than had been attempted before; (2) to obtain further information that would aid in the appraisal of economic possibilities; (3) to study the conditions of growth suitable for continuous mass culture on a large scale; and (4) to distribute experimental quantities of Chlorella for studies of possible end uses of the product.

Throughout the pilot-plant program the species Chlorella pyrenoidosa (Emerson's strain) was used. Since all previous data had been obtained under essentially pure culture conditions, closed systems that could be readily cleaned or replaced were adopted. Only natural illumination was used for the pilot units.

Author Index No.	16-4, BIOLOGY	Master File No.
13(cont'd)		16-4-3

The paper discusses the following in detail:

1. Laboratory and Intermediate-Scale Operations - This section discusses the use of agar slants, flasks and vertical columns.

2. Large-Scale Operations - This section of the paper discusses the three large-scale culture units which were developed and studied during the project. The operation of the first unit satisfied the first objective of the program, namely, continuous relatively large-scale production of high-protein Chlorella. It also provided material for end-use studies by industrial and research organizations. The second unit constructed never functioned satisfactorily and was therefore abandoned. The operation of the third unit was satisfactory, and no settling occurred. However, the objective of investigating the effect of turbulence on growth was not achieved.

3. Supplementary Studies - The discussion in this section is concerned with the studies made on vertical columns, studies in flasks and a flow study.

4. Handling the Product - This section discusses freezing, spray drying, lyophilization, solvent drying with extraction and hygroscopicity.

5. Measurement Techniques - This section of the report is devoted to a discussion of determination of pH, determination of algal concentration, determination of Carbon Dioxide concentration, determination of concentration of major nutrients, determination of microelement concentration, visual observation and illumination and weather data.

6. Discussion of Results - The results of plastic growth tubing, auxiliary equipment, nutrient medium, Carbon Dioxide, recycle of medium, contamination, temperature, illumination, concentration of algae, hydrodynamic problems, intermittent light by turbulent flow, growth inhibition and variation in cell density, and yield per unit area are discussed in this section of the report.

Author Index No.	16-4, BIOLOGY	Master File No.

15 Abbott, W.E., "Oxygen Production in Water by Photosynthesis," Sewage Works Journal, 20, 3, 538 (May, 1948). 16-4-4

Biochemical production of oxygen measured by incubating comparable samples of sewage or effluent for 48 hours at the same temperature in the dark and exposed to the light from a north window. In one case, the D.O. increased from 7.7 to 44.7 ppm in the light and decreased to 0.0 in the dark. The photosynthetic organisms were not identified.

16 Allen, M.B., "General Features of Algal Growth in Sewage Oxidation Ponds," Publication No. 13, State Water Pollution Control Board, Sacramento, Calif. (1955). 16-4-5

Studies of four sewage oxidation ponds indicate Chlorella and Scenedesmus are the photosynthetic organisms most important in the functioning of ponds--Chlorella being the principal algae in ponds where sewage undergoes oxidation.

Growth of Chlorella on sterilized sewage in light did not result in any decrease in oxidizable organic matter. It was concluded that oxidation of organic matter in sewage is carried out by bacteria and other non-photosynthetic organisms and that growth of the usual pond algae in sewage occurs only at the expense of CO_2 produced by microbial oxidation or absorbed from the air.

Chlorella grew more luxuriantly in sewage with bacteria than in sewage alone, probably because of the increased CO_2 content. Growth of algae in sewage is limited by two major nutrients--carbon and nitrogen. For optimum algal growth sewage must be supplemented with other sources of nutrient.

The maximum yield of algae from domestic sewage in the laboratory is 1-2 gm. dry weight per liter. In the field the maximum yield was about 0.5 gm. dry weight per liter.

17 Allen, M.B., "Photosynthetic Nitrogen Fixation by Blue-Green Algae," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-6

A study was made of the nitrogen fixing properties of Anabaena cylindrica, a blue-green algae. This is rapidly growing and under proper conditions of nutrition and illumination it was possible to obtain a daily increment of 2.0 gms. of dry weight of cells per liter of culture medium or 26 gms. per sq. meter of illuminated surface. This rate may be taken as typical of this type of algae under favorable conditions.

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17(cont'd)		16-4-6

The nutritional requirements of blue-green algae differ from those of the green algae as follows:

	Blue-Green	Green
Calcium	Macro quantities Calcium cannot be replaced by Strontium	Micro quantities
Molybdenum	10 μg./liter Mo cannot be replaced by Vanadium	0.1 μg./l.
Cobalt	Required for pigmentation	not required
Sodium	5-10 ppm required regardless of amounts of K present	not required
Nitrogen	Nitrogen fixation by Anabaena differs from that of heterotrophic microorganisms such as azotobacter in that it is not prevented by the presence of combined Nitrogen in the medium. Nitrogen was not fixed in the presence of ammonia or urea. Under favorable conditions, growth of Anabaena proceeds at the same rate and to same density whether molecular or combined Nitrogen is used as Nitrogen source.	

Under conditions of adequate nutrition, growth of Anabaena increases with increasing light intensity up to at least 16,000 lux. Growth was as rapid with 13 hrs. of illumination each day as with 24.

The blue-green algae are more tolerant of moderately high temperature than the green algae. Examination of 40 pure cultures of various blue-green algae showed that all grew well at 35°C. and most at 40°C.

No marine nitrogen-fixing blue-green algae have been isolated but Anabaena is fairly tolerant of salt, growing normally in 1.5% NaCl. A comparison of yields of blue-green algae with those obtained with green algae and higher plants such as tomatoes and potatoes shows that the amount of cell material produced by photosynthesis per month is of the same order of magnitude for all three types of plant; e.g., computed in dry weight, tons per acre per month:

Tomatoes	3
Potatoes	5
Scenedesmus	7.8
Anabaena	3.4

The Nitrogen fixed by blue-green algae is available to rice plants.

Author Index No.	16-4, BIOLOGY	Master File No.

18 Altshuler, B. and Palmes, E.D., "Mechanical Exchange of Air and Airborne Particles Between Tidal and Reserve Air," Unpublished research, New York Univ. Dept. of Industrial Medicine, New York Univ. Bellevue Medical Center, New York, N.Y. (May, 1957). 16-4-7

A novel use of aerosols allows the mechanical flow component of pulmonary ventilation to be experimentally distinguished from the effect of the superimposed gaseous diffusion.

In the study of the effect of particle size on aerosol deposition in the human respiratory tract a method was developed for the simultaneous and continuous measurements of respiratory flow, aerosol concentration and CO_2 concentration during individual expirations. A particle of 1/2 micron diameter, which has least probability of being deposited during respiration, has considerable stability in the supporting respiratory gas and may be left suspended in the respiratory tract for several breaths. The records obtained during wash-in and wash-out breaths when the subject is shifted between breathing, evidence of the degree of the mechanical exchange of air and aerosol between tidal and reserve air. Experimental data, their analytical treatment, and the implications for the understanding of the mechanism of pulmonary ventilation and the associated handling of aerosols are being collected and analyzed.

The mechanical exchange of tidal air is shown to play a minor role in pulmonary ventilation. However, it plays a significant role in the deposition of aerosols. In fact, a gross difference in aerosol deposition between subjects can be explained by measured differences in the extent of mechanical mixing; these subjects appeared to be similar in all other respects.

21 Bassham, J.A., "Effect of Environmental Condition on Photosynthesis in Marine Algae," Final Progress Report, May 1, 1953 to Apr. 15, 1955, Univ. of California, Contract Nonr-222(19), (Jan. 28, 1955). 16-4-8

Objective: To study the effects of environment on various marine algae in order to select a species and set of growth conditions under which a high rate of photosynthesis can be maintained while using nutrient solution sea water with a minimum of enrichment.

Results: Numerous species of marine and fresh water algae were tested for rate of growth and photosynthetic activity. In the presence of ideal psychological conditions (CO_2, light, nutrient, etc.) small unicellular fresh water green algae (e.g., Chlorella pyrenoidosa and Scenedesmus obliquus) photosynthesized at the greatest rate per unit volume of algal suspension. Larger and more complete forms photosynthesized at a much slower rate.

Author Index No.	16-4, BIOLOGY	Master File No.
21(cont'd)	No marine species were found which had as high photosynthetic activity as fresh water Chlorella. A marine Chlorella photosynthesized as rapidly as the fresh water forms in terms of chlorophyll content. The chlorophyll deficiency in the marine forms may be due to an undetermined nutrient deficiency.	16-4-8
22	Bassham, J.A., "Use of Controlled Photosynthesis for Maintenance of Gaseous Environment," Report, U.C.R.L. 2707, Univ. of California Radiation Lab. Contract No. W-7405-eng-48, Berkeley, Calif. (Sept., 1954).	16-4-9

Purpose: To determine whether livable oxygen and CO_2 pressures in a closed space in which men must live can be maintained by the use of photosynthesis of green algae.

Results: Computations based on the known respiratory rate of man and the photosynthetic rates of Chlorella indicate:

1. A man weighing 154 lbs. (70 kg.) doing light work would require about 600 liters of O_2 over 24 hours or an average of 25 liter/hr. Chlorella can easily form 25 liters per hr/kg. of wet weight of algae so that the respiration of one man could be balanced by the photosynthesis of 1 Kg. wet weight of algae. A 1% suspension of algae in nutrient solution is practical for maintaining growth so that 100 liters of algal suspension is required for each man.

2. The light requirement for Chlorella (1% suspension) in layer 0.4 cm. thick would be about 600 f.c. from each side if the light were all of 6800A° wave length.

3. Volume required per man for pumping, aerating, harvesting and control mechanisms would be about 50 cu. ft.

4. The power required for an algae gas-exchange system is:

   for a man, 120 k cal/hr. = 0.2 hp.
   but efficiency of conversion of electrical energy to visible light energy is about 20% in standard fluorescent light and efficiency of conversion of red light to chemical energy by Chlorella on a large scale probably not more than 25%.

   Therefore, for 1 man we obtain 0.2/(.2 x .25) = 4 hp. requiring about 100 grams of atomic fuel per year per man if efficiency of conversion of fuel to electrical energy of 0.02% were obtained.

Author Index No.	16-4, BIOLOGY	Master File No.
22(cont'd)		16-4-9

5. The ratio of CO_2 to O_2 in the gas exchange of a respiring man is about 0.8. The photosynthetic gas ratio CO_2/O can be maintained at 0.8 by controlling the ratio of nitrate to NH_3 in the nutrient.

6. The nitrogen requirements of the algae:

A kilogram of algae producing 25 liters of O_2 per hour at a gas exchange ratio of 0.82 would take up 20.5 liters of CO_2 or 0.915 moles of carbon. Cells produced are about 50% carbon and 10% nitrogen so that 0.16 moles of nitrogen per hour is needed. This can be supplied by addition of 13.6 gm. $NaNO_3$, 4.8 gm. of urea, or 2.4 gm. NH_4 per hr. Lesser amounts of P and other elements would be needed.

If the algae harvest is used for food, then human excrement would have to be processed by bacterial action to provide nutrient for algae. This would require some further O_2 uptake and CO_2 evolution and would require increase in volume and energy requirements of algal cultures.

Use of urine alone as such may be questionable.

24 Bassham, J.A., Shibata, K., Steenberg, K., Bourdon, J., and Calvin, M., "The Photosynthetic Cycle and Respiration: Light-Dark Transients," Report, U.C.R.L. 3331, Univ. of California Radiation Lab. Contract No. W-7405-eng-48, Berkeley, Calif. (Mar., 1956). 16-4-10

Studies of the transient changes in radiocarbon found in various photosynthetic and respiratory intermediates in Scenedesmus, which result when changing from a condition of steady-state photosynthesis in the light to dark and then back to light again, indicate the following metabolic mechanisms:

(a) The carboxylation step in the carbon-reduction cycle of photosynthesis results in the formation of two molecules of 3-PGA from one RuDP molecule, one CO_2, and one H_2O.
(b) This carboxylation reaction proceeds for about thirty seconds in the dark after the light is turned off and its rate is proportional to the falling concentration of RuDP, and stops when the latter concentration falls to zero.

Author Index No.	16-4, BIOLOGY	Master File No.
27(cont'd)	3. On voyages longer than 5 months algae could be used for food and atmospheric control. The weight requirements vary from 1.8 kg./man/day to 0, depending on length of trip.	16-4-11
	4. In the future more rapid algae growth techniques should permit algae eventually to be useful in trips as short as a few weeks.	
32	Brunel, J., Prescott, G.W. and Tiffany, L.H. (Editors), "The Culturing of Algae," A Symposium, The Charles F. Kettering Foundation, Yellow Springs, Ohio (1950). A section (pp. 19-26) by E.G. Pringsheim deals with the soil-water culture technique for growing algae.	16-4-12
33	Buettner, K., Chapter VI, Bioclimatology of Manned Rocket Flight, "Space Medicine," (edited by J.P. Marbarger), Univ. of Illinois Press, Urbana, Ill. (1951). Shows the detailed computations for determining the equilibrium skin temperature of an orbiting space vehicle.	16-4-13
37	Burlew, J.S. (Edited by), "Algal Culture from Laboratory to Pilot Plant," Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). A discussion of algal culture by various authors in which discussions are given on conditions for growth of algae, growth of algae in mass culture, pilot plant experiments, and possible uses of microscopic algae. An extensive bibliography is given on the mass culture of Chlorella and immediately related subjects. 22 papers on various subjects are included. Chlorella and Scenedesmus, green algae, are common inhabitants of fresh water and soils. <u>Chlorella</u> - Four main strains C. pyrenoidosa (Emerson strain) used mainly. C. vulgaris (Emerson strain) C. vulgaris (Trelease or Columbia Strain) C. vulgaris (Wann or Cornell strain) Chlorella is a standard organism for study of the mechanism of photosynthesis. It is hardy and rapidly growing. Its chloroplast takes up a main portion of the cell and its high rate of photosynthesis exceeds the rate of respiration 10-100 times. It excretes relatively little organic matter.	16-4-14

Dried cells contain over 50% protein which contains the ten amino acids now considered essential. It has a low molecular weight which means it can be digested readily.

Utilization of Light
Algae and higher plants are about equal in utilization of light. They can use as much as 20% of the incident energy in the visible part of the spectrum. In full sunlight the utilization is reduced to 2-3%. This "light saturation" can be partially eliminated by intermittent light and other means.

The upper limit of intensity of sunlight which is utilized with full efficiency by C. pyrenoidosa is estimated at 400 f.c. In summer sunlight during the middle of the day is at least 8,000 f.c. The increased light increases output of algae slowly. Conditions must be arranged so that algae can utilize sunlight as efficiently as they can weak light.

Maximum Average Daily Yield has been computed at 70 grams per square meter, but this is more than 5 times better than has been obtained to date. Methods of evaluating growth are: (a) number of cells; (b) volume occupied after centrifugation called "wet volume," or "packed cell volume;" (c) weight of cells after centrifugation or after drying to constant weight; (d) optical density.

A.D. Little concluded that although their maximum yield was only 4 grams per square meter per day, 20 grams can be realized under advantageous climatic conditions.

Effect of Old Culture Medium
Some difference of opinion but growth-inhibiting substance "chlorellin" reported by Pratt for Chlorella vulgaris. Other workers do not confirm this.

Algal Species
Most experiments have been carried on with Chlorella because species of this genus grow rapidly and tolerate wide variety of cultural conditions--"an algal weed." Some other algae may be better.

Effective Temperature
For C. pyrenoidosa the optimum is probably 25°C. at light saturation, but a higher temperature is better if the cells are cooled to 15-20°C. during the night.

Effect of Carbon Dioxide
Probably the growth rate is independent of CO_2 concentration between 0.1 and 5.0% expressed in terms of composition of gas phase and equilibrium with suspension. More recent data indicate a range of 0.56 to 4.43%. Above 5% toxic effects appear.

Design of Plant
The elements of design are:

1. Container with transparent upper surface.
2. A means of circulation of culture medium so that algae do not settle.
3. Means of controlling temperature.
4. Means of introducing CO_2 and other nutrients continuously.
5. Means of harvesting algae almost continuously.
6. Means of processing harvest so that it is preserved till used.

Container
The best so far for pilot plant operation is a long tube of transparent polyethylene plastic only 0.004 inches thick. When partly filled it flattens to an elliptical cross-section with a width of nearly 4 feet and a height of 8-12 inches depending on the proportions of liquid and gas. It facilitates introduction of CO_2 as a gas phase in contact with the entire layer of liquid.

Open Culture
In open culture it is difficult to keep CO_2 concentration high enough for maximum growth. For sewage oxidation lagoons may be an exception because enough nitrogen and CO_2 may be provided.

Contamination
The contaminants apt to cause trouble are rotifers and other large organisms which eat algae. Amoeba and vorticella apparently did not grow rapidly in healthy cultures, but under certain conditions these might be harmful. Bacteria may not have a critical effect in large scale operation. Means should be provided for keeping contaminants under control.

Open air culture experiments in Germany became heavily infected by protozoa such as zooflagellates, ciliates and amoebae. Because of their rapid growth flagellates caused most trouble and within two to four days after infection the cultures became useless. Scenedesmus has greater resistance to protozoa than Chlorella.

In Israeli experiments 2-4-D was suggested to keep cultures free from secondary algal infections. Chlorella is fairly tolerant to 2-4-D.

Harvesting and Drying

University of California report indicated that algae may be separated from culture medium by simple alum flocculation followed by settling. Since the suspension of algae is less than 1%, the use of a super-centrifuge is good except for cost. Perhaps settling followed by centrifuge would be more efficient. Algal cells when removed from the centrifuge are thick paste containing 75% water. It spoils in less than one hour in a warm room. The algal cells may be preserved by "freeze drying," by spray drying, or defatting. Freeze drying is probably the best but may be too expensive under pond conditions.

Intermittent Experiments with Light

Algae can use light in very short flashes. The initial light-sensitive reaction of photosynthesis stops when the light goes off and resumes when it goes on. Cell division may continue during the dark period at the same or even increased rate. Turbulent flow may allow the entire surface of culture to be occupied by cells all utilizing light at the greatest efficiency. It may increase the yield threefold. The efficiency of energy conversion by green plants in general is estimated at 1-2% of the solar radiation which reaches the earth's surface and is useable in photosynthesis. Short term experiments with Chlorella have indicated the calculated efficiency of 25%. Only light of wave length shorter than 7,000Å is active in photosynthesis. Experiments with intermittent light showed that the intermittent dark periods cause no retardation in the overall logarithmic growth at earlier stages of culture, but at later culture stages when the amount of available light decreased considerably because of population density, the overall rate of growth was decidedly decreased by the dark period. Cells grown under weak light are smaller than those grown under strong light, but the chlorophyll and nitrogen content (percent by weight) are lower in larger cells than in the smaller ones.

Stable foam formed as a result of agitation or aeration of cultures at concentrations of algae of about 0.3 to 0.4 grams per liter. This is important from an operational viewpoint. Two anti-foamers seemed non-toxic, Dow-Corning Anti-Foam A, and Span 85 of Atlas Powder Co. The details of use have not been worked out.

Improved Strains of Algae

Strains of Chlorella that thrive at considerably higher temperatures and with higher growth rates than C. pyrenoidosa have been isolated. It seems that at high cell density the same yield would be produced at 39°C. as at 25°C. reducing thereby the requirements for cooling.

Israeli experimenters expect to study a large diploid Chlorella obtained by camphor treatment of algae by Pearsall.

Inorganic Nutrition of Algae

Any normal water supply sterilized but free from any toxic ions would be satisfactory. The major nutrients required of algae are similar to those of the higher plants. Chelating agents are used to keep trace elements in solution. Much more information is required on chelating agents. For example:

1. Chelating agents are highly selective. In a medium replete with metallic ions, which will be complexed by a given chelater and what will be the equilibrium?
2. Schwartzenbach has determined equilibrium constants in uni-metallic solutions with EDTA. What is equilibria in mixed solutions?
3. Perhaps an efficient system for the supply of micronutrients can be worked out biologically using serial concentrations of chelating agents without determining either the equilibria or the mechanism of ion exchange.

As a source of nitrogen for Chlorella, urea is better than KNO_3, because it gives better yields, causes only minor changes in pH and furnishes a greater supply of nitrogen without seriously decreasing the growth.

Growth of Algae for Food

Composition of dry C. vulgaris (six-day experiments) is as follows:

Component	%
Moisture	5
Nitrogen	8
Crude protein	50
True protein	45.5
Ether extract	3
Ash	7.4
Phosphorous	1.1
Potassium	1.5
Magnesium	0.5
Iron	0.04
Sulphur	1.1

These analyses were made on freeze dry samples.

Composition of Chlorella (H.W. Milner) varied widely depending upon environmental conditions. For example, ash varied from

1.36 to 20.2%. On the basis of ash-free dry weight the following ranges were obtained:

Carbon	49.51 - 70.71%
Hydrogen	6.78 - 10.53
Nitrogen	1.17 - 14.11
Oxygen	17.87 - 34.40
"R" Value	37.92 - 63.33

Calculated compositions

Protein (N x 6.25)	7.3 - 88.0
Carbohydrate	5.7 - 38.0
Lipide	4.5 - 86.0

"R" value is the level of reduction of total content of organic matter in plant material and is computed as follows:

$$R = \frac{(\%C \times 2.664 + \%H \times 7.936 - \%O) \times 100}{398.9}$$

"R" runs from 0 for CO_2 to 100 for methane.

Preliminary experiments suggest that freeze dry Chlorella cells contain more than 1200 ppm of beta carotene. Vitamins A, B and C are present, but C is lost on drying or storing.

Thawed, undried Chlorella alone had a vegetable-like flavor and aroma and was rated by "Flavor Panel" at A.D. Little as "food-like and food satisfying" but with some of the "notes" unpleasantly strong. There was a noticeable tightening at the back of the throat ("gag factor") and a lingering, mildly unpleasant aftertaste. When used to 15% in a chicken base soup, the stronger, less pleasant "notes" were much reduced and "gag factor" not noticeable. The conclusion was that Chlorella and soups made from it were suggestive of vegetables and generally palatable and acceptable. The appearance may not be so generally acceptable. The defatted product, "Viobin," had a different flavor. The flavor of dried Chlorella alone is too strong to enjoy eating large quantities of it and in this way it may be compared with herbs. These conclusions on the flavor and acceptability are tentative.

In Venezuela "Plankton soup" which is largely algae was served to patients in a leper colony. They found that dried Chlorella has a vegetable-like flavor resembling raw lima beans or raw pumpkin. The patients gained weight on the diet of algae.

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37(cont'd)		16-4-14

German experiments on mass culture of algae were made to produce fat. Preliminary experiments indicated that the diatom Nitzschia palea and Chlorella pyrenoidosa were most promising. The lipide content of cultured organisms ranged from 40 to 70%. The fats were triglycerized of stearic, oleic and linoleic acids. Fat formation is initiated when there is low concentration of available nitrogen in the nutrient solution. Fogg and Collyer reported that the chrysophyta, especially Chlorella, produce more lipides than the blue green algae.

Hydrodynamic Problems (Ippen)
Head loss is important at velocities much above 1 ft. per second. A more serious limitation may be the surface instability above the critical Froude number. Operation above the critical Froude number results in surging which might decrease tube life. For 3 inch depth the maximum velocity will be less than 1.5 ft./sec. and even at 5" depth, which is believed to be the greatest practical for tubes, velocities must be less than 1.8 ft./sec.

38 Burlew, J.S., Current Status of the Large-Scale Culture of Algae, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 3, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-15

An introduction and summary of the current status of large-scale culture of algae are given. The author examines the entire monograph of which this article is the first chapter and provides some background information.

Pertinent highlights follow:

The composition of Chlorella pyrenoidosa can be controlled.

Dried algal cells may contain over 50% protein. In algal culture every sunny day gives the same result, as algae are always at the height of the growing season. Algae and higher plants have the capacity to utilize the energy of visible light. The maximum efficiency of light utilization in photosynthesis may be from 30 to 80% according to different workers.

A maximum average daily yield from experiments described in which the highest efficiency of energy utilization was observed amounted to 70 gm./m^2. For every pound of dry algae harvested a minimum of two pounds CO_2 and 1/12 pound of combined nitrogen are required.

A concentration of 0.2 gm./l. dry weight of C. pyrenoidosa contains about 20 billion cells per quart of moderately thin suspension.

The same yield per unit area can be obtained with almost any infinite number of combinations of volume, depth, and concentration provided that none of the light is wasted by absorption, and that there is sufficient depth and concentration for optical extinction.

Requirements of a plant for growing algae on a large scale include:

1. A container with a transparent upper surface.
2. A means of circulating the culture medium within the container so that the algae do not settle.
3. A means of controlling the temperature.
4. A means of introducing Carbon Dioxide and other nutrients continuously.
5. A means of harvesting the algae almost continuously.
6. A means of processing the harvest so that it is preserved until used.

One proposed plant was estimated to cost $1.30/ft^2. Suspension in large scale culture will contain less than 1% of algal cells by weight. Harvesting by means of super-centrifuge is feasible but costly.

Algal cells can be frozen or dried. Freeze drying is less likely to change vitamin content. Spray drying is easily applicable on large scale. Defatting yields an additional liquid fatty fraction containing protein.

Saturation effect of light intensity places limitations on efficiency with which solar energy can be utilized by algae. Algae can utilize light in very short flashes. Dark time/light time ratio at least equal to 10 should be employed for fully efficient utilization of incident light.

Turbulent flow to increase exposure on thin surface layer is possibly a means of avoiding waste of light.

Algae may be used as food. Dried Chlorella has a vegetable-like flavor. Does not have components of pharmaceutical value. Proteins are difficult to extract. Fat fraction contains large percentage of unsaturated acids.

Author Index No.	16-4, BIOLOGY	Master File No.
41	Caldwell, D.W., "Sewage Oxidation Ponds--Performance, Operation and Design," Sewage Works Journal, 18, 3, 433 (May, 1946). A comprehensive report of the early work with sewage oxidation ponds in California, Nevada and Arizona. Microscopic examinations at the U.S. Naval Station, Shoemaker, Calif. showed that Euglena, a chlorophyll-bearing protozoan, was found to be predominant, usually in nearly pure culture.	16-4-16
48	Davis, E.A. and Dedrick, J., Culture Medium, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 119, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). The authors state that from the standpoint of the commercial production of algae, the question concerning the recycling of medium is important. Accordingly, the growth of Chlorella was compared in fresh and physiologically old media. The experiment was carried out in plastic (Tygon) and glass tubing culture units, in conjunction with an experiment to find the daily yield of Chlorella.	16-4-17
49	Davis, E.A., Dedrick, J., French, C.S., Milner, H.W., Myers, J., Smith, J.H.C. and Spoehr, H.A., Laboratory Experiments on Chlorella Culture at the Carnegie Institution of Washington, Department of Plant Biology, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 105, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). In this paper the authors are concerned with the discussion of the following items: 1. Outdoor Mass-Culture Units, namely large bottles, rocking tray, and plastic and glass tubing. 2. Quantitative Studies in Controlled Experimental Culture Units - This section is devoted to a discussion of Carbon Dioxide concentration, culture medium, night temperature and aeration, day and night temperatures with full sunlight and with partial shading, high-temperature strain of Chlorella, turbulence and diurnal fluctuations in cell division and enlargement. 3. Harvesting by Settling - In this section the authors discuss cultivation of Chlorella in a vertical sedimentation tube, measurements of sedimentation rates of Chlorella, and the increase in cell density in the settling chamber of the glass tubing culture apparatus.	16-4-18

Author Index No.	16-4, BIOLOGY	Master File No.
49(cont'd)	4. Conclusions: Optimum Conditions for Growth of Chlorella - Here the authors state their opinion of the optimum conditions for Chlorella growth, based on results of tests that were conducted.	16-4-18
50	Davis, E.A., Myers, J. and Dedrick, J., Quantitative Studies in Controlled Experimental Culture Units: Carbon Dioxide Concentration, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 117, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953).	16-4-19

The authors state that the lowest concentration of Carbon Dioxide that supports maximum growth of Chlorella has been a matter of considerable doubt and that experiments, therefore, were performed to determine the effect of the partial pressure of Carbon Dioxide on the growth rate of Chlorella.

54 Fink, H., "On the Protein Quality and the Liver Necrosis Preventive Factor of Unicellular Algae," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-20

Scenedesmus obliquus dried to a powder by infrared radiation was fed to white rats over a 120 day period. The dried algae was supplemented with brewer's yeast, rich in protein (8%) and 15% rye and wheat protein. During the 120 day period the algae fed animals gained weight at least as well as those fed a milk protein diet. The rats seemed to enjoy the algal diet: no rats died during the experiments and the hair covering looked dense and bright.

In a second experiment the rats were fed a diet consisting of protein--92% from algae and 8% from brewer's yeast. As a control an equal number of rats were fed a diet with protein 92% milk solids, 8% brewer's yeast. All ten of the animals fed the algal diet survived the experiment, made normal increases in weight, were lively and healthy, and had shiny dense coats.

On the milk diet, one animal died after 20 days and only two survived the 120 days. Deaths were from necrosis of liver.

After 240 days, the experiment was ended because no more algae powder was available. All the algae fed rats survived.

It was concluded that for digestible protein of Scenedesmus no supplement by amino acids of cereals is necessary.

Two recent articles, one Russian, one English, contradict these results (Elster, H.J., Naturw. Rundschau, 8, 318, 1955). J.E. Rhyther examined the toxic effect of Chlorella vulgaris

54 (cont'd) 16-4-20

and Scenedesmus quadricauda on plankton and found that excreta of these algae impaired filter activity and food intake of daphne. Aging algae retard growth, impair the population and cause death of daphne after 10-13 days.

Venberg discussed the effect of the toxins of phytoplankton on fish, birds, cats and dogs. Paralysis of hind legs and liver diseases were observed. In man, serious muscle aches and passing paralysis may follow. Microcystis, Aphanizomenon, Oscielatoria, Gonyaulax and Prymnesium are well known toxin producers. For example, Prymnesium has killed fish.

It is necessary to explain this contradiction. Since there are said to be 40,000 species of unicellular algae, some may be poisonous and others not. Another explanation is that the toxins are inactivated when the toxins are dried. Since the algae were dried carefully by infrared radiation, the toxins would have to be very unstable. This destruction of toxins by heat is not uncommon. For example, the pods of scarlet runner pea are said to be poisonous when eaten raw, but they are commonly eaten as a vegetable when cooked.

For human consumption, species with pleasing taste must be found. Some indications that diminution or at least quality fluctuations of the cultured algae for nutrition occur even without infection by inferior or even noxious species. Some waste-water grown Scenedesmus proved to be of inferior quality.

56 Fisher, A.W., Jr., "Engineering for Algae Culture," Advance Copy, World Symposium on Applied Solar Energy, Phoenix, Ariz. (Nov. 1-5, 1955). 16-4-21

Author presents eight questions pertinent to the design, construction and operation of a commercial plant for the production of algae and attempts to answer them.

1. Do algae provide a potentially useful product?
   Yes.

2. Is production of algae on a large scale technically feasible now?
   Experiments in confined atmospheres and open cultures indicate large scale production is possible. In one unit of A.D. Little, Inc., a single culture was grown continuously for over three months. The symbiotic growth of algae and bacteria in sewage oxidation ponds confirms this.

3. What apparent advantages does the mass culture of algae offer over other sources of supplemental foods?
   The rapid growth rate, the use of inorganic carbon, and the high protein, fat and vitamin make algae desirable if costs are reasonable.

4. On the basis of existing knowledge, what investment would be required to produce a given amount of dry algae?
   Based on our present knowledge of a closed or confined atmosphere system, and on a large scale plant producing 12,500 lbs. dry algae per day, the capital cost would be about $260 per lb. per day. Of this cost, about one-half would be needed for cooling and circulation. This high cost indicates the need for research to produce algae more economically.

5. On the basis of existing knowledge, what would be the cost of producing the project?
   Based on pilot plant studies and on large scale production, the operating cost is estimated at 25 cents per pound. To this must be added overhead. A breakdown of costs is presented.

6. What are the critical factors in algal culture with respect to investment and operating cost?
   A. Investment Costs
      Since the cost of circulation and cooling makes up about 50% of the initial cost, research to reduce or eliminate these items by the use of algal strains tolerating higher temperatures or other means could be very productive. The design of the distribution system for the algae and the process for preparing the mixture of CO_2 and air require study. The rate of circulation of the culture which has a considerable effect on investment is still open to question because of the uncertainty of the effect of turbulence on growth rate. Faster growing strains of algae and more efficient growth conditions are urgently needed.
   B. Operating Costs
      Labor, supervision and plant overhead account for nearly 30% of operating cost. Utilities and power comprise about 10%. Assumption was made that the average life of polyethylene tubing for culture growth is one year. Improvements in polyethylene and introduction of new plastics suggest that longer life is possible. Future tests on the length of useful life of tubes will be required.

Summary

The most important research required for more efficient algae production includes:

1. Increasing growth rate per unit area.
2. Simplifying or eliminating cooling of the culture.
3. Improving harvesting methods and equipment.
4. Reducing labor requirements.
5. Improving design and efficiency of operations and equipment.

(Abstracter's note: All of these factors are extremely important in confined space areas.)

7. How and by how much might research, development and engineering studies of these factors reduce cost?
   Of the five factors mentioned above, the first two involve growth rate and cooling.

Growth Rate

By the use of thermophyllic types of algae and the use of intermittent light, perhaps by the use of turbulent flow, the yield of algae may possibly be increased to 50 tons per acre per year instead of the 35 tons used in the initial computations.

Cooling of the Culture

The strains of Chlorella used in nearly all the experimental work thus far show a sharp maximum growth rate at about 25°C. with significantly lower rates at 30°C. and almost no growth at a few degrees higher. In a closed system, cooling is essential and the removal of heat by cooling water is the most straightforward method. The water would be cooled and recirculated.

A new strain of Chlorella isolated by Sorokin and Myers (Science, 177, 330, 1953) shows optimum growth rate at 39°C. Use of this organism would reduce or eliminate cooling needs. Initial attempts by Tamiya to use thermophyllic strains in pilot plant work were not successful because the temperature had to be maintained near the optimum for good yields.

A method suggested for cooling in arid areas consisted of the storage of heat by the melting of hydrated salts during the day with loss of heat by convection and radiation at night. Optimistically, operating cost could be reduced to about 12 cents per pound.

8. Under present and possible future costs, can algae be considered as a competitive source of food?
   In future, yes.

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65 Geoghegan, M.J., Experiments with Chlorella at Jealott's Hill, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 182, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-22

The author states that in 1949 experiments were started at Jealott's Hill to investigate the possibilities of culturing unicellular algae as a source of food. The growth and composition of these organisms are influenced by many factors, most of which are interrelated. Determination of the optimum cultural conditions would involve considerable time and effort, so they followed a somewhat arbitrary approach, the aims being to devise a technique which would give reasonably high yields of a product with a tolerably constant composition, and to determine the composition of the product and its value as a food. He then discusses:

1. Methods Used for Culturing Chlorella Vulgaris - In this section the author discusses the culture vessels used, medium, inoculum, temperature, Carbon Dioxide supply, light, effect of dark periods, energy yield, depth of culture and agitation.
2. Yield of Dry Matter
3. Composition of Dry Matter
4. Nutritional Value
5. General Observations - The author states that it appears, from preliminary estimates, that Chlorella would be too costly to produce solely for use as a food, and that economical production is likely to depend upon the possibility of using one or more of its constituents as a basic material in chemical manufacture, any residue being disposed of to best advantage.

67 Gotaas, H.B. and Oswald, W.J., "Algal-Bacterial Symbiosis in Sewage Oxidation Ponds," Third Progress Report, Series 44, No. 4, Univ. of California, Institute of Engineering Research, Berkeley, Calif. (Dec. 31, 1952). 16-4-23

This report discusses the work carried out by the Algal-Bacterial Symbiosis Project during the period January 1, 1952 to December 31, 1952. The work was partially supported by Research Grants 2601 (C), 2601 (CX) and 2601 (CS) from the National Institutes of Health of the U.S.P.H.S. and by the Division of Civil Engineering and Irrigation and the Sanitary Engineering Research Laboratories of the University of California.

During the period covered in this report, the author states that systematic studies were completed on the growth characteristics of C. pyrenoidosa cultured in sewage and on the effect of

67(cont'd) | | 16-4-23

light intensity on E. gracilis. Other work included exploratory studies of the effect of illumination periodicity, illumination frequency, and of sewage strength on photosynthetic oxygenation.

68 Gotaas, H.B. and Oswald, W.J., "Utilization of Solar Energy for Waste Reclamation," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-24

The authors have attempted to set up basic rational formulations for the design of a process for growing algae in liquid wastes.

Average yields of 30-35 dry weight tons per acre per year have been obtained for algae growth in pilot plants at Richmond, Calif.

During July and August, rate yields of 65-70 tons per acre have been observed. The yield of algae varies from 0.75 to 1.5 tons per million gallons of municipal waste processed through the pond.

73 Gummert, F., Meffert, M.E. and Stratmann, H., Nonsterile Large-Scale Culture of Chlorella in Greenhouse and Open Air, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 166, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-25

The work reported on in this paper was undertaken to evaluate the possibility of biological utilization of the huge quantities of Carbon Dioxide from waste gases available in the industrial district of the Ruhr. The work on diatoms (Harder and von Witsch) was the first in Germany to show the feasibility of the large-scale culture of algae. Studies of the literature and further investigations indicated that Chlorella was a more suitable genus for this purpose. The authors state that for a year and a half they have experimented to find out whether large-scale nonsterile cultures of algae can be grown under the local light and temperature conditions. The optimum conditions for such cultures, as well as economic utilization of the algal product, were also studied.

The authors describe the following:

1. <u>Experimental Plants and Culture Conditions</u> - In this section, they report on experimental plants, nutrient medium, temperature, aeration, strain of Chlorella and light conditions.
2. <u>Harvesting of the Open-Air Cultures</u>

3. Contamination - This section of the paper discusses foreign algae and protozoa.
4. Yields from Greenhouse and Open-Air Cultures - Here the authors discuss yield of organic matter, utilization of energy, and yields of lipides, chlorophyll and protein.

75 Haldane, J.B.S., "Biological Problems of Space Flight," Journal of the British Interplanetary Society, 10, 4, 154 (July, 1951). 16-4-26

A report of an informal talk by Prof. J.B.S. Haldane to the British Interplanetary Society on April 7, 1951.

Prof. Haldane stated a man at rest uses 1/2 cu. ft. of O_2 per hour and one CF/hr. at daylight work. CO_2 volume is 80 to 90% of volume of O_2 used up, depending on what he has been eating. Thus 50 CF of O_2 could last two days or longer aboard a space ship. Reckoning the O_2 by weight, 1/2 to 1 Kg of O_2/day needed, or one ton would last three men for more than one year. The O_2 can be stored in liquid form, the storage vessel consisting of three flasks, one inside the other.

A convenient way of absorbing CO_2 is in soda lime. Food supplies would weigh more than O_2. They would be carried dry and wetted before eating. The best plan to maintain a supply of water would be to remove it from the air by refrigeration and from the crew's excretion by distillation.

Both food and O_2 supplies could be continually renewed by making use of photosynthetic activity of plants. He recommended keeping algae in tanks, through which CO_2 would be bubbled in intense sunlight. It would be necessary to breed some species of edible algae which could live on sunlight and human excrement. This would make a balanced system, but would only operate satisfactorily near the sun, not for long voyages to Neptune or beyond.

To keep the ship from leaking, pressure should be kept to a minimum. At anything less than a quarter atmosphere breathing even pure O_2 will not maintain life. At high pressures pure O_2 is total at three atmospheres, while N_2 becomes poisonous at 8 and ordinary air at 10.

80 Hopkins, G.J. and Neel, J.K., "Raw Sewage Lagoons," Water and Sewage Works, 103, 12, 566 (Dec., 1956). 16-4-27

As of January 1, 1956, there were 100 oxidation ponds in Missouri Basin States for towns ranging from 150 to more than

80(cont'd) 16-4-27

10,000 in population. Most of these are treating raw sewage without any preliminary settling. Most lagoon facilities consist of single chambers. In the Dakotas and Montana the recommended capacity is one acre, four feet deep, for 100 persons, or 4 acre feet to stabilize a daily load of 16-20 pounds. Experiments at Kearney, Neb. indicated that higher loadings could be used--at times to more than 1000 people per acre. Based on these experiments, Missouri now permits a loading of 400 people per acre for interim treatment.

Degree of purification depends largely upon the temperature. At Kearney, Neb. the BOD reduction varied from 32-90 percent with the lower figure representative of winter conditions. During favorable seasons, 90 percent removal was obtained with a loading of more than 1000 persons per acre. Coliform removal averaged 95 percent over the entire operating period. Costs averaged for 15 communities in South Dakota $3.23 per capita for land, and $13.06 for construction, a total of $16.28 per capita.

83 Hundley, J.M., Ing, R.B. and Krauss, R.W., "Algae as a Source of Lysine and Threonine in Supplementing Wheat and Bread Diets," Science, 124, 3221, 536 (Sept. 21, 1956); also, Nutrition Reviews, 15, 87 (Mar., 1957). 16-4-28

The authors' results indicate that Chlorella is a better source of threonine than purified soya protein and is equal to several animal-protein foods of high biological value when used as food supplements isonitrogenous to Chlorella.

Their data indicate that algae protein may have considerable potential application as a source of amino acids that are generally low in cereals.

89 Jorgensen, J. and Convit, J., Cultivation of Complexes of Algae with Other Fresh-Water Microorganisms in the Tropics, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 190, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-29

The authors state that the industrial interest in the large-scale cultivation of microalgae, which has been manifest in the United States and elsewhere since the publication of the work of Spoehr and his co-workers with the versatile Chlorella pyrenoidosa, may justify the publication of work carried on for many years in Venezuela on the cultivation of highly hetergeneous complexes of fresh-water microorganisms. The report reflects more the insistent struggle to develop a basically sound idea than the presentation of precise biochemical data. They discuss in detail:

1. The Maracaibo Lake Project, specifically, the need for carotene, collection from the lake and the Venezuelan Government concession.

2. The Cultures at Cabo Blanco - In this section the authors discuss the method of culture, microorganisms present, harvesting, the administration of plankton "soup" to leprous patients and current research being conducted at Cabo Blanco.

93 Kok, B., Experiments on Photosynthesis by Chlorella in Flashing Light, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 63, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-30

Intermittence of illumination of an algal culture may provide a means of utilizing a larger fraction of the sunlight shining on a given area. A quantitative study of the effect of intermittence on photosynthesis, the author states, was expected to yield basic data that could be used in designing a system for growing algae under suitable conditions of intermittent illumination, such as might be realized in a turbulently flowing culture. He then goes on to describe experiments paying particular attention to:

1. Experimental Technique - Here he discusses the general method, light source, intermittence and algal suspension.

2. Results - In this section he discusses typical observations, comparative rates and efficiencies, and precision.

3. Intermittence Patterns - In this section the author discusses ratio of dark time to flash time, absolute values of flash time and dark time, cells grown outdoors, effect of temperature and effect of intensity.

4. Discussion - This section is devoted to a discussion of loss due to respiration, intermittence through turbulence and a conclusion in which he states that from these experiments comes the conclusion that it should be possible to grow high yields of algae in full sunlight, provided that the turbulence and density of the culture can be adjusted to produce the proper pattern of intermittence in illumination of the individual algal cells.

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94 Kok, B., "The Yield of Sunlight Conversion by Chlorella," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-31

Algae grown under exactly known conditions of illumination, i.e., under sodium light, were able to convert more than 20% of the absorbed radiation energy (590 mμ) into organic material. The pigments of green cells only absorb light of wave length shorter than 700 mμ and therefore of only about half of the total solar radiation. The sodium light represents about the mean of the visible solar spectrum, and it was concluded that the best possible yield of sunlight conversion by green cells is about 20% of absorbable radiation, or 10% of total solar radiation. Under optimal conditions, higher plants are also capable of about equal yield. The optimal value of 10% is not typical but at this maximum rate domesticated plants would yield harvests 50-100 tons dry weight per acre (30-80 gm./m^2/day). Under natural conditions the caloric value of total yields of dry weight (including roots and stalks) does not exceed 0.5-1% of the incident solar energy.

The maximal growth rate of algae is probably limited by other systems than their photosynthetic apparatus. He concluded that a trial and error approach towards increased yields of algal cultures might quicker yield results than the quantitative exploration of all factors involved.

95 Krauss, R.W., "Nutritional Requirements and Yields of Algae in Mass Culture," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-32

Nutritional Requirements for growth of most algae, except for lack of demonstration of boron requirement, very low Ca requirement and the probable cobalt requirement, are qualitatively similar to those for higher plants. The presence of an element in a medium does not mean the element is available to algae. Precipitation might make them unavailable and chelating agents have been successfully employed to prevent trace metal precipitation. Minor nutrients are Fe, Mn, Ca, Cu, Zn, Mo and Co. A list of metal-requiring enzymes emphasizes the importance of the trace metals in metabolism.

It is now well established that 0.03% CO_2-in-air--that normally is found in the atmosphere--is adequate to sustain maximum photosynthetic efficiency if sufficient volume of mixture is brought in contact with the cell surface. The 1-5% CO_2-in-air mixtures commonly employed are necessary if all cells are to be supplied with a sufficient amount. Bicarbonate ions are not a suitable source of carbon.

The fundamental problem in mass culture of algae is the maintenance of a reservoir of energy and nutrients for a long enough time to permit an economically large harvest.

Two techniques used:

1. Myers maintained constant growth rate by diluting the growing population with fresh medium at a rate commensurate with the rate of growth. Increments of culture volume could be removed from the culture vessel and cells harvested.
   The slow continual flow of fresh medium into the culture and the outflow of medium and cells serves to hold the light intensity at a constant (mutual cell shading) and prevents reduction in nutrient level on accumulation of inhibitor. This method has been successful.

2. Krauss recycling system replenishes absorbed nutrients by returning elements to the culture at the same rate at which they are removed by the algae. Harvest of algae is accomplished by pumping the culture through a continuous centrifuge. Supernatant medium is automatically returned to the culture to avoid appreciable loss of water. The culture vessels consisting of shallow (15 cm.) 300 liter vats are illuminated by batteries of fluorescent and incandescent lamps balanced to give high irradiance and spectral distribution similar to that of sunlight. Temperature kept constant in air conditioned chamber. (Diagrams shown.) The operation of the recycling apparatus is based on the assumption that the rates of nutrient absorption are known. The amount of nutrient replaced can be calculated from the dry weight of the cells harvested and from the following table:

Elemental Composition of Green Algae

Element	Percent Dry Weight
Carbon	51.4 - 72.6
Hydrogen	7.0 - 10.0
Oxygen	28.5 - 11.6
Nitrogen	7.7 - 6.2
Phosphorous	2.0 - 1.0
Sulfur	0.39 - 0.28
Magnesium	0.80 - 0.36
Potassium	1.62 - 0.85

Element	Percent Dry Weight
Calcium	0.08- 0.005
Iron	0.55- 0.040
Zinc	0.005- 0.0006
Copper	0.004- 0.001
Manganese	0.01- 0.002
Cobalt	0.0003-0.00003

To determine whether an algae can be grown in a recycling device for a prolonged period by using a replacement formula based on analysis of normal cells, 300 liter cultures of Scenedesmus and Chlorella were initiated using a modified Knop's solution consisting of 1 gm. KNO_3, 0.25 gm. KH_2PO_4 and 0.25 gm. $MgSO_4 \cdot 7H_2O$ per liter. Micronutrients as EDTA chelated metals were added initially to give the following concentration: Fe and Mn, 10 ppm; Ca and Co, 3 ppm; Cu and Zn, 1 ppm. Replacement stock solutions were prepared as follows:

Replacement Formula for Mass Culture of Green Algae

Major Nutrients

Salts	Grams per Liter
HNO_3	334
KH_2PO_4	53
$MgSO_4 \cdot 7H_2O$	27
MgO	2

Micronutrients

As the inner complex salts of EDTA

Metal	Grams per Liter
Fe	1.000
Mn	0.100
Ca	0.500
Cu	0.040
Zn	0.025
Co	0.003

(1 ml. of each stock replaces that amount of each included element absorbed by 1 gram dry weight of algae.)

The results showed that the initial and replacement solutions are capable of sustaining continuous production. The maximum sustained yield was within 85% of that predicted theoretically.

Using 5% CO_2-in-air, the yield is greater in a covered (plate glass) culture because a CO_2-in-air mixture covers the entire surface of the culture. Using more air flow or 10% CO_2-in-air in open culture improved the yield because of the increased light intensity and more available CO_2. In small scale experiments, 10% CO_2-in-air has been considered toxic.

Differences in yield under fluorescent, incandescent, and combined light sources indicated that the incandescent battery was adding little to the total yield, although consuming 42% of the combined wattage. The exclusion of much of the red end of the spectrum, including infrared, from solar radiation prior to its reaching the culture can be expected to have little detrimental effect on yield, especially when intensities are above the average 1000 f.c. used at culture surface.

The 12 hour light-12 hour dark cycle was somewhat more efficient than the continuous 24 hour light period.

A comparison of Scenedesmus with Chlorella showed that Chlorella gave a sustained yield of 38.2 gms. dry weight per culture per day, which was 15% greater than that for Scenedesmus. This is about 9 tons dry weight per acre per 100 days in continuous light 1/10 maximum sunlight intensity.

Experiments indicated that the chelating agent or some breakdown product is absorbed in considerable quantity and is probably metabolized by the cell. Whether the iron which enters the cell is actually carried across the membrane by the EDTA cannot be settled without further study. Martell and Schwartzenbach have observed that the iron complex of EDTA is photolabile. Not only is the complex broken by light but the acid itself is destroyed.

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97 Leben, C. and Barton, L.V., "Effects of Gibberellic Acid on Growth of Kentucky Bluegrass," Science, 125, 3246, 494 (Mar. 15, 1957). 16-4-33

Article describes experiments using gibberellic acid on crab grass. Kentucky bluegrass was sprayed once after fertilization (10-10-10) at rates of 0, 215 and 645 #/acre. Rates of acid application from 0 to 112 grams per acre applied in 100 gallons of water. Indication that under conditions of heat both fresh and dry weight increased. Notable stimulus under

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unfavorable conditions of growth. Cut grass moistened with 10 to 100 μg/liter acid showed marked growth stimulation.

Reference suggested acid induced growth under conditions of low light intensity and low temperature.

107 Mayer, A.M., Eisenberg, A. and Evanari, M., "Studies on the Deep Mass Culture of Algae in Israel," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-34

The basic unit in which all experiments have been carried out has been a concrete tank 2 m. x 1 m. x 1 m. deep. The front of the tank is transparent with a perspex or glass window and is so oriented that the transparent side faces south. A stirrer of the paddle type rotating about a horizontal axis was used most of the time. The light intensity on the horizontal surface reached 25,000 f.c. about noon. In the winter the southern wall receives an appreciable amount of the total light but in summer its contribution is almost negligible. The tank contained 2100 liters. CO_2 was added in measured amounts once a day by bubbling it through a very fine diffuser. The amount passed through was 300 liters during one hour daily.

Three species of Chlorella have been used: Chlorella vulgaris (Hopkins strain), C. pyrenoidosa Tx71105 (from J. Myers) and C. ovalis Butcher Plymouth 86. The culture was harvested by a Sharples super-centrifuge. Yields of 20 gm. per sq. meter of total illuminated area were readily obtained.

No problem of infection arose. Protozoa have never been a problem and foreign algae were generally not noted. Chlamydomonas cannot compete with Chlorella.

The effectiveness of the southern transparent wall seems doubtful especially since it invariably became coated by algae. The yields obtained were not optimal and higher yields are expected with a new, more efficient stirrer.

C. vulgaris was most encouraging species.

C. ovalis is a saline species and grows in 4% NaCl, but its growth rate under saline conditions is much reduced.

Table 2 follows:

Salts Used in Nutrient Solution

Macroelements	Quantity per liter in gm.
$(NH_4)_2SO_4$	3
$MgSO_4$	1.2
KH_2PO_4	2.5
EDTA (Ethylene diamine tetracetic acid)	.25
KOH	.31
Microelements	**Quantity per liter in mg.**
$FeSO_4 \cdot 7\ H_2O$	48
$MnCl_2 \cdot 4\ H_2O$	27
$CaCl_2$	11
$ZnSO_4 \cdot 7\ H_2O$	2.2
$CuSO_4 \cdot 5\ H_2O$	2.6
$Co(NO_3)2 \cdot 6\ H_2O$	6

113 Meffert, M.E., "Algal Culture in Sewage," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-35

Outdoor experiments were carried on to determine:

1. Is it possible to cultivate algae in sewage? Under what conditions?
2. What is the yield and composition of the algae?
3. Is it possible to reduce the amount of nutrient and vitamins for the growth of the algae? What purification of sewage is obtained?

The alga, Scenedesmus obliquus, was used because it is not destroyed by the protozoa in the sewage. Now sterilized selected sewage from the Ruhrverband was used in the experiments. The total nitrogen content of the sewage (20-30 mg./l.) was so low that the algae were only allowed to double in quantity before harvesting and adding more sewage.

The Carbon Dioxide liberated by the bacteria was changed to carbonate and bicarbonate and was therefore not usable by the algae. Digester gas was added to supply CO_2. Under these circumstances the yield of algae under favorable light conditions was 7-10 grams per sq. meter per day.

The crude protein in the algae grown in sewage was only 50-63% of that obtained with adequate nitrogen. In 2-4 hours contact with the algae, the permanganate oxygen consumed of the sewage was reduced about 70%.

Eleven references are cited.

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114 Milner, H.W., The Chemical Composition of Algae, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 285, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-36

The primary concern of this paper is the composition of the green unicellular fresh-water algae. Very little information on composition is available for fresh-water algae, other than the unicellular green ones and a few diatoms. Information is available on the components of marine algae, such as alginic acid, laminarin, agar, mannitol and iodine, to mention but a few. Emphasis in this paper is placed on work giving quantitative information about the amount or composition of algal constituents and not to the mere presence of various constituents in algae.

The author reviews the following:

1. Composition of Plant Materials - Included in this discussion are elementary composition, degree of reduction, protein, carbohydrate and lipide content, and effect of environment.

2. Lipides in Algae - This section discusses, in detail, lipides in Chlorella and, briefly, lipides in other algae.

3. Proteins and Amino Acids in Algae

4. Carbohydrates in Algae

5. Minor Components of Algae - Included in this section of the paper are discussions on minerals, sterols, pigments and vitamins found in algae.

6. Distribution of Algal Components - This section contains an alphabetical list of substances, to which key numbers have been assigned, and a list of algae in which the substances are found. The key numbers are used for cross reference.

115 Myers, J., "Algae as an Energy Converter," Preprint, World Symposium on Applied Solar Energy, Phoenix, Ariz. (Nov. 1-5, 1955). 16-4-37

The machinery of the algal cell may be described by two types of processes: (1) photosynthesis, and (2) secondary synthesis which depends upon it. The rate or multiplying character of algal growth may be expressed as first order reaction rate or compound interest rate constant (e.g., k in equation $N = N_0e^{kt}$ where N is cell number and t is time).

Requirements of algal cell machinery.
CO_2 - 1.8 lbs. per lb. Chlorella
Temperature - less than 38°C. (100°F.)
Chlorella and most algae used killed by prolonged exposure above 30°C. (85°F.) but a high temperature one, Chlorella T x 71105, grows at temperatures up to 39°C. (102°F.).

Light--most important--within the visual range 4000-7000Å degrees satisfactory--corresponds to about 40% of solar radiation at earth's surface. Response to light intensity is linear but only to a rather low limit and levels off to a flat plateau of light-saturation. The light-saturation point for Chlorella occurs at about 500 f.c. (white light) as compared with maximum solar illuminance of 10,000 f.c.

The illuminance in the culture will fall off roughly according to Beer's law, which means (1) that the depth of the culture and the cell concentration are reciprocal functions, and (2) that there is a further reduction in actual efficiency of use of sunlight.

Efforts have been made or are being made to increase the yield per unit area in three ways:

(a) Use of turbulence of culture to produce advantageous intermittent light effects for individual cells.
(b) The use of light diffusers to spread the high surface illuminance over a greater area in the horizontal dimension of a deep culture.
(c) The search for algae with equal efficiencies but higher levels of light saturation.

Chlorella should be regarded as an algal weed chosen because it is hardy and easily grown and because of the greater initial background information. We must explore for species with growth characteristics and products of particular usefulness.

116 Myers, J., "Algal Growth: Processes and Products," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). 16-4-38

When all nutrient requirements are adjusted to optimum levels, yield becomes limited by the rate of input light energy and the efficiency with which it is used. Kok with Chlorella in illumination with the yellow sodium line, obtained efficiencies of overall algal cell synthesis in the range of 18-24% under favorable nutrient conditions over three day periods. The author's experiments using the yellow and green mercury lines have given efficiencies of about 15% for Chlorella pyrenoidosa. He adopted 20% as a reasonable maximum value of efficiency for use of white light. In large cultures, under sunlight illumination, the efficiencies range 2-3%, or about the same as for crop plants under most favorable conditions. The major discrepancy between maximum efficiencies and actual results under sunlight lies in the very high light intensity of sunlight and the difficulty of light saturation.

Three ways of increasing overall efficiency or yield per unit area have been suggested.

1. Selection of algae with higher values of light saturation even when grown in dense cultures at low specific growth rate.
2. Utilization of intermittent light by turbulence of culture. Probably the turbulence would need to be so great that the gain would be offset by increased power consumption.

3. Manipulation of the incident light intensity so that it approaches the value of light saturation by spreading incident sunlight over an area of culture greater than the ground surface area. For example, by including surfaces toward the mean position of the sun so that a thin layer of culture flowing over them would be exposed to oblique illumination of lower intensity. The author uses diffusing cones with their bases at the illuminated surface.

The second part of paper is concerned with the nature and possible variability and control of the algal product.

Chlorella and Scenedesmus excrete so little organic matter that 90-100% of the carbon assimilated may be recovered in the cells produced, so that the algal product is nearly identical with Chlorella cell composition. This does not necessarily apply to all algae as chlamydomonas excreted organic matter including glycocolic and oxalic acids. Algae may use one of two different methods of disposition of accumulating products. It may convert them to intracellular carbohydrate and fat, or it may excrete excess photosynthate as an organic acid or carbohydrate or some other transformation product of these. Conditions controlling such excretions are not yet known.

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18. Wassink, E.C., Kok, B., and van Oorschot, J.L.P., pp. 55-62 in Ref. 1.

117 Myers, J., Growth Characteristics of Algae in Relation to the Problems of Mass Culture, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 37, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-39

Biological information of significance for the mass culture of algae can best be treated by considering, first, the characteristics of growth under controlled and measurable conditions; then the extrapolation of these characteristics to the case of high-density cultures; and finally, the limitations which it is expected will be introduced by the use of sunlight illumination. In this paper the author discusses, using Chlorella pyrenoidosa (Emerson strain), the following:

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1. Growth of Chlorella under Measurable and Controlled Conditions including growth constant k and measurement of k.

2. Factors that Affect the Growth Rate, namely, k as a function of light intensity, k as a function of temperature, k as a function of Carbon Dioxide concentration, k as a function of components of the medium, effects of autoinhibitors on k, k as a characteristic of the organism, characteristics of growth of other algae and temperature tolerance.

3. Growth in High-Density Cultures - Here the author discusses a typical growth curve, exponential growth, linear growth, limiting density and optimum density.

4. Growth at High Densities Under Sunlight Illumination, including efficiency of utilization of energy, flashing light, use of improved strains of algae and diurnal intermittence of illumination.

Finally, the author adds an Appendix in which he discusses calculations on light absorption by Chlorella.

118 Myers, J., et al, "Study of a Photosynthetic Gas Exchanger as a Method of Providing for the Respiratory Requirements of the Human in a Sealed Cabin," Report to the Air Research and Development Command, Laboratory of Algal Physiology, Contract No. AF 18(600)-618, Univ. of Texas, Austin, Tex. (Oct. 13, 1955). 16-4-40

Report covers work done May 1, 1953 to October 31, 1955.

Preliminary Considerations

Discussion based on alga, Chlorella pyrenoidosa, and on an illuminated tank of algal suspension aerated with the air of the sealed cabin. Fluorescent lighting will be used and a cooled condenser will be required. Following estimates made for long-time, steady-state growth conditions:

1. Quantity of Algae required to balance the gas exchange of one man is 2.3 kilograms fresh weight of Chlorella. CO_2/O_2 exchange quotient of the alga may be balanced against that of the human.

2. Volume at wave length 6800 Å. A suspension containing 10 grams per liter will absorb 97% of the incident light at a thickness of 0.4 cm. If layer is illuminated from both sides, a thickness of cm. is reasonable. Therefore, illuminated surface of 240 sq. ft. required for

230 liters of suspension per mean, or 80 cu. ft. total volume per man.

3. Power requirements based on light to chemical photosynthetic conversion efficiency of about 1.9% would be 10 H.P. electrical energy per person. Heat dissipation problem may be serious.

4. Nature and magnitude of expended and produced materials. The exchanges per man hour will produce 23 grams dry weight of algae containing 50% protein and will require 1.8 gm. of fixed nitrogen and 1.2 gm. of mineral salt. Water must be recycled. All human urine might be cycled through exchanges to furnish much nitrogen. Part of the algae can be used as food.

Experimental Evaluation

1. Best lamp available now or in foreseeable future (5 years) is fluorescent lamp.

2. Human urine may be recycled to provide a portion of the nitrogen requirement for algal growth but the results of continued urine accumulation are uncertain.

3. The CO_2/O_2 quotient is about 0.75 and lower than for man. The use of urea would give a higher result.

Conclusions

1. A model gas exchanger utilizing an algal suspension can be made to work reliably for periods of at least three weeks (the longest attempted) under steady-state conditions.

2. Thermodynamic efficiencies of 15-16% have been observed for oxygen production equivalent to 9.1 liters per hour per kilogram fresh weight of algae have been observed. This approaches estimated value of 11.0 liters/hr., which was basis for prediction that 2.3 kg. of Chlorella would support gas exchange of one man.

121 Oswald, W.J. and Gotaas, H.B., "Photosynthesis in Sewage Treatment," Proceedings, American Society of Civil Engineers, Separate 686, 81 (May, 1955); also, Trans. ASCE, Paper 2849, 122, 73 (1957). 16-4-41

The stabilization of organic matter in sewage wastes requires oxygen which in secondary treatment plants is normally obtained from the atmosphere. The primary source of atmospheric oxygen is photosynthesis for which the sun supplies the energy and water supplies the oxygen. Sewage contains the necessary nutrients for photosynthetic organisms to produce oxygen while

Author Index No.	16-4, BIOLOGY	Master File No.
121 (cont'd)	at the same time, fixing these valuable nutrients as well as solar energy in reclaimable material. Laboratory and pilot plant investigations of sewage treatment in open ponds by photosynthetically produced oxygen have been carried on during the past four years. These studies have provided some basic principles which can be utilized for the engineering design of the process as well as for the prediction of the operational performance of new or existing oxidation ponds. The present paper formulates design criteria based on these principles.	16-4-41
122	Oswald, W.J., Gotaas, H.B., Golueke, C.G. and Kellen, W.R., "Algae in Waste Treatment," Sewage and Ind. Wastes, 29, 4, 437 (Apr., 1957). The authors present a theoretical analysis of the phenomena occurring in stabilization ponds for sewage treatment and their relationship to loading and oxygenation.	16-4-42
123	Oswald, W.J., Gotaas, H.B., Ludwig, H.F. and Lynch, V., "Algae Symbiosis in Oxidation Ponds. III. Photosynthetic Oxygenation," Sewage and Ind. Wastes, 25, 6, 692 (June, 1953). Test organism in laboratory studies was Euglena gracilis. The source of light was fluorescent lamps. The maximum population of Euglena gracilis in sewage was found at 400 f.c. and it remained nearly constant to about 1200 f.c. From 1200 to 2400 f.c. the population decreased slightly. With a relatively strong synthetic sewage, the maximum Euglena developed at 2400 f.c. Temperature was maintained between 24 and 26°C. Bacterial population reached maximum at 100 f.c. A large part of the carbon utilized by the algae is not incorporated into the cells, but much of it appears in the effluent supernatant, perhaps as a highly oxidized excretory product of the Euglena.	16-4-43
124	Pearse, L., et al, "Oxidation Ponds," (A.P.H.A. Report), Sewage Works Journal, 20, 6, 1025 (Nov., 1948). Design: Oxidation ponds not suitable where the soil is loose and sandy. The sewage should be clarified and minimum detention time for settled domestic sewage should be 25 days with a minimum surface area of one acre per 400 contributory population. Three feet is regarded as minimum depth. In Texas, the current BOD loading varies from 20-40 lbs. BOD	16-4-44

per acre foot per day with BOD reductions of about 50%.

Operation: Odors, mosquitoes and weeds on banks are mentioned as difficulties. The effluents were permanently stable, with BOD values as good or better than those of trickling filter effluents. The reduction of coliform organisms was as good as with chlorination. Final overflow from ponds designed for 15 days detention showed 5-50 coliforms per ml. as compared with 100,000 per ml. in the original sewage.

125 Perret, C.J., "An Apparatus for the Continuous Culture of Bacteria at Constant Population Density," Jnl. of General Microbiology, 16, 1, 250 (Feb., 1957). 16-4-45

A self regulating continuous culture apparatus is described, designed for studying growth and enzyme production in bacteria which require complex media. It might also be suitable for the cultivation of suspended tissue cells.

126 Petersen, C.S. and Carroll, R.W., "Biological Effect of Hydroxylysine," Science, 123, 3196, 546 (Mar. 30, 1956). 16-4-46

Hydroxylysine (2,6-diamino-5-hydroxhexanoic acid) occurs in collagen of terrestrial and marine aminos and gelatin derived from these, but little is known of its biological significance.

Fig. 1 (pp. 546) shows effect of additions of 2, 20, 1000 μg of racemic hydroxylysine per ml. of double strength medium on responses of streptococcus faecalis to increments of lysine. Amount of l-lysine reduced more than 20 μg for half maximum growth by addition of 7 μg of racemic hydroxy compound per tube (0.4 μg natural isomer).

Assays of lysine in hydroxyzates of foods and tissues may be affected if test organisms leuconoster mesenteroides P-60 and streptococcus faecalis are usual in basal media that contain no hydroxylysine.

13 references listed.

127 Pratt, R., "Studies on Chlorella Vulgaris. IX. Influence on Growth of Chlorella of Continuous Removal of Chlorellin from the Culture Solution," American Journal of Botany, 31, 418 (1944). 16-4-47

Describes experiments which have been interpreted as indicating that algae produced a growth-inhibiting substance called "chlorellin."

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134 Renn, C.E., "Algae Research on Oxidation Ponds," American Journal of Public Health, 44, 5, 631 (May, 1954). 16-4-48

In general, a discussion of others' work. Some opinions are: "From the engineer's point of view, carrying out biological self-purification of polluted waters in oxidation ponds has the single great advantage of being controllable." "It is generally undesirable to discharge the dense algae suspension developed in short-term oxidation ponds directly to streams. Although sewage has been converted to relatively inoffensive algal organic matter, the total BOD loading may be as great or greater than the plant influent."

The difficulties in harvesting algae were emphasized. Settling without the addition of coagulants is ineffective because of the motility of a large part of the population.

145 Smallhorst, D.F., Walton, B.N., Jr. and Myers, J., "The Use of Oxidation Ponds in Sewage Treatment," Preprint, American Public Health Association, New York, N.Y. (1953). 16-4-49

Factors affecting algal growth are: (1) nutrients available; (2) light; and (3) temperature. Nitrogen content of algae is high (up to 1% dry weight). Algae utilize nitrogen either as ammonia or nitrate. Photosynthesis in an algal cell reaches a maximum rate at a light intensity of 50-500 f.c. (Full sunlight is about 10,000 f.c.). Since illuminated algae excrete no other gas than oxygen, they may produce oxygen concentrations up to 39.2 ppm at 25°C. This high concentration of oxygen makes possible the rapid oxidation of sewage organic matter. Incandescent light at night seemed to speed up formation of oxygen but fluorescent lighting was not very effective.

The growth of Chlorella is seriously inhibited at temperatures above 30°C.

Carbon Dioxide is taken up by algae mainly as free CO_2 or H_2CO_3 not as bicarbonate or carbonate. In surface layers, the pH rises because of removal of CO_2 by photosynthesis; at night the pH decreases as a result of CO_2 production by bacteria and algae.

Author Index No.	16-4, BIOLOGY	Master File No.

146 Smith, J.H.C., Cultivation of Chlorella in a Vertical Sedimentation Tube, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 143, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-50

The author states the industrial cultivation of unicellular algae requires a feasible and economical procedure for harvesting. The practicality of one possible method, gravitational sedimentation, has been tested both by long-term experiments on growing Chlorella under natural conditions and by quantitative determinations of rates of settling.

148 Special Study Group, Class 1956, Command and Staff School, Maxwell Air Force Base, "The Human Element in Future Air Power," Special Study Number 9a, Air Command and Staff College, Command and Staff School, Maxwell Air Force Base, Alabama (Apr. 20, 1956). 16-4-51

A study of factors which pertain to air crews has been made. Part I--will deal with air power from the present until 1965 and will cover physical and physiological limitations imposed on air crew personnel flying in aircraft programmed through that period. Part II--treats air power beyond 1965 and the limitations air crew personnel will face with the advent of manned space flight. Part III--deals with those psychological problems with which air crews described above are faced through both time periods.

Part II is of particular interest. It discusses the several environmental problems including oxygen, elimination of waste gases, radiation, elimination of bodily wastes.

Proposed solutions for the solid waste elimination problem are even more ingenious and are limited only by the imagination and ingenuity of the space ship designer. A total of four pounds of solid waste per man per day is estimated. This total included food scraps, refuse and other sewage. One solution is to store the material in containers and return them to earth with the vehicle, similar to the chemical toilets in use today. Another means is to throw or expel the material from the vehicle into space. This, although the easiest and the cheapest, would play havoc with any visual observation in progress and would not be without danger, since clouds of micrometeors would be formed. A third solution visualizes the shooting of the material in a container, into outer space, propelled by a small, short-lived rocket engine. If the rocket were fired toward the earth and in the opposite direction of that of the space vehicle, it would quickly reach "burn-out" and fall toward the earth, being completely incinerated as it entered the atmosphere.

Author Index No.	16-4, BIOLOGY	Master File No.
150	Spoehr, H.A., Smith, J.H.C., Strain, H.H., Milner, H.W. and Hardin, G.J., "Fatty Acid Antibacterials from Plants," Publication 586, Carnegie Institution of Washington, Washington, D.C. (1949). Inhibition of bacterial growth, probably photo-oxidized fatty acids, are produced by C. pyrenoidosa (Emerson Strain) as demonstrated by Spoehr.	16-4-52
157	Tamiya, H., "Growing Chlorella for Food and Feed," Preprint, World Symposium on Applied Solar Energy, Phoenix, Ariz. (Nov. 1-5, 1955). In this paper the author reports on the results of experiments conducted in Japan in the past four years, with the view to finding out a feasible method of mass culturing unicellular algae. A new culture method (An Open Circulation System With a Device of Intermittent Sweeping) is proposed, which the author states proved to meet tolerably the requirements of: (a) the maintenance of adequate temperature of the culture solution, or the use of algal strains of different temperature-tolerance according to the climate or seasons, (b) the construction of a culture unit which is as refractory as possible against various meteorological happenings, (c) the prevention of contamination of culture by air-borne microorganisms which are harmful to algae, and (d) the low cost of construction and operation of the plant. A tentative estimate is made of the production cost of algae to be produced by extension of this method to a large scale. He also reports some experience dealing with the use of Chlorella as human food.	16-4-53
158	Tamiya, H., Sasa, T., Nihei, T. and Ishibashi, S., "Effect of Day-Length, Day-and-Night-Temperatures, and Intensity of Daylight Upon the Growth of Chlorella," Preprint, Conference on Solar Energy: The Scientific Basis, Univ. of Arizona, Tucson, Ariz. (Oct. 31-Nov. 1, 1955). (1) Effect of variation of day-length, day-and-night-temperatures and of intensity of daylight upon the growth rate of Chlorella was investigated using combinations of conditions which were varied as follows: Day-length: 6 hours (18 hours dark), 12 hours (12 hours dark), 18 hours (6 hours dark), and 24 hours (no darkness). Day-and-night-temperatures: 25°, 15° and 7°C. Intensity of daylight: 50, 10, 2, and 0.4 kilolux.	16-4-54

(2) In general the rate of growth was affected by changes of day-temperature by far more profoundly than by changes of night-temperature. In the temperature range studied, the higher the day-temperature, the greater was the growth rate. Higher night-temperatures had no recognizably favorable effect except when the day-temperature was as low as 7°.

(3) In general, the growth rate was directly proportional to the day-length ("day-limited growth") at shorter day-lengths. Such a proportionality extended to longer day-lengths, the lower the daylight intensity; and the intensity of daylight, under which a day-limited growth occurred markedly, was higher, the higher the day-temperature. At longer day-lengths, and especially under stronger daylight, the growth rate tended to become independent of day-length (the phenomenon of "day-saturation"), or to become rather smaller with the increase of day-length (the phenomenon of "day-oversaturation"). The latter phenomenon was accompanied by a bleaching of algal cells. Both the day-saturation and oversaturation occurred <u>ceteris paribus</u> more markedly at lower day-temperatures. The day-oversaturation occurred most profoundly when both the day and night temperatures were 7°, but ceased to occur when day temperature was 7°, and night temperature was 25°.

(4) Although the growth rate increased, in general, with the increase of day-length, the favorable effect of long-day condition decreased with the decrease of day-temperature. At 7°, and especially when the daylight intensity was high, there was almost no difference in the growth rates under short-day and long-day conditions. It was also observed that the temperature dependence of growth rate decreased and eventually tended to disappear with the decrease of daylight intensity and with the shortening of day-length, and that the daylight intensity, under which the growth rate became light-saturated, was lower at lower day-temperatures. All these facts indicate that the short-day condition and weaker daylight become relatively less disadvantageous with the decrease of day-temperature.

(5) The phenomena of day-limited and day-saturated growths as they were conditioned by temperature, intensity of daylight and day-length were explained on the basis of observations made earlier by Tamiya, et al,

who, by determining the relative rates of light-dependent and light-independent phases in the growth process of algae, have found that the light-independent phase has a considerably greater temperature-coefficient than the light-dependent phase.

(6) The phenomenon of "day-oversaturation," which occurred at lower temperatures and under stronger daylight, was explained as being due to the injurious effect of strong light upon the so-called "light cells" which have been shown by Tamiya, et al, to become abundant in cultures when the temperature was low and light was strong.

4 references are cited:

1. H. Tamiya, E. Hase, K. Shibata, A. Mitsuya, T. Iwamura, T. Nihei and T. Sasa: Kinetics of growth of Chlorella, with special reference to its dependence on quantity of available light and on temperature. Algal Culture from Laboratory to Pilot Plant, Edited by J.S. Burlew, Carnegie Institution of Washington Publication 600, 1953, p. 204.
2. D.I. Arnon: Am. J. Bot., 25 (1938), 322; Science, 92 (1940), 264.
3. H. Tamiya, T. Iwamura, K. Shibata, E. Hase and T. Nihei: Biochem. et Biophys. Acta, 12 (1953), 23.
4. F.W. Went: Am. J. Botany, 31 (1944), 140.

159 Tamiya, H., Shibata, K., Sasa, T., Iwamura, T. and Morimura, Y., Effect of Diurnally Intermittent Illumination on the Growth and Some Cellular Characteristics of Chlorella, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 76, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-55

Though the light source to be utilized in large-scale mass culture of unicellular algae is expected to be natural sunlight, the effect of diurnal alternation of light and dark periods upon the growth and various cellular characteristics of algae has not yet been studied systematically. The authors state that with a view to filling in this gap in knowledge, they performed experiments, using Chlorella ellipsoidea as material, and then go on to describe:

1. Experimental Procedure in which they discuss culture conditions and measurements.

2. Growth Curves - Here the authors discuss packed cell vol. & number and cell size.

Author Index No.	16-4, BIOLOGY	Master File No.
159(cont'd)	3. Discussion - The authors conclude their paper with a discussion covering formative metabolism, dark and light cells and effect of intermittent illumination.	16-4-55
160	Thimann, K.V., "Solar Energy Utilization by Higher Plants," Preprint, World Symposium on Applied Solar Energy, Phoenix, Ariz. (Nov. 1-5, 1955).	16-4-56

The author states that in spite of the fact that all of our agriculture and animal husbandry, as well as most of our nutrition, is concerned directly with the flowering plants, their utilization of the sun's energy has been relatively little studied. Students of photosynthesis in recent years have been mainly concerned with four lines of advance: (1) the nature of the light reaction; (2) the biochemical steps following the fixation of CO_2 and leading to formation of sugar; (3) the free-energy efficiency of the process; and (4) the photosynthetic activities of bacteria. The second and third have been mainly studied with Chlorella, the fourth necessarily with bacteria, and the first partly with Chlorella and partly with isolated chloroplasts; only in the second have leaves and leaf fragments of higher plants been occasionally used. This neglect arises partly from the feeling that photosynthesis in leaves is too "complicated" to shed light on the process per se, but partly from the widespread feeling that the efficiency of photosynthesis in leaves is lower than in the algae.

167	Wassink, E.C., Kok, B. and van Oorschot, J.L.P., The Efficiency of Light-Energy Conversion in Chlorella Cultures as Compared with Higher Plants, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 55, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953).	16-4-57

It has been estimated that the efficiency of energy conversion by green plants is about 2% of the solar radiation which reaches the earth's surface and is usable in photosynthesis (excluding the infrared). This means that during their growth they convert about 2% of the usable solar energy into chemical energy (organic matter). Calculations based on optimal yields of agricultural crops in the Netherlands obtained figures of from 1% to about 2% of the usable radiation incident on the cultivated surface. The estimates were based on the total dry weight of the crop, assuming its average composition to be CH_2O.

For comparison, the efficiency that one would expect to obtain can be calculated from the rate of photosynthesis.

Extensive experimental evidence was collected, e.g., in short-time experiments with Chlorella. Assuming a quantum yield of 0.10-0.12 per mol. of oxygen evolved, and quanta of 50Kcal/mol. $h\nu$, the calculated efficiency is about 25%.

The author reviews:

1. Efficiency of Chlorella Growth in Small Cultures including preliminary observations, balance experiments and additional observations.

2. Efficiency of Chlorella Growth in Mass Cultures including outdoor and indoor mass cultures.

3. Efficiency of Higher Plants

He then summarizes that the efficiency of light-energy conversion in both small-and large-scale cultures of Chlorella is 12 to 20%, provided the intensity of the illumination is not too high. The same holds for cultures of higher plants. Outdoor stirred mass cultures of Chlorella in full summer light show efficiency values of 2 to 3%, as do good field crops of higher plants. Excessive illumination seems an important factor in producing low efficiency under natural conditions.

172 von Witsch, H. and Harder, R., Production of Organic Material by Green Algae and Diatoms, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 154, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-4-58

Laboratory experiments on the mass culture of autotrophic microorganisms were inaugurated in Gottingen during the Second World War, particularly with a view to the production of fat. From preliminary experiments with various organisms it was concluded that the diatom, Nitzschia palea, and the green alga, Chlorella pyrenoidosa, were most promising for practical purposes of culture. These organisms were cultured in nutrient solutions in glass tubes, 3 cm. X 25-30 cm. and 6 cm. X 150 cm., with an air stream enriched with about 0.5% CO_2 at about 15 liters per hour, and illuminated with water-cooled 300-watt lamps, yielding up to 10,000 lux. (1 lux.= 0.0929 f.c.).

Author Index No.	16-6, HYGIENE & SANITATION	Master File No.

63 Gee, A.H., "Organoleptic Appraisal of Three-Component Mixtures," Symposium on Odor, A.S.T.M. Special Technical Report No. 164, p. 33, American Society for Testing Materials, Philadelphia, Pa. (1954). 16-6-1

Three kinds of odorants were introduced in various proportions into a specially devised dynamic flow system suitable for organoleptic appraisal of the resulting odor mixture. The methods and equipment were developed under a United States Air Force contract in connection with the control of undesirable odors in hospital aircraft, without masking alarm or signal odors indicative of mechanical trouble or of an incipient fire on the airplane.

The components of cabin air are: (1) odors of infected wounds and of body discharges; (2) odor control agents; (3) vapors and smokes from gasoline, hot lubricating oil and hydraulic fluid, burning electrical insulation, and scorching paint. These were appraised in experimental mixtures by the use of profile scoring. Plotting the results showed the effects of the control agents.

The malodors were partly masked by aldehyde. Ozone cancelled the malodors but must be used with care. Smokes and other alarm odors were unaffected by the control agents.

The author concludes that the methods presented are convenient for the investigation of three-component odor mixtures, when it is necessary to vary the components independently in seeking a solution for a complex odor control problem. The results are reproducible and lend themselves to graphic representations in which the effects of the separate components can be readily seen.

Additional information on tests available in AFTR No. 6565, Part 1, May, 1951; Part 2, Sept., 1951; Part 3, May, 1952; and Part 4, Sept., 1952.

64 Gee, A.H. and Pinkes, A.H., "Control of Odors in Evacuation Aircraft," Aero Medical Lab. Contract No. AF 33(038)-18819, AF Technical Report No. 6565, Part 2, ASTIA No. ATI-159415, Foster D. Snell, Inc., New York, N.Y. (Sept., 1951). 16-6-2

This is the second part of the work on an odor control project which has as its ultimate aim the control of elimination of malodors on evacuation aircraft by some suitable

Author Index No.	16-6, HYGIENE & SANITATION	Master File No.
64(cont'd)		16-6-2

agent, preferably for use in aerosol form, without masking such alarm odor signals as the fumes of gasoline, hydraulic fluid, hot oil, scorching paint or burning insulation.

The present report gives the characteristics and behavior of the alarm odors, which are neither suppressed by malodor nor masked by many of the control agents at levels at which the control agents appear to be useful.

137 Ross, H.E., "Orbital Bases," Journal of the British Interplanetary Society, 8, 1, 1 (Jan., 1949). 16-6-3

A portion of the article on the orbital bases is concerned with air, food and water. The author is assuming 24 men in the orbital station at some distance of say 500 miles above the earth's surface.

The food consumption will be 3#/person/day or 2.97 tons of food in three months. This food supply will be brought to the station by a supply ship.

Air and water the author feels can easily and conveniently be studied for it will be assumed that the air and water are being obtained from hydrogen-peroxide.

The oxygen and water requirements for 24 men for 24 hours are:

O_2, 26,952 liters = 38.5 kilograms = 34.7#.

H_2O, variable but at least 180 pints = 102.15 kilograms = 225#.

Additional water needed for cooking, washing and bathing.

Therefore, total water required/day/24 men = 1,302#.

Assuming 4% wastage and loss of O_2 need to provide 40 kilograms, or 88.2#. Assuming 90% H_2O_2 we will have 210# of H_2O_2 required per day, and this will yield 121# pure water.

Article recommends keeping the atmospheric pressure as low as possible to prevent leakage, about 160 mm Hg. The atmosphere of the station is in doubt--that is, use of pure oxygen, special proportions of oxygen and nitrogen, oxygen and inert gas, or standard air.

The problem of eliminating 15.9 liters (33.4 grams) per minute; 22,900 liters or 48.0 kilograms, or 106# of CO_2 per 24 hours remains. CO_2 elimination can, of course, be achieved

137(cont'd) 16-6-3

in various ways--by chemical absorption or adsorption, by centrifuging, fractional liquification, etc., etc. Simplicity is the major attraction for the space station. The fouled air is piped through pipes exposed to the outer atmosphere on the side away from the sun and the CO_2 will be frozen out.

Thermal cracking of CO_2 is worthy of consideration because thermal energy is available. As for regeneration of the atmosphere of the station by green vegetation, this method is open to severe practical criticism, especially so if operation over long periods of time is required.

Additional water savings can be accomplished by recapturing the water vapor discharged from lungs and skin by condensation similar to the CO_2 process. Some 62 kilograms or 137# of H_2O/24 hours can be saved.

165 Turk, A., "Odor Control Methods: A Critical Review," Symposium on Odor, A.S.T.M. Special Technical Report No. 164, p. 69, American Society for Testing Materials, Philadelphia, Pa. (1954). 16-6-4

Methods commercially available for control of odors may be divided into four classifications: combustion, adsorption, absorption, and vapor mixing. The article discusses each of these.

Deodorization by combustion methods occurs because final products are odorless or have higher threshold values. Partial oxidation may increase odor. Use of platinum alloy-activated alumina catalyst permits oxidation at 500 to 800° F. lower than uncatalyzed incineration. Other catalysts include copper, chromite, various metallic oxides, and Fischer-Tropsch catalysts.

Adsorption control is practically limited to use of activated carbon.

Absorption methods may be suitable for odorous vapors. Process is usually a washing process.

Vapor mixing may also be considered as odor counteraction by the mixture of two vapors which reduce or neutralize an unacceptable odor, or increase its acceptability by masking it. Also reactions may occur. Dangers of the method are enumerated.

M-100

Author Index No.	16-6, HYGIENE & SANITATION	Master File No.
173	Yaglou, C.P., Riley, E.C. and Coggins, D.I., "Ventilation Requirements," Paper 1031, Trans., A.S.H.&V.E., 42, 133 (1936); also, Heating, Piping and Air Conditioning, 8, 1, 65 (Jan., 1936).	16-6-5

A report of research to study general problem of ventilation odors under normal conditions with the possibility of establishing ventilation requirements for various groups of individuals under both winter and summer conditions.

The tests employed and data taken are discussed. Tabular data as well as empirical formula are derived.

Some parameters for ventilation requirements, air space, outdoor air supply, air conditioning, equipment functioning with respect to body odors are developed.

Author Index No.	16-9, NUTRITION	Master File No.

31 Brooks, F.A., "More Food from Solar Energy," Preprint, World Symposium on Applied Solar Energy, Phoenix, Ariz. (Nov. 1-5, 1955). 16-9-1

The author states that the ultimate objective of the application of solar energy for biological uses is the direct production of food from inorganic raw materials. But sugar, for which factory production seems nearest, happens to be the one food now in actual surplus even on a world-wide basis. More essential foods are the very complex proteins, and synthetic production of these seems rather distant. A supplemental source of food is more urgently needed than most of us realize because already agricultural production is inadequate, if the entire present population of the world were to be properly nourished.

57 Fisher, A.W., Jr., and Burlew, J.S., Nutritional Value of Microscopic Algae, "Algal Culture from Laboratory to Pilot Plant," (Edited by J.S. Burlew), p. 303, Publication 600, Carnegie Institution of Washington, Washington, D.C. (1953). 16-9-2

Present knowledge of the nutritional value of algae is limited, largely because of the lack of experimental material. The small amount of quantitative information available applies only to animal nutrition. It is supplemented by assays of Chlorella for different nutritional factors and by some qualitative observations concerning the use of algae in human nutrition. The authors discuss the following items in detail.

1. Nutritional Factors in Chlorella - The discussion here is concerned with the protein, amino acids and vitamins found in Chlorella.

2. Animal-Feeding Tests - This section of the paper discusses rat-feeding tests and chick-feeding tests. The authors state the results of the preliminary tests they have reported in this paper were reasonably encouraging and improved methods of preparation along with further variations in the composition of the rations may well show more favorable results. No evidence of toxicity or other adverse reaction, or of refusal to take rations containing Chlorella, was found. They believe further work on the culture of algae should have as one of its objectives the clarification of the nutritional properties of material grown and processed in various ways.

3. Algae as Human Food - This section discusses the limited knowledge of human consumption of algae and its acceptability as human food.

Author Index No.	16-11, PHARMACOLOGY & TOXICOLOGY	Master File No.

90 Kathan, R.H. and Webster, A.P., "Design of a Packed Column for Removal of Carbon Dioxide from Submarines," Quarterly Report of Miscellaneous Tests and Minor Investigations, Part I, ASTIA No. AD-38132, Naval Medical Field Research Lab., Camp Lejeune, N.C. (Aug., 1953). 16-11-1

Prior to the advent of snorkelling, about the only time excessive concentrations of Carbon Dioxide became a problem in submarines was when the boat was in distress, either on the bottom from an accident, or when being held down by enemy action. With snorkelling, however, accumulation of Carbon Dioxide during normal operations may occur and definitely presents a hazard. Many studies have been made and are being made on the physiological effects of prolonged exposure to low concentrations of Carbon Dioxide. In addition to the effects of prolonged exposure to Carbon Dioxide on personnel, a concentration of 4% CO_2 becomes a very great hazard in the event of flooding down for an escape. If the submarine were on the bottom in 200 feet of water, flooding down would give a pressure of seven atmospheres and the concentration of CO_2 would rise to an effective 28% (on a partial pressure basis). Further, after flooding down, the partial pressure of all other noxious gases, chlorine, carbon monoxide and stibine becomes correspondingly increased. Other gases, not necessarily toxic, but merely obnoxious, such as head odors, body odors, cooking odors, oil odors, affect the habitability of the vessel and the removal of the odors or the minimizing of them has been a continual problem.

147 Specht, H., Toxicology of Travel in the Aeropause, "Physics and Medicine of the Upper Atmosphere," (edited by C.S. White and O.O. Benson, Jr.), p. 171, Univ. of New Mexico Press, Albuquerque, N.M. (1952). 16-11-2

Four general media of excretion: exhaled air, urine, perspiration, feces. In the breath CO_2 and H_2O are the major constituents. Other volatile components diffused from the blood are small amounts of N_2, acetoacetic acid, volatile oils from certain foods, also gases formed in the blood such as H_2 and CH_4. According to Haldane & Smith there is no special odorless toxin in exhaled air.

In urine, the greater part of the excretion products are non-volatile, but small amounts of ammonia, etheral sulphates and the substances also cited above to be in exhaled air may be found.

In the glandular excretion of the skin there are again small amounts of these volatile substances, but the bulk

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of the excretion other than water is non-volatile.

In the feces a variety of substances formed through the action of bacteria, some of which are toxic. The volatile substances, largely contained in the flatus, are CO_2, N_2, O_2, H_2, CH_4 and the minor constituents previously mentioned. In the feces proper the toxin substances indole, skatole, H_2S, phenol and various amines range to high potency. Water distilled from feces may leave residues of toxicants.

The rate of O_2 use varies with activity and individuals but average values for non-strenuous activity are about 614 liters per day, which weighs 1200 grams. Output of CO_2 is about 515 liters, which weighs 1008 grams per day. The output of metabolic constituents of the breath other than O_2, CO_2 and H_2O is low, variable and unknown. Water is lost to the atmosphere in direct proportion to the undersaturation of the inhaled air. Values probably range from 175 cc per day for dry air to 350 cc per day.

The further excretions of the skin are NaCl, urea, with minor quantities of potassium and lactic acid. No estimate of the quantity of odorous substances is available.

The urine amounts to about 1500 cc per day. The volatile constituents are minor if no decomposition takes place to free the ammonia which constitutes about 0.9 gram per day. Of the 2.5 grams of sulfate excreted daily, only 5% is excreted as ethereal sulfates.

The volatile contents of the feces contribute a different group of gases. The flatus may vary somewhat in composition but average daily values are 230 cc of CO_2, 210 cc of N_2, 80 cc of O_2 and 480 cc of $H_2 + CH_4$. Diets should be planned to reduce these to a minimum. These gases are slightly soluble in the blood and thus are also lost via the exhaled air at a very low rate. In a confined atmosphere they would accumulate to an equilibrium value which might prove to be asphyxial. The other volatile materials in flatus have low vapor pressures and are noticeable mainly because they are aromatic.

Indole may be present in feces to the extent of 60 mg per 100 grams, giving a total daily quantity of about 90 mg. Water recovered from excreta by distillation would have only a minor contamination with these materials.

Present and proposed methods for removal of noxious materials: CO_2 may be removed by alkaline scrubbers. These will also absorb some of the volatile substances previously referred to. These methods generally used in submarine air conditioning and were successful in stratosphere balloon flights. Disadvantage is bulkiness of equipment and the progressive decrease in efficiency. The use of sodium or potassium peroxides, which free oxygen while absorbing CO_2 and water might be tried.

Condensation of volatile substances: at the temperatures prevailing in the shadow of a space craft, all but the lighter gases will be frozen out and a suitable means might be devised to recover those which are useful and to concentrate and remove the noxious ones. H_2 would be the most difficult constituent, although quantitatively it may be of negligible magnitude. Oxidation of H_2 and other volatile organic materials might be considered, but this would be at the expense of O_2.

In one sense the most attractive proposals for dealing with CO_2 and water are those using green plants. Active photosynthesis provides an O_2/CO_2 ratio of 1.0 or better.

The leafy plants are nature's best engineered adaptation to a gaseous atmosphere. They have managed to distribute all photosynthetic cells in nearly monocellular layers so that maximum surface is presented. Ley has made some suggestions in this direction and it is interesting to pursue these speculations a little further. He estimates that a square meter of pumpkin leaf will supply the oxygen required at rest by one man. By extension, he calculates that a minimum of one cubic meter of such plant tissue will supply the needs of two men at moderate activity. This extrapolation seems somewhat exaggerated, since doubling the number of persons and a five-fold increase in metabolism would involve only one order of magnitude extension. Data from Brown and Escombe indicate that 0.07 cc of CO_2 per sq. cm. per hour can be handled by catalpa leaves. This is calculated to permit an estimate of about 30 sq. meters (323 sq. ft.) per man per day. On the other hand, Emerson and Arnold indicate that algae will produce about 4 moles of oxygen per second/cu. mm $\times 10^{10}$. This results in an estimated 1 sq. meter (1 mm of algae thick) per man per day at moderate activity. Similar estimates in our own laboratory by Dr. F.S. Brackett indicate the same order of magnitude.

Ley seems to consider the engineering of this matter quite readily feasible--yet on his calculations, assuming that a leaf if about one millimeter thick in terms of cells, it would require 1000 sq. meters (10,764 sq. ft.) of surface

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which is constantly illuminated to take care of these plants. According to the catalpa leaf data about 30 sq. meters per man per day would be required. In either case, the practical problem of exposure and orientation with proper circulation calls for construction and design radically different from that which has been publicized.

The use of algae, indicated both by Ley's comments and according to Emerson and Arnold's data to be of high efficiency, is fraught with other difficulties. In order to suspend the algae in water so that proper exposure and nutrition result is costly in weight and space and poses problems in circulation that require kinetic energy in a weightless situation.

At the moment it seems that a liquid oxygen source and chemical treatment of Carbon Dioxide, aided by thermal condensation, must be the means of choice until research evolves more direct methods of converting solar energy to our needs.

149 Spector, W.S. (Editor), "Handbook of Toxicology," Vol. I, W.B. Saunders Co., Philadelphia, Pa. (1956). 16-11-3

The volume includes two tables:

I. Lethal Doses of Solid and Liquid Compounds: Laboratory Animals
II. Lethal Concentrations of Gases, Vapors, and Fumes in Respired Air: Laboratory Animals

Prepared under Contract No. AF 33(616)-2873, Aeromedical Laboratory, WRDC.

Author Index No.	25-0, PHYSICS	Master File No.
62	Gast, P.R., Chapter 9, Insolation of the Upper Atmosphere and of a Satellite, "Scientific Uses of Earth Satellites," p. 73, Univ. of Michigan Press, Ann Arbor, Mich. (1956).	25-0-1

The temperature of a satellite will be the resultant of the sum of radiations from three sources: directly from the sun, solar radiation returned from the atmosphere and the earth (both 6000°K radiation), and low-temperature (250°K) radiation from the earth. Assuming various characteristics for the model of the satellite (absorptivity of the surface, shape, mass, specific heat) and orbit trajectories (distance of perigee and apogee, duration of insolation, and duration in shadow of the earth), the ranges of maximum and minimum temperatures may be calculated. For one possible elliptical trajectory the mean temperatures for an 0.8-meter, 100-kg spherical satellite are not far from 0°C; as the satellite in its orbit passes from sunlight into the shadow of the earth, the temporary maximum temperatures in the sunlight range from 13° to 3°C and the temporary minimum temperatures in the shadow from -3° to 5°C. The highest maximum temperature is with the sun in line with the projected major axis and the illuminated satellite at a perigee of 300 miles, and the lowest minimum temperature with the sun in the same position and the satellite at an apogee of 1000 miles. Measurements of insolation freed from difficulties of atmospheric attenuation and measurements of the albedo of the earth will be possible from a satellite vehicle. But to achieve the required accuracy, rather precise knowledge of the orientation of detectors is essential. Hazards which are unique to the environment may be encountered in attempting measurements from a satellite--the effects of the vacuum ultraviolet irradiation and of accumulation of micrometeorites on surfaces of detectors or on the surfaces of windows, and on the surfaces of the skin of the satellite.

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Author Index No.	25-8, THERMODYNAMICS	Master File No.
34	Buettner, K., Thermal Aspects of Travel in the Aeropause--Problems of Thermal Radiation, "Physics and Medicine of the Upper Atmosphere," (edited by C.S. White and O.O. Benson, Jr.), p. 88, Univ. of New Mexico Press, Albuquerque, N.M. (1952). Shows how to compute the equilibrium skin temperature of an orbiting space vehicle.	25-8-1

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M-108

Author Index No.	29-2, FOOD & CONTAINERS	Master File No.
60	Fox, S.W. and Ise, C., "Chemical Changes in Protein of Sterilized Meat," Research Project Report No. 7, Contract No. DA44-109-qm-1762, ASTIA No. AD-89549, Quartermaster Food and Container Inst. for Armed Forces, Chicago Hq., QM Research & Development Comm., Iowa Agricultural Experiment Station, Iowa State College of Agriculture and Mechanic Arts, Ames, Iowa (Apr., 1954 - Sept., 1955).	29-2-1

The potential use of ionizing radiation as a means of sterilization of various foodstuffs and pharmaceuticals has stimulated a great deal of interest in this field of investigation. The advantages of this particular type of sterilization are very attractive for a number of reasons. One of the most attractive features of this type of sterilization for heat-sensitive materials is small temperature increase during the process. This lends itself to a number of applications. Another feature of this method is the rapidity of the process, for the material is exposed for only a few seconds.

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Appendix 1

Report on

SKIN EXCRETIONS

Prepared by

William T. Ingram

It has been estimated that about two million sweat glands are found over the cutaneous surface. The whole epithelial surface serves as a means of heat release from the body through evaporation. The sebaceous glands, single and compound, are found over the cutaneous surface, usually in association with hair. Sweat and sebaceous glands and epithelial surface account for the excretions of the skin.

The skin surface usually has an acid reaction and may exert a bactericidal effect. Dirt and fat may interfere with this reaction. The water vapor loss from epithelial evaporation (insensible perspiration) does not carry over solutes. However, the sweat glands do release many electrolytes, organic acids and compounds, and inorganic salts in minute quantities. Sebaceous gland secretions are mixed with sweat, and the composition is not exactly known. The fatty, oily material does contain in small quantities, cholesterol, some simpler fatty acids, fatty acid esters, albumins, and inorganic salts. The sebum may spread over the skin in a protective layer or may pack in the gland-cutaneous surface as a cheese-like mass. Organic constituents of what is thought to be a mixture of sebaceous and sweat gland excretion is believed to include small quantities of urea, uric acid, creatinine, lactic acid, ethereal sulphates of phenol and skatol, amino acids, sugar in traces, and albumin.

CO_2 is also believed to be released in minute quantities with marked sweating.

A review of the chemical composition of sweat by Robinson and Robinson[136] offers a range of values reported by various research studies. The components are here summarized:

1. Sodium Chloride

   NaCl and water are the principal substances whose loss by sweating may affect the homeostasis of the individual to a serious degree. Concentration of NaCl is variable. Individual values as low as 5 mEq/l to as high as 100 or 148 mEq/l have been reported. Average values ranging from 18-97 mEq/l have been reported in at least 86 separate studies. Normal output from skin (no sweating) is ca. 0.2 mEq/hr. of Cl^-. Sodium runs somewhat higher because of other sources of Na.

2. Potassium

   Lower than Na. Averages about 4.5 mEq/l with range from 1 to 15 mEq/l. Potassium concentration varies inversely with the Na concentration and the Na/K ratio varies directly with the Na concentration. Na/K = 15 in unacclimatized men, dropping to 5 after a 5-day adaptation period.

3. Calcium

   Ranges from 1 to 8 mgm per 100 ml.

4. Magnesium

   0.04 to 0.4 mg/100 ml.

5. Copper

4.4 to 7.5 mcg/100 ml.

6. Manganese

3.2 to 7.4 mcg/100 ml.

7. Sulphates

4 to 17 mgm/100 ml.

8. Iron

0.1 to 0.2 mgm/100 ml.

9. I_2, F_2, Br_2

Have been reported.

10. Lactic Acid

Values reported range from 4 to 40 mEq/l.

11. pH

Most observers found between 4 and 6.8.

12. Glucose

Extremely low. Reported from 0.1 mgm/100 ml. to 9 mgm/100 ml.

13. Nitrogen

Much more dilute than corresponding values in urine. Average values range from 23 mgm/100 ml. (tot. N) to 140 mgm/100 ml.

14. Urea N

Averages ranged from 12 to 39 mgm/100 ml. in several studies.

15. NH_3N

Most investigators report in range of 5 to 9 mgm percent.

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16. Creatinine

Ranges from 0.1 to 1.3 and averages 0.4 mgm/100 ml.

17. Uric Acid

Reports range from 0 to 1.5 mgm/100 ml.

18. Amino N

Extremely low, but 18 different amino acids have been identified.

19. Phenol and Histamine

Reported.

Johnson, Hamilton, and Mitchell report that the total amount of pyridoxine and its metabolites(88) and the total amount of nicotinic acid and its metabolites(87) present in sweat appear to be too small to have any significant influence on the requirements of persons sweating profusely. The same authors also report that the choline loss(85) through sweat is not affected by hot, moist atmosphere in comparison with the loss in normal air, and that folic acid excretion(86) is increased under conditions of profuse sweating.

Howell(81) reporting on quantity of water loss indicates that 25 to 40 gms. per hour are lost through insensible perspiration with 1/3 to 1/2 of that being given off from lungs. Approximately 600 ml. of water is released from skin per 24 hours. However, the quantity may reach 2500 ml. per hour with strenuous muscular work. Supplemental water requirement to be satisfied by oral intake is estimated at 1200 to 1300 ml. per day.

CO_2 release is estimated at 7 - 8 gms. per 24 hours, increasing with marked sweating.

Comments

It appears from the foregoing that:

1. There are minute quantities of organic materials, water and water vapor released to atmosphere from skin excretion.

2. The quantitative values have been partially but not completely established. While the quantities may seem inconsequential in a normal atmosphere subject to air replenishment, the accumulative effect of these materials, some toxic and some odor producing on deterioration, in conditions of a closed ecology remains to be determined. It is obvious that the air cleansing system of the closed space will have to remove such materials as detritus from epithelial sources, fatty acids, fatty acid esters, albumins, ammonia, and other forms of nitrogen, urea, uric acid, inorganic salts, and metals such as sodium and potassium.

3. Occupants of a closed space will find it necessary to give special attention to personal hygiene. Skin excretions will have to be removed carefully with minimal amounts of water. Since the washings will be concentrates wastes, they too will have to receive special handling. The quantity of water wastes developed from skin washings has not yet been determined. While dry washing with special preparations may be considered, these washing compounds may contribute to contamination of the enclosed air mass, and there is no knowledge at

present as to the significance of this contamination. Further, dry washings cannot be considered as a complete substitute for some form of washing that will raise and carry off the accumulation of sebum and concentrated salts remaining after evaporation. The potential breakdown of bacterial protection introduced by excessive accumulation of sebum and salts on the cutaneous surface is one requiring careful examination. The potentiality of chemical irritation of the cutaneous tissue due to excessive concentrations of excreted substances is also the subject of conjecture.

4. Future investigations are indicated along the following lines:

a. Study of sebum quantitatively.

b. Study of sebum deterioration and exploration of the mechanisms of treatment that will hold odor levels below those tending to produce physical discomfort to an occupant of a closed space, wherein all air supply is self contained and cyclic in reuse.

c. Further study of sweat gland excretion as in b. above.

d. Study of levels of concentration of various components of skin excretion that may be tolerated by the skin without physical discomfort or without serious surface irritation effects.

e. Study of skin washings quantitatively to determine probable treatments required to permit safe disposal or possible water recovery for reuse. Permanent frozen storage is one alternative if the water is not required for reuse.

Appendix 2

Report on

THE CULTURE OF ALGAE

Prepared by

Gail P. Edwards

The types of algae commonly used in the studies of photosynthesis are the green algae, Chlorella and Scenedesmus. These are common inhabitants of fresh water and soils. Chlorella, most frequently used, is hardy and grows rapidly. Its chloroplast takes up a main portion of the cell and its high rate of photosynthesis exceeds the rate of respiration 10 - 100 times. The four main strains of Chlorella used for study are:

C. pyrenoidosa (Emerson strain)

C. vulgaris (Emerson strain)

C. vulgaris (Trelease or Columbia strain)

C. vulgaris (Wann or Cornell strain)

I

Mechanics of Photosynthesis

In nature, light energy is used for the formation of carbohydrates from inorganic carbon dioxide. This process is called photosynthesis and an over-simplified general reaction may be written:

$$\text{light} + CO_2 + H_2O \longrightarrow CH_2O + O_2$$

Many theories have been proposed to explain the reactions. In photosynthesis, the light receiving unit is the chloroplast. According to Thimann,(160) although the shape varies, the structure of the chloroplast is about the same in all the plants examined so far. It consists of fine green particles or grana which appear in the electron microscope as flat discs embedded in a colorless stroma. Usually starch or other polymers are present.

A number of chlorophylls are known. For example, Thomas[161] states that chlorophyll a in higher plants is accompanied by chlorophyll b. The chlorophylls are accompanied by carotenoids and in red and blue-green algae by phycobilins. The photosynthetic pigments belong to the class of molecules with the strongest absorption bands in the visible ranges. Since natural and synthetic pigments have absorption peaks at various wave lengths, it is necessary to have a mixture of pigments to cover the visible range economically. Only one of the pigments in the chloroplast, chlorophyll a, is able to carry on the photochemical reaction of photosynthesis. All light energy absorbed by other pigments must be transferred to chlorophyll a and this can be done with nearly 100% efficiency by fluorescence. From chlorophyll a, the light energy enters the chain of chemical reactions which fixes and converts carbon dioxide to the final photosynthetic products.

Little is known about the oxygen producing reaction but in the reduction, Duysens[51] believes pyridine nucleotide is important. The pyridine nucleotides are the most universal and important oxidation-reduction catalysts in living things. Aided by adenosine triphosphate, pyridine nucleotide is able to reduce carbon dioxide.

According to Gaffron,[61] in the reaction with chlorophyll, two hydroxyl groups are combined to form a peroxide and the peroxide decomposes to release molecular oxygen.

These and other theories are discussed by Bassham and Calvin.[23]

<u>Light</u>

Only light of wave lengths shorter than 7000 A° is active in photosynthesis. With artificial light, both incandescent anf fluorescent lamps have been used. There has been some difference of opinion as to their relative effectiveness. Smallhorst, Walton and Myers(145) stated that incandescent light at night seemed to speed up formation of oxygen but fluorescent lighting was not very effective. On the other hand, Krauss(95) who studied differences in yield under fluorescent, incandescent and combined light sources, found that the incandescent battery was adding little to the total yield of algae although consuming forty-two percent of the combined voltage. Krauss also believes that the exclusion of much of the red end of the spectrum, including infra red, from solar radiation prior to its reaching the culture can be expected to have little detrimental effect on yield, especially when intensities are above the average 1000 f.c. used at culture surface. Light within the visual range 4000 - 7000 A° degrees is satisfactory.

As to the intensity of light required, Burlew(38) reported that algae can use light intensity for photosynthesis as low as 10 f.c. Cells of green algae can utilize in photosynthesis only a limited amount of light energy at a time. Myers(117) found that the minimum intensity of light required for maximum rate of growth of Chlorella is in the neighborhood of 400 f.c. under unilateral illumination. Increasing the intensity of light beyond 400 f.c. increased the yield of algae but at a diminishing rate. In summer, sunlight during the middle of the day is at least 8000 f.c. When growing under light of very low intensity, algae have utilized as much of 20 percent of the incident energy in the visible part of the spectrum. When they are growing in the full sunlight, the conversion is reduced to 2 to 3 percent. A twenty-fold increase in incident energy results in only a fourfold increase in the amount used by the algae. Algae and higher plants appear to be about equal in their capacity to utilize the energy of visible light.

The cells of green algae can utilize in photosynthesis only a limited amount of light energy at a time. This phenomenon called "light saturation" has been explained as due to an injurious effect upon the light cells. It imposes a serious limitation on the efficiency with which solar energy can be utilized by algae. In a culture which is deep and dense enough to absorb nearly all of the light, mutual shading of the cells gives a gradation of light below the surface that partially offsets the limitation. Experiments[4] have shown that in a Chlorella culture, the light intensity decreases with depth and concentration according to the Beer-Lambert law of light absorption.

When Chlorella is grown outdoors without regulation of environmental conditions, not only diurnally intermittent variations of light intensity occur but there are also variations of day-and night-lengths accompanied by diurnal changes in temperature. Light saturation can be partially overcome by intermittent light because algae can use light in very short flashes. Kok[93] reported numerical values of the order of a few milliseconds for the critical flash time as a function of the incident intensity. For Chlorella pyrenoidosa, the dark time must be at least ten times as long as the flash time for fully efficient utilization of the incident light in photosynthesis. Burk, Cornfield and Schwartz[36] have reported a longer critical dark time.

In a study of the effect of the variation of day-length, day and night temperatures and of intensity of day light upon Chlorella, Tamiya et al[158] found that the rate of growth was affected by changes of day-temperature to a much greater degree than by changes in night temperature. Up to 25°C, the higher the day temperature, the greater was the growth rate. Higher night temperatures had no favorable effect except when the day-temperature was as low as 7°C.

In general, the growth rate was directly proportional to the day length at shorter day lengths. This proportionality extended to longer day lengths, the lower the daylight intensity. At longer day lengths, and especially under stronger daylight, the growth rate tended to become independent of day length. The phenomenon of "day-oversaturation" which occurred at lower temperatures and under stronger daylight was explained as being due to the injurious effect of strong light on the so called "light cells" which have been shown to become abundant in cultures when the temperature was low and the light was strong.

This critical dark time is of utmost importance in large scale culture for if an algal cell is exposed to light of high intensity for a short time it can absorb all that light in the first stage of photosynthesis and then utilize it in succeeding stages in the dark. Several methods of obtaining maximum efficiency have been proposed. Davis[49] in small scale experiments obtained an increase in yield of 70 percent with turbulence in a high-density culture illuminated with high-intensity artificial light. Several other methods of diluting sunlight in such a way that no algal cell receives illumination above the saturation intensity have been proposed.

Under carefully controlled conditions, Kok,[167] using sodium light was able to obtain 23.5% conversion of absorbed radiation energy into organic matter. Of about 30 determinations of efficiency, the majority were between 12 and 21 percent. Myers[115] obtained efficiencies of 15% but doubts that he had optimum conditions. No strain of algae has been found which is capable of utilizing bright light with full efficiency. In fact, exposure to bright light exerts inhibitory effects upon photosynthesis which according to Kok[94] result in inactivation or pigment molecules or complexes leading to ineffective light absorption and therefore, a decrease in yield in weak light.

Myers[115] states that the requirements of algae cell machinery are:

CO_2 - 1.8 lbs. per pound of Chlorella

Temperature less than 38°C (100°F)

Chlorella and most other algae are killed by prolonged exposure above 30°C but a high temperature one, Chlorella T x 71105, grows at temperatures up to 39°C.

Fisher[56] stated that initial attempts to use the new thermophyllic strain of Chlorella in pilot plant work were not successful because the temperature had to be maintained near the optimum for good yields.

This constant temperature may not be difficult to control.

According to Fisher,[56] the strains of Chlorella used in nearly all of the experimental work to date, shows a sharp maximum growth rate at about 25°C with significantly lower rates at 30°C and almost no growth at a few degrees higher. In a closed system, cooling is essential.

II

Nutritional Requirements

Krauss[95] states that the nutritional requirements for the growth of most algae except for the need for cobalt, the low calcium requirement and the absence of need for boron, are qualitatively similar to those for higher plants. The presence of an element in a medium, however, does not mean that the element is available to the algae because precipitation may make them unavailable. Chelating agents have been successfully used to prevent the precipitation of such trace elements as iron, manganese, calcium, copper, zinc, molybdenum and cobalt.

It is well established that the concentration of carbon dioxide normally found in the atmosphere (0.03%) is adequate to maintain maximum photosynthetic efficiency if sufficient volume of liquid is brought in contact with the cell surface. If all cells are to be supplied with a sufficient amount, then according to Krauss, the 1-5% mixtures of CO_2 in air are necessary. In 300 liter cultures, 10% CO_2 in air mixtures improved the yield of algae although in small scale experiments a 10% mixture is considered toxic.

Davis, Myers and Dedrick(50) found under their experimental conditions, the growth rate was not significantly influenced by differences in concentration of CO_2 between 0.56 to 4.43% as long as the culture medium was kept in equilibrium with the lower concentration of CO_2.

The fundamental problem in mass culture is the maintenance of a reservoir of energy and nutrients for a long enough time to permit an economically large harvest. Two procedures have been used. Krauss(95) proposes a recycling system and replenishes consumed nutrients by returning elements to the culture at the same rate at which they are removed by the algae. The algae is harvested by pumping a portion of the culture through a continuous centrifuge and returning the liquid to the culture. Myers maintained a constant growth rate by diluting the growing population with fresh medium at a rate commensurate with the rate of growth. Portions of the culture are removed for harvesting the algal cells. The slow continual flow of fresh medium into the culture and the outflow of medium and cells tends to hold the light intensity at a constant (mutual cell shading) and prevents reduction in nutrient level or accumulation of inhibiting substances. Both methods have been successful.

Krauss[95] found the elemental composition of green algae to be as follows:

Element	Percent Dry Weight
Carbon	51.4 - 72.6
Hydrogen	7.0 - 10.0
Oxygen	28.8 - 11.6
Nitrogen	7.7 - 6.2
Phosphorus	2.0 - 1.0
Sulfur	0.39 - 0.28
Magnesium	0.80 - 0.36
Potassium	1.62 - 0.85
Calcium	0.08 - 0.005
Iron	0.55 - 0.040
Zinc	0.005 - 0.0006
Copper	0.004 - 0.001
Manganese	0.01 - 0.002
Cobalt	0.0003 - 0.00003

In starting his recycling experiment, Krauss used a modified Knop's solution consisting of:

KNO_3	1.0 gr/liter
KH_2PO_4	0.25 gr/liter
$MgSO_4\ 7H_2O$	0.25 gr/liter

Micro-nutrients as EDTA chelated metals were added initially to give the following concentrations: Fe and Mn, 10 ppm; Ce and Co, 3 ppm; Cu and Zn, 1 ppm. After the start of the experiment, replacement stock solutions of each of the six chelated EDTA metals and of the compounds HNO_3, KH_2PO_4, $MgSO_4\ 7H_2O$ and MgO were added in such a way that 1 ml. of each replaced the amount of the element absorbed by 1 gram dry weight of algae. Krauss found that much of the chelating agent or some decomposition product is absorbed and probably metabolized by the cell.

Many other nutrient formulas[48, 159] have been used.

III

Mass Culture

Algae have been grown in so called mass culture systems usually on pilot plant scale by many investigators. According to Tamiya,[157] the two common methods proposed for full scale mass culture are the closed circulation method and the open shallow trench or tank method.

In the closed circulation method, the culture is cycled through a clear plastic tube or through a shallow concrete trench with a plastic ceiling. The plastic tube offers the greatest surface exposed to the light and would be expected to be a more efficient system than a trench with only one surface exposed to the light. The closed system has the advantages that it is not affected by dust or contamination by the atmosphere. Tamiya has also pointed out numerous disadvantages. The vinyl plastic coatings became brittle within a few months and many small holes developed. Furthermore, the algal cells precipitated and adhered to the plastic walls. These were very difficult to remove and not only made harvesting difficult, but they became a cause of contamination and interfered with the passage of light into the culture. The closed system which requires more cooling equipment than the open tank method requires about five times as much power for operation.. The initial cost of the closed system is estimated to be less than half that of the open system.

In the open system, the culture is constantly aerated with air enriched with carbon dioxide. The equipment is durable and requires very little maintenance. Tamiya found that in Tokyo, dust and dirt had to be removed every two weeks and contamination had to be prevented by the use of chemicals. He also proposed a modification of the open trench system using shallow circular tanks in which the culture was recirculated through a rotary distributor system. One unit was operated for six weeks very successfully with yields of 7 - 11 grams of dry algae per square meter per day.

According to a report from A. D. Little, Inc.,[13] a stable foam is formed as a result of agitation or aeration, in cultures at concentrations of algae above 0.3 to 0.4 g/l. The layer of foam could reduce the light reaching the culture and is therefore of some importance from the standpoint of operation. Two non-toxic antifoam agents, Dow-Corning Antifoam A, a silicone, and Atlas Powder Co. Soan 85 were used successfully. Geohegan[65] found Silicone D C 200 satisfactory for breaking the foam.

Brooks[31] suggested that pumps might be eliminated if the circulation could be obtained by the application of heat to induce thermo-syphon circulation as has been done with solar water heaters.

A self-regulating continuous culture apparatus has been proposed by Perret.[125] The growth vessel is a tilted cardioid-shaped flask spinning about its long axis. Agitation is obtained without foam formation and colonies of microorganisms do not form on the walls of the vessel.

Mayer, Eisenberg and Evanari[107] studied deep mass cultures in an open concrete tank one meter deep. The side of the tank facing south contained a glass window but it quickly became coated with algae and lost its effectiveness. The culture of 2100 liters was circulated with paddle type stirrers rotating about a horizontal axis. Carbon dioxide was bubbled in through a fine diffuser for an hour each day. They used three species of Chlorella: C. vulgaris (Hopkins strain), C. pyrenoidosa (T x 71105) and C. ovalis (Butcher Plymouth 86). Yields of 20 grams per square meter of total illuminated area were readily obtained. Chlorella vulgaris seemed to be the best species.

Experiments by A. D. Little, Inc. of Cambridge, Massachusetts[13] indicated that although several problems remain to be solved, thin plastic tubes for culture growth are feasible. They had considerable leakage from seals and punctures in the polyethylene tubes but were able to mend them with a special electrical scotch tape. Leakage became so serious in one unit after about six weeks operation that the day to day data became meaningless. They also reported the settling and sticking of settling algae on the sides and top of the tube were serious when contaminants were present.

IV

Harvesting of Algae

The suspension of algae in a large scale culture unit will be quite dilute, containing not more than one percent of algal cells dry weight. In a photosynthetic gas exchange system, the algal cells must be harvested and disposed of. They retain moisture tenaciously and until thoroughly dry, are unstable. The algal paste from a centrifuge contains about 75 percent water and spoils rapidly--in less than an hour in a hot room.

Several methods of harvesting and dewatering algae have been suggested by Burlew.[38] Probably the most practical method is by the use of centrifuges. The use of a preliminary moderate speed centrifuge to reduce the volume to be handled by the supercentrifuge might be economical. Gravity sedimentation has been estimated to require an area about one-tenth that of the growth area. The algal paste containing about 25 percent solids which is the product of the supercentrifuge must be dried immediately to prevent spoilage. Drying has been accomplished by freezing, spraying, defatting and with infra red radiation. Burlew believes the material dried by freezing is least likely to have lost some of its vitamin content. Fink[54] suggested that careful drying may destroy toxic by-products produced by the algae.

In a confined space, the harvested algae would have to be used, either as food or for some other purpose or stored. In the case of storage, the algae should be thoroughly dried to preserve it so that it would occupy the smallest possible volume.

V

Contamination of Cultures

Reports on the contamination of algal cultures in open tanks have not been in agreement. Smith,[146] von Witsch and Harder,[172] Geohegan,[65] and Mayer et al,[107] had no difficultiy with contamination, although no special precautions were taken to keep foreign organisms out.

On the other hand, Gummert, Meffert and Stratman[73] experienced difficulties from contamination by blue green algae and protozoa. The blue green algae seemed to be eliminated by using no calcium compounds in the nutrient media. In one summer, the cultures became heavily infected by zooflagellates, ciliates and amoeba. Because of their rapid growth, the zooflagellates caused most trouble and algal cultures became useless 2 to 4 days after infection. They believe that Chlorella cultures are more readily attacked by protozoa, the more unfavorable the conditions become for growth of the alga. Attempts to exterminate the protozoa were practically without success but it was observed that the alga Scenedesmus had a greater resistance to protozoa than did Chlorella. These observations were proved correct in subsequent experiments. Von Witsch and Harder[172] reported destruction of algal cultures by colorless flagellates only when the cultures were exposed to direct sunlight.

Tamiya[157] was troubled with contamination by protozoa, rotifers and fungi. The most harmful were Chilodonella and Diurella which in the worst case, ate up the entire algal population within one or two days. After testing many chemicals, he found two which prevented contamination, did not affect the growth of algae and were reasonable in price. These were 2, 4-Dinitro - 6 - cyclohexyl phenylacetate (effective concentration: 1 - 3 grams per ton of culture solution) and Pentachlorophenyl acetate (effective concentration: 2 grams per ton of culture solution).

Davis and Dedrick[48] studied urea as a source of nitrogen because they believe it does not support the growth of culture contaminants.

VI

Sewage Treatment

Oxidation ponds have been used for many years in the western and southwestern parts of the United States. In 1948 Pearse[124] reported that a minimum detention period for settled domestic sewage should be 25 days with a minimum surface area of one acre per 400 contributory population. This is approximately 100 sq. ft. per capita. B.O.D. values in the effluent were as good or better than those from trickling filters. As knowledge of the subject has increased, the loading has become greater. Gotaas and Oswald[67] conclude that for most conditions (California) detention periods should not be less than one day for summer conditions nor more than 6 days for winter conditions. No statement was made as to the degree of purification except that depending upon the method of algae removal, up to 96% removal of B.O.D. could be obtained. Algae and suspended matter were removed by centrifuging. In 1957, Oswald[122] et al reported that in Richmond, California, shallow stabilization ponds which were oxygenated through photosynthesis have given

B.O.D. removals above 85 percent on a sustained basis with B.O.D. loads of 225 lbs. per acre (1 acre for 1300 persons) per day in summer and 100 lbs. per acre per day in winter.

The mechanics of purification in sewage oxidation ponds is similar to that in stream purification and other methods of aerobic biological treatment. The organic matter is attacked and oxidized in the presence of dissolved oxygen by bacteria. During this oxidation, carbon dioxide is produced. The carbon dioxide, a required food for algae, is utilized in the presence of light, and oxygen is produced. This in turn is available to the aerobic bacteria active in the oxidation of the sewage.

According to Allen,(16) the growth of Chlorella on sterilized sewage in light did not result in any decrease in oxidizable organic matter. He concluded that oxidation of organic matter in sewage is carried out by bacteria and other non-photosynthetic organisms and that the growth of the usual pond algae in sewage occurs only at the expense of CO_2 produced by the organisms or absorbed from the air. Although Chlorella grew more luxuriantly in sewage with bacteria than in sewage alone, this could be explained by the increased CO_2 content. Growth of algae in sewage is limited by the major nutrients, carbon and nitrogen. For optimal algal growth, Allen believes sewage must be supplemented with other sources of nutrient.

Types of Algae Used

Scenedesmus has been found in several sewage oxidation ponds. Krauss,(95) however, found that Chlorella produced 15 percent more culture per day by weight than Scenedesmus.

Chlamydomonas has been studied by Gotaas and Oswald(67) but experiments in Israel(107) indicate the Chlamydomonas cannot compete with Chlorella.

The nitrogen fixing properties of the blue green algae, Anabena cylindrica has been studied by Allen.[17] This organism grows rapidly and produced a daily increment of 2.0 grams of dry weight of cells per liter of culture medium or 26 gr. per sq. meter of illuminated surface. The blue green algae are more tolerant of moderately high temperature than the green algae. Examination of 40 pure cultures of various blue green algae showed that all grew well at 35°C and most at 40°C.

Gotaas and Oswald[67] reported that blue green algae are usually relatively scarce in sewage oxidation ponds and found only in samples collected at the borders of ponds.

The chlorophyl - bearing protozoan Euglena has been found in nearly pure culture in sewage ponds at the U. S. Naval Station, Shoemaker, California. Oswald, Gotaas, Ludwig and Lynch[123] studied Euglena gracilis in laboratory scale experiments with sewage. The maximum population in sewage was found at about 400 foot candles and it remained nearly constant to about 1200 f.c. From 1200 to 2400 f.c., the population decreased slightly. With a relatively strong synthetic sewage, maximum Euglena developed at 2400 f.c. Illumination was furnished by fluorescent lamps. Temperature was maintained between 24 - 26°C. A large part of the carbon utilized by Euglena is not incorporated into the cells but much of it appears in the effluent supernatant liquor, perhaps as a highly oxidized execratory product of the Euglena.

Oswald[122] et al found that in sewage oxidation or stabilization ponds, inhibition of bacteriological oxidation occurred in ponds having dense algal blooms. They report that when algae are growing vigorously and removing carbon dioxide from the bicarbonate alkalinity of the sewage, a pH up to about 11.0 may be obtained. This high pH seems to be the major reason for the low B.O.D. removals in ponds having dense algal growths.

The question whether the carbon dioxide from the bicarbonate ion can be utilized by algae still seems to be controversial. Meffert,[113] reported that Scenedesmus can utilize practically no carbon dioxide from bicarbonate carbonate mixtures. Myers[117] found that Chlorella absorbs little if any carbon dioxide from bicarbonate or carbonate. Krauss[95] said that bicarbonate can supply certain types of algae with a utilizable source of carbon and quoted Osterlind as having demonstrated that although Chlorella is unable to utilize bicarbonate, Scenedesmus does so readily. Oswald and Gotaas[123, 121] reported the utilization of bicarbonate by algae.

VII

Inhibiting Excretions

Since recycling of the medium is essential in large scale continuous culture, it is important that there should be no inhibiting substances formed and allowed to accumulate during the growth of the algae. The available information about the inhibiting effect of old cultures is not in agreement. Pratt[127] working with Chlorella vulgaris, demonstrated that growth of a culture was inhibited by a very low concentration of material produced by the cells and excreted into the medium. The inhibiting substance was called "Chlorellin." Its chemical identity was not known.

Spoehr, Smith, Strain, Milner and Hardin[150] showed that inhibitors of bacterial growth, probably photo-oxidized fatty acids, are produced by Chlorella pyrenoidosa (Emerson strain). Myers[117] reported that the phenomenon of growth inhibition by Chlorellin-like material has not been demonstrated in C. pyrenoidosa or any other alga except that used by Pratt.

Fink[54] studied the effect of feeding Scenedesmus obliquus, dried to a powder by infra red radiation, to rats and found that the algae-fed animals gained weight at least as well as those fed a milk protein diet. In a 120 day feeding experiment, all ten rats fed protein, 92% from algae and 8% from brewer's yeast, not only survived but were lively, healthy and had shiny dense coats. Of the ten rats fed protein consisting of 92% milk solids and 8% brewer's yeast, only two survived the test. Deaths were from necrosis of the liver. Fink then quoted two recent articles, one English and one Russian, published in 1954 and summarized by Elster. The first by J. E. Rhyther reported on the toxic effect of Chlorella vulgaris and Scenedesmus quadricauda on plankton. He found that the excreta of these algae impaired the filter activity and food intake of daphne. Aging algae produce more toxins than young growths and will retard the growth and cause death of daphne after 10 - 13 days. In the other article, Vinberg discussed the effect of toxins of phytoplankton on animals (fish, birds, cats and dogs). Paralysis of hind legs and liver diseases were observed. In man, serious muscle aches and temporary paralysis may occur. The toxins are especially effective as long as the producing cells are living. After death of the cells, the toxic effect ceases quickly. He stated that the algae, Microceptis, Aphanizomenon, Oscillatoria and Convaulax are well known toxin producers.

Fink in explaining this contradiction, stated that in as much as there are said to be 40,000 species of unicellular algae, some may be poisonous and others not. He believed it possible that toxins may have been destroyed when the algae were dried with infra red radiation.

VIII

Use of Algae for Food

The main objective of large scale cultivation of algae has been its production for food. Some of the large marine algae have been collected and dried for food in Japan, along the coast of Europe and in New England for many years. Milner[114] has shown that there is a general similarity in the chemical composition of all algae, and it seems reasonable to assume that the microscope algal forms would also be suitable for food. There has not been much direct evidence to prove the validity of this assumption.

Protein seems to be the most abundant constituent of the unicellular green alga and it varies widely in fresh water algae. Milner reported that a sample of Chlorella pyrenoidosa has a calculated protein content of about 50% based on an ash free dry weight. All of the essential amino acids were found to be present. A variety of vitamins have been found in Chlorella and it has been estimated by Fisher and Burlew[57] that about a quarter pound of dry Chlorella would provide more than the minimum requirement of all except vitamin C, which is present in freshly harvested algae but largely lost in drying. Fisher and Burlew concluded from various animal-feeding tests made by several investigators that the results were reasonably encouraging. In no case was there any evidence of toxicity or other adverse reaction or refusal to take the rations containing Chlorella. Fink,[54] found in animal feeding tests, that dried Scenedesmus was equal to the best animal protein.

Hundley and Ing[83] investigated the supplementary value of dried alga when added to a flour and bread diet for rats. In the first experiment, weanling rats were fed a basal diet containing 92% white wheat flour and adequate quantities of minerals and vitamins. Rats receiving the basic diet grew poorly. The addition of either 4% dried alga or 0.75% lysine to the basal diet increased the growth rate approximately threefold. The addition of threonine and lysine to the basal diet gave growth approximately equal to that obtained from lysine and alga. It appeared that the dried alga supplied the threonine required by the rats receiving the flour diet.

Tamiya(157) reported that dried algal powder has an appearance and taste similar to that of powdered green tea and powdered sea weed, "Aonori" which are relished as beverage and food ingredients, respectively, by the Japanese. The algae can be easily mixed with tea or Aonori or entirely substituted for them in such foods as noodles or rice crackers. Large quantities of Chlorella could be used with "Miso" which is prepared from fermented soy beans. Miso soup, an indispensable part of breakfast in Japan, was made even tastier than usual by the addition of algal powder.

Fisher and Burlew(57) believe that the flavor of dried Chlorella alone is too strong for one to enjoy eating large quantities of it. It might be compared to many of the herbs which are pleasing as a garnish. Freshly harvested Chlorella (not frozen) and soups made from it were suggestive of vegetables and generally palatable and acceptable.

In Venezuela, Jorgensen and Convit(89) prepared plankton "soups" as accessory food for leprous patients. The harvested "soup" was boiled for about 20 minutes and a little salt was added to improve the flavor. The taste varied with the species complex and the patients drank it willingly. The effect of the plankton soup on the patients could not be definitely established but in the majority of cases, there was a marked improvement in energy, in weight and general health. Certainly no ill effects resulted from it.

IX

Confined Space

Two studies have been made to determine whether a photosynthetic gas exchange will provide for the respiratory requirements of humans in a sealed cabin. The first report was prepared by Bassham(22) of the University of California. His computations based on the known respiratory rate of man and the photosynthetic rates of Chlorella indicated that a man weighing 154 lbs. (70 kg.) doing light work would require about 600 liters of oxygen in a 24 hour period or an average of 25 liters per hour. Chlorella can easily form 25 liters of oxygen per hour per kilogram of wet weight of algae. The respiration of one man would be balanced by the photosynthesis of one kilogram, wet weight, of algae. A one percent suspension of algae containing one kilogram of algae in nutrient solution would have a volume of 100 liters (3.5 cu.ft.). For the growth of a one percent suspension of Chlorella in a layer 0.4 cm thick, about 600 f.c. of light would be required from each side if the light were all of 6800 A° wave length. The ratio of carbon dioxide to oxygen in the gas exchange of a respiring man is about 0.8. The photosynthetic gas ratio CO_2/O_2 can be maintained at 0.8 by controlling the ratio of nitrate to ammonia in the nutrient. A kilogram of Chlorella producing 25 liters of oxygen per hour at a gas exchange ratio of 0.82 would require 20.5 liters of CO_2 and 0.16 moles of nitrogen (e.g. 13.6 grams Na No_3) per hour, in addition to smaller amounts of phosphorus and other elements. Use of urine alone as a source of nitrogen would be questionable. It was estimated that the power required for the system would be 4 h.p. per man. This power could be supplied by about 10 grams of atomic fuel per year. The total volume required per man for pumping, aerating, harvesting and control mechanisms was estimated to be 50 cu.ft.

If the algae were harvested for food, then human excrement would have to be processed by bacterial action to provide nutrient for the algae. This would require more oxygen and carbon dioxide evolution and would mean, therefore, an increase in volume and energy requirements for the system.

The second report which was prepared by the University of Texas[118] was more conservative. Based on a suspension of the alga, Chlorella pyrenoidosa, in an illuminated tank aerated by recycling cabin air, it was estimated that 2.3 kg fresh weight of Chlorella would be required to balance the gas exchange of one man. A layer of a one percent suspension of algae 0.4 cm thick will absorb 97% of the incident light of wave length 6800 A°. With illumination from both sides, a thickness of one centimeter seems reasonable. An illuminated surface of 240 sq. ft. would be required for the 230 liters of suspension per man. The power requirements based on light to chemical photosynthetic conversion efficiency of about 1.9% would be about 10 h.p. electrical energy per person. It was suggested that the heat dissipation problem may be serious.

According to the Texas report, the exchanges per man hour will produce 23 grams dry weight (1.2 lbs. per day) of algae containing 50% protein. This will require 1.8 grams of fixed nitrogen and 1.2 grams of nutrient salts per hour with recycling of the water. They believe that all of the human urine might be cycled through exchanges to furnish much of the nitrogen. The effects of continued urine accumulation are uncertain. The gas ratio of carbon dioxide to oxygen under the conditions mentioned is about 0.75 but could be increased by the use of urea. The total volume required for the gas exchange system was estimated at 80 cu.ft. per man. Investigation indicated that the best lamp for this purpose available now or in the next five years is the fluorescent lamp.

The main difference in the two reports is in the estimation of the efficiency of the algae in the gas exchange. The California report assumes that 25 liters per hour of oxygen can be supplied by one kg of wet weight of algae whereas the Texas report assumes a yield of only 11 liters. This difference in the amount of algae required affects the amount of light, power, total volume and weight required.

X

Desirable Characteristics of Algae

Some of the desirable characteristics which an alga suitable for use in a confined space should have are:

The development of a species of algae which would

1. Grow efficiently at a high temperature, say 40 - 50°C.
2. Give a high growth rate with higher rates of evolution of oxygen.
3. Derive part of its CO_2 needs from bicarbonate ion (danger of high pH resulting would need phosphate buffer - perhaps).
4. Grow in mass culture without change over long periods by recirculation of media.
5. Be very hardy - resist contaminating agents and inhibiting substances.
6. Have a pleasant flavor.
7. Free from toxic substances.
8. Produce no substances which would inhibit its own growth.
9. Have good food value - as complete as possible - easily digestible.
10. Be able to utilize the nitrogen from urine.

XI

Suggestion of Problems Requiring Further Study

Some of the problems requiring further study are:

1. Development of more suitable strains of algae in terms of temperature, taste, rate of growth and production of oxygen.

2. Long term experiments, lasting a year or more, of continuous cultere (pilot plant scale) to test mutation of organisms, the cumulation of toxic by-products and deterioration of fluctuations in quality of cultured algae for nutrition.

3. Determination of the utilization of the bicarbonate ion as a source of carbon dioxide, the effect on the pH, the culture medium and the need for an additional buffer.

4. The use of urine as a source of nitrogen: the effect on the use of algae as food and its effect on culture contaminants.

5. The use of sewage as a food material for aerobic bacteria which in turn would supply carbon dioxide for the algae growing with them.

6. Separate aeration of sewage and algal cultures with recirculation of air from algal to sewage culture to algal culture, etc.

7. The toxic effects of Chlorella and Scenedesmus on man and animal.

8. Determination of the actual thermodynamic efficiency of Chlorella to reconcile the Texas and California assumptions as to the rate of oxygen formation per unit of algae.

9. Efficient dewatering and drying equipment since the algae must be dried for use as food or stored.

10. The use of chemical antifoamers.

11. The use of chemical agents to inhibit the growth of biological contaminating agents.

12. The effect of these chemical agents on the long term cultivation of algae.

13. The long term effect of cosmic rays or other radioactive emissions on algal cultures.

14. Definition of the use of algal cultures, i.e., for gas exchange only or for waste treatment also.

15. The range of vitamin content among different species of algae.

16. The development of suitable equipment for the growth of algae in a confined space.

17. The development of more durable plastics for a closed circulation culture system.

18. The prevention of growths on the inside of transparent or translucent material or more efficient means for cleaning such material.

19. The development of equipment for the culturing of algae to approach the theoretical efficiency.

20. Simplification of the cooling of the culture or elimination of the need for cooling.

Appendix 3

Report on

STUDY OF METHODS FOR OBTAINING OXYGEN FROM CARBON DIOXIDE

Prepared by

Henry J. Masson

The Specific Problem -- Oxygen from Carbon Dioxide

The writer was assigned the problem of devising means of treating the carbon dioxide in any manner so as to recover the oxygen and convert the carbon to a useful form or compound. The carbon dioxide is produced by the respiratory actions of the crew and any other reactions which may be taking place.

As we are dealing with a closed system, the accumulation of carbon dioxide must be prevented, but maintained at the level of a normal atmosphere. Accordingly, it may be captured and rendered innocuous by conversion to a neutral compound or ideally decomposed and the oxygen made available for use in a cyclical process.

A number of treatments appear to be of interest. The reaction which is ideal, and immediately suggested, is that which has been occurring in nature since the beginning of time and on an enormous magnitude. That is the reaction

$$CO_2 + H_2O \longrightarrow CH_2O + O_2 + Q$$

$$\text{or} \quad 6nCO_2 + 6nH_2O \longrightarrow (C_6H_{12}O_6)_n + 6nO_2 + Q$$

to be carried out in a living cell (natural photosynthesis) or in a non-living system (artificial photosynthesis). If the foregoing reaction can

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be made to take place under the conditions of the project, then a dual result may be anticipated. Oxygen will be made available for human or other consumption and an energy possessing substance (a carbohydrate) which may be used as a food or food supplement, a fuel, or where auxiliary energy is required, for some life sustaining process. If the reaction can be made to function as a continuous process, which is the ideal, then there will be a constant removal of carbon dioxide to the normal level and at the same time a steady supply of oxygen and carbohydrate made available. One of the desirable features of the foregoing reaction is its flexibility. That is, the rate at which the reaction takes place will depend upon the concentration of carbon dioxide at any time. It may be possible to adjust controls so that the concentration of carbon dioxide may be fixed and the reaction will thereafter maintain this level.

The foregoing is an ideal solution and is based upon a well known, but not too well understood process which, as indicated, has been going on in nature for millions of years and is responsible, in large part, for maintaining throughout the atmosphere - at least a mile or so above sea level - the conditions desired within the closed system, i.e., a fixed concentration of oxygen. This suggested solution envisages the translation or adaptation of the processes of nature using natural or artificial photosynthetic processes to a miniaturized installation always under control by man. This approach will be discussed in detail later. The foregoing, in a sense, is a materials balance or equilibria. There is, however, in addition, the associated energy balance. The reaction is endothermic and photoenergy must be provided. This phase will be discussed later under environmental factors. Neither balance is 100% efficient. Therefore, there will be a progressive degradation of the system resulting in a continuous accumulation of non-processable or uncyclicable material. Analogically the same holds true for the energy changes involved - a progressive loss which must be made up from other sources.

Other Studies

In addition to the foregoing, the following studies or approaches are pertinent and therefore under survey:

1. the decomposition of carbon dioxide to provide oxygen;
2. the reaction of carbon with other substances to liberate oxygen;
3. the removal of carbon dioxide but without liberation of the oxygen or conversion to useful substances;
4. the independent generation of oxygen from other substances, as for example, water.

The foregoing classifications are to be interpreted as a framework for examining paths of literature and later experimental investigations. Fortunately, and significantly, literature surveys frequently and serendipity disclose ideas or facts of use in the solution of the immediate problem and other areas of the project.

Environmental Factors

This section is inserted at this point because a general background has been established and a detailed discussion is to follow. The various solutions as may be suggested by the literature study and such critical explanatory experiments which appear worthy of further study are somewhat handicapped or rendered inconclusive by a lack of more exact and working knowledge of environmental conditions. These are: (a) size and distribution of free working space for the installation of equipment; (b) astrophysical factors - that is, what solar or nuclear radiations will the system be subjected to and what effects may be anticipated on suggested processes; (c) what forms of energy will be available - their quantity and intensity - for use in various recovery and cyclical processes; (d) what will be the gravitational, temperature, pressure and other conditions in the enclosure.

Accordingly, the treatment to follow makes certain assumptions - in part qualitative - but treated quantitatively when justified. That is, energy for example, of the kind, quantity and intensity will be available for any suggested process.

Findings to Date

These will be treated according to the classification outlined in the introduction.

1. As indicated, one of the most important reactions in nature, basic in character, and suggestive of a fruitful overall approach to the problem is the reaction $CO_2 + H_2O$ and carried out in vivo in nature by means of which oxygen and cellulose lignocellulose and other carbohydrates are produced. These are probably initial products to be followed by secondary reactions whereby fats, protein and other complexes are produced. Expressed impirically the basic reaction is

$$6nCO_2 + 6nH_2O \xrightarrow{\text{catalyst}} (C_6H_{12}O_6)_n + 6nO_2 + Q$$

The reaction requires a catalyst. In the processes carried out in plants this is chlorophyll. In contemplated artificial photosynthetic processes a synthetic compound having equivalent photoresponses would be substituted. The reaction is endothermic absorbing radiant energy from the sun, therefore, there must be available light of the proper wave length to be absorbed by the system and stored as a chemical complex.

The foregoing reaction, because of its importance, has been the subject of investigation by some of the best chemical and botanical minds for over 150 years. Accordingly, the literature of the foregoing and related reactions is extensive and is concerned with all features, including the environmental conditions, mechanics of and vehicles used (algae up through large plants). The most extensive and interpretative review of the literature is, "Photosynthesis and Related Processes," by E. I. Rabinowitch.[129, 130, 131] These volumes have been read completely in a search for suggestive approaches. In this regard the author is discouraging, stating that "complete photosynthesis - i.e., the reduction of carbon dioxide to a carbohydrate and oxygen, has never been achieved outside a living cell" (p. 61). The reference here is to artificial photosynthesis. Insofar as natural photosynthesis is concerned, based upon the foregoing and other references, the tentative conclusion may be advanced, but without reflection, that existing studies would lead to processes which, if carried out on a useful scale would be cumbersome, bulky, slow, inefficient and difficult to control, especially if installed in a space ship. Since we are dealing with a living organism there is the possibility of mutation taking place if the shielding from external radiation is inadequate. Significant, however, is the low efficiency which, under ideal conditions is about 25%, but under normal conditions only about 2 - 3%. One has the feeling that certain of the investigative approaches used, although yielding what may be basic data, has not visualized the ultimate objective, i.e., an industrial process under the control of man. Since there is still a substantial amount of basic data to be developed, in fairness it may be explained that experimental designs and objectives are circumscribed and do not anticipate reduction to practice. The problem is a daring one and therefore, the approach should be spectacular. New approaches must not be inhibited by previous concepts. Daniels,(47) a distinguished scientist and investigator in the field of photosynthesis, states, "Is there any chance of beating nature at her own game and developing artificial photosynthesis with organic dyes and enzyme substances? Might not these cause the combination of carbon dioxide and water using reactions somewhat different from those occurring in the growth of green plants? There seems to be no theoretical reason why such a development cannot be successful in the distant future." Elsewhere he states, "Atomic energy for military purposes was developed with the aid of two billion dollars in three war years under conditions of centralized authority and secrecy. It would be interesting to see what might be done with two million dollars in three years for the greater utilization of solar energy for peaceful purposes under conditions of decentralization and independent initiative, aided by rapid publication of results."

The above statements sound a note of optimism. As certain experimental approaches will be designed later, there will be briefly outlined, at this point, the basic facts involved.

Carbon dioxide, as a gas and water vapor are transparent and therefore, do not absorb solar radiation. However, the green chlorophyll present in most living plants absorbs completely most of the visible sunlight covering from 4000 angstroms in the blue region to 6500 angstroms in the red region. The chlorophyll then transfers the absorbed solar energy to the water which decomposes releasing the hydrogen. This in turn reacts with the carbon dioxide, thereby producing reduction products. The hydrogen reacts with the reduction products and produces complex intermediate compounds of the carbohydrate class having the empirical formula $(CH_2O)_n$ where n is a large integral number. Based upon his investigations Farrington concludes that ten photons are required to produce one molecule of carbohydrate. In red light each photon contributes 40,000 calories per mole and ten photons will contribute 400,000 calories. In other words, 400,000 calories are required to produce a carbohydrate molecule containing one gram atom. Also, since ten photons are required to convert one molecule of CO_2 and one molecule of H_2O into a molecule of carbohydrate and a molecule of O_2, the reaction must take place in a series of steps, each requiring the absorption of one photon. It should be noted that a large amount of energy is required to produce a carbohydrate molecule containing one gram atom of carbon and that under most favorable conditions, the efficiency is very low. Therefore, the energy requirements for this reaction are very high.

Very recently Calvin and Sogo[43] have advanced a further explanation of how plants utilized sunlight to build carbohydrates and oxygen. They reason by analogy from the photobattery, which is designed to capture sunlight and convert it into an electrical current. They advance the idea that portions of plant cells called chloroplasts act as "photobatteries" capturing sunlight and converting it into a kind of electrical current merging with the chemical reactions taking place in photosynthesis. Using radioactive carbon, the complex chemical steps by which plants convert CO_2 and H_2O and solar radiation into carbohydrates and oxygen were traced. Studies by other scientist have disclosed that "chloroplasts which contain the light-capturing green plant pigment have a well ordered, quasicrystalline structure containing alternate layers of proteins, chlorophyll and fats." This arrangement is what suggested the photobattery concept.

Dr. Calvin has advanced the theory that a certain quantity of the sun's energy might strike an electron in the chlorophyll, bouncing an electron out and leaving a "hole". The electron would then be conducted through the chloroplast, the same sort of mechanism as in the photobattery, until it became attached to a carbon atom of the carbon dioxide participating in the photochemical process. In the meantime, the hole left in the chlorophyll molecule is occupied by an electron stolen from an adjacent water molecule. This in due course splits the water into its hydrogen and oxygen components, the oxygen escaping into the atmosphere, and the hydrogen being used as a building material in the photosynthetic process. The theory was supported by a crucial experiment in which a radio-frequency wave was sent through a chloroplast while light was shining on it and also in the dark. It was observed that part of the wave is absorbed in the light, indicating the presence of free electrons bounced out of the chlorophyll.

A group of scientists(45) working at Washington University have added further confirmation of the foregoing hypothesis. A molecular bridge between the rapid chemical steps that power plant and animal life has been discovered in the unusual molecules known as free radicals. These investigators used a new instrument known as the electron spin resonance spectrometer, which employs radio energy in the presence of a strong electromagnet to reveal the presence of unpaired electrons. Now free radicals are known to contain unpaired electrons and are therefore capable of exerting a magnetic effect in the spectrometer. In the case of normal molecules, all electrons are paired in a way that concels their magnetism so that they are not detected by the spectrometer. In one of the significant experiments the investigators ground up spinach leaves in a sugar solution to obtain from the broken cells the green particles called chloroplasts that contain most of the active agents of photosynthesis. This preparation contained free radicals. An intense light was arranged to illuminate the glass cell containing the chloroplasts in the spectrometer. When the light is turned on the spectrometer indicates a sudden increase in free radical content. Studies also indicate that the chloroplasts contain two types of substances with unpaired electrons. One of these is a complex of the green substance of plants, chlorophyll, with protein. When this complex is illuminated, the absorbed light causes the release of unpaired electrons. When the light is turned off these disappear.

If the light is continued, the unpaired electrons generated in the chlorophyll are passed on to a second free radical, which in turn gives up the electron to enzymes that carry out the photosynthetic reactions. The investigators thereby demonstrated for the first time the occurrence of a free radical chain reaction in photosynthesis.

They also examined the living cells of chlorella in the electron spin resonance spectrometer. In this case also, the instrument showed the presence of a free radical apparently identical with the radical found in spinach chloroplasts.

As in the previous case, when the light is turned on the amount of this free radical in living chlorella cells increases suddenly and decreases when the light is turned off.

The foregoing advance in our knowledge of the mechanism of photosynthesis suggests further lines of investigation which appear fruitful. This takes the form of an artificial chloroplast composed of synthetic dye and protein. This will be explained under "further investigations."

There are scattered references in the literature to gibberllic acid as a substance, mere traces of which accelerate the growth of plants. This might be added to accelerate photosynthetic processes. It is produced by Charles Pfizer, Brooklyn, New York.

Another area of exploration of photosynthesis is the application of the laws of mobile equilibria - specifically pressure and temperature.

A study of the basic reaction

$$\underset{\text{2 vols.}}{6nCO_2 + 6nH_2O} \longrightarrow (C_6H_{12}O_6)_n + \underset{\text{1 vol.}}{6nO_2} + Q$$

indicates that since there is a decrease in volume an increase in pressure will shift the equilibrium to the right and since the reaction is endothermic, an increase in temperature will have the same effect. The foregoing is a bit on the theoretical side and may not apply to the foregoing because of the chain reaction nature and that the energy absorbed is in the form of actinic rather than thermal. However, a series of critical experiments are suggested.

The study of the foregoing reaction as a means for producing O_2 and a useful carbohydrate would be helpful not only to the project but also have vast social and economic impacts of a very favorable nature and therefore, the expenditure of funds for this project has application far beyond present thinking. The following additional references are pertinent.[95, 116]

2. <u>The Decomposition of Carbon Dioxide to Provide Oxygen</u>

When heated to increasingly higher temperatures carbon dioxide undergoes the following reaction

$$2\ CO_2 \longrightarrow 2\ CO + O_2 - Q \qquad \text{(a)}$$

The latest reference on the reaction is by Fehling and Leser.[52a] Based upon a study of the constants for the reaction they state, "The dissociation of CO_2 begins at about 1500°C but even at 2000°C no more than 10% is decomposed into CO and O_2. At 2200°C the decomposition of molecular into atomic oxygen becomes significant. With a further increase in temperature dissociation increases rapidly. At 3000°C molecular oxygen reaches a maximum value, about 18%, and at still higher temperatures the gas would consist almost entirely of CO and atomic oxygen." There is another possible reaction

$$2\,CO \longrightarrow 2\,C + O_2 - Q_1 \qquad \text{(b)}$$

On the basis of the foregoing, certain conclusions emerge. (1) reaction (b) in all probability does not take place at least under conditions ordinarily attainable and (2) that even for this reaction (a) the temperatures required are very high (3000°C - app. 5400°F). At these temperatures the amount of molecular dissociation is only 18%. Higher temperatures serve only to dissociate the molecular oxygen into atomic oxygen. If the oxygen is to be recovered from the equilibrium mixture it would have to be cooled very quickly to prevent the reverse reaction taking place. It would be unusual if the recovery was more than 10%. The production of such high temperatures is a difficult one attainable probably only by means of an electric arc or sparks or solar furnace.

The carbon monoxide produced is very poisonous but could be converted to a harmless and perhaps ecologically useful product.

In the foregoing reaction the form of energy to bring about the dissociation is thermal. It might be fruitful to combine this with other forms of energy. There is also the treatment of liquid CO_2 by bombardment with electrons. No reference to this has been found in the literature.

3. The Reaction of Carbon Dioxide with Other Substances

As indicated, the compound carbon dioxide is chemically very stable, difficult to decompose, and not especially reactive at ordinary temperatures except as will be shown later. Consequently, when an opportunity to react with another substance is presented it is the oxygen which will react with the substance rather than with the carbon. Again this is a generalized statement. The objective in this area of reactions is to find, ideally, a substance which will react with the carbon and liberate the oxygen.

The high stability of carbon dioxide is evidenced by the large amounts of energy involved in its formation or reduction. The following is a list of its actual or potential reactions with comments concerning their relevancy to the basic problem.

(a) $CO_2 + H_2O \rightarrow H_2CO_3$

This is the normal reaction with water at room temperatures but the product is unstable and is easily decomposed by a modest rise in temperature. This reaction should not be confused with that of photosynthesis.

(b) $CO_2 + NaOH \rightarrow NaHCO_3$

$2NaHCO_3 \rightarrow Na_2CO_3 + CO_2 + H_2O$

These reactions may be used to remove the CO_2 from the enclosure but the use of $Ca(OH)_2$ is superior.

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

The $CaCO_3$ is insoluble.

(c) The reactions between carbon dioxide and hydrogen are interesting. They are:

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O \qquad (a)$$

$$CO_2 + 2H_2 \rightarrow \underset{\text{(graphite)}}{C} + 2H_2O \qquad (b)$$

related reactions are

$$CO_2 + H_2 \rightarrow CO + H_2O \qquad (c)$$

$$CO + 3H_2 \rightarrow CH_4 + H_2O \qquad (d)$$

$$C + CO_2 \rightarrow 2CO \qquad (e)$$

The foregoing reactions can be carried out under the environmental conditions existing in the closed system. The H_2 may be obtained by the electrolysis of water.

In addition to the above reactions there is a vast spectrum of reactions by means of which many useful compounds may be produced. For example, the methane can be converted to C_2H_4 and C_2H_2 which in turn can be converted to C_6H_6 and other cyclic compounds. Or the following catalytic reaction may be used to produce methyl alcohol

$$CO + 2H_2 \rightarrow CH_3OH$$

Depending upon the choice of catalyst ethyl alcohol, acids and esters may be produced.(132, 133)

(d) Excreta etc. can be decomposed to form NH_3 or the ammonia may be formed from other sources. In any case there is a significant reaction between CO_2 and NH_3.

$$CO_2 + 2NH_3 \rightarrow NH_4\,CO_2\,NH_2$$

$$NH_4\,CO_2\,NH_2 \rightarrow NH_2\,CO\,NH_2 + H_2O$$

The product is urea which may be used for further synthesis.

(e) If concern is for the production of O_2 there are the reactions of water with alkali peroxides, i.e.

$$2Na_2O_2 + 2H_2O \longrightarrow 4NaOH + O_2$$

1 lb. Na_2O_2 produces 2.3 cu.ft. of O_2

1 lb. Li_2O_2 produces 3.9 cu.ft. of O_2

or by the electrolysis of water,

$$2H_2O \longrightarrow 2H_2 + O_2$$

Suggested Further Investigations

In the course of the literature survey certain observations have been made and hypotheses formulated. These have functioned as "thought starters", an environment for creative thinking and by deduction, an incitation to further exploration and experimentation. The following may be considered as a basis for future projects and the reduction to laboratory experimentation of the surveys described in the previous pages.

1. The adaptation of photosynthesis to the environmental conditions of the closed system. This falls into two catagories:

   (a) Natural photosynthesis using living cells.

   (b) Artificial photosynthesis with organic dyes and enzymes.

   (a)(a) The most suggestive approach to the design of these experiments is based upon the report by Krauss.[95] The use of gibberellic acid[97] to accelerate the foregoing reactions is suggested.

   (b)(b) In this approach the effort is to create a synthetic cell - a photobattery - using organic dyes and enzymes as chloroplasts.

2. In the foregoing reactions, to study the effect of pressure, temperature, variations in concentration of CO_2 and H_2O vapor and light cycles.

3. Study of the effect of various forms of energy on the decomposition of carbon dioxide.

4. The study of the effect of the bombardment by electrons on carbon dioxide in various physical states.

Appendix 4

Report on

HANDLING AIR CONTAMINANTS RESULTING FROM A CLOSED ECOLOGICAL SYSTEM

Prepared by

Gerald Palevsky

General

In a closed ecological system, in which humans are present and are required to carry on sedentary work in a confined space for an extended period of time, the atmosphere must be suitable for life and conducive to work. Within the closed ecological system there is no external source of fresh or diluting air. It is therefore imperative that the spent air, by recycling and treatment, be returned to the room atmosphere in such a condition as not to impair the functioning of the humans present.

The control of temperature, humidity, air motion, foreign matter, microorganisms, and the balancing of the CO_2 - O_2 ratio are all major factors to be considered in making the environment acceptable for habitation. The ventilation of the confining space is not merely the supplying of fresh air, or the replacement of spent O_2, but encompasses the exhausting of heat, dust, toxic gases, fumes and noxious odors which may be present in the sealed space, while returning a usable, uncontaminated air. An examination of each of the above-mentioned, singly and in relationship with each other, is necessary for an understanding of the problems of ventilation and air conditioning.

Temperature

The temperature on the skin of the vehicle is dependent upon type and location of orbit, type of material employed for the hull, thickness of skin,

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shape of hull, engineering devices for developing temperature gradient both through the skin and around the hull, and length of time in sun and shadow, as well as distance from heat source. The temperature on the hull in turn will influence the temperature within the compartment. It seems probable that average gross temperatures can be established, and that satisfactory cabin temperatures then be provided through appropriate research on this problem. Fluctuations are anticipated. Other sources of heat within the confined area will be the occupants themselves, operating mechanical equipment, hydroponic or biological growth systems, and heat from propulsion. It appears that comfort temperature control will have to be established through a heating-cooling unit controlled within the confined space. A modified unit similar in operation and design to a commercial air conditioning system installed in homes today might be adequate for the purpose. Means of altering the energy gradient through the hull of the confining cabin by reducing or changing insulation will also bear investigation.

Humidity

Water vapor will be present in the enclosed atmosphere from normal respiration and from insensible perspiration. Since the enclosed cabin is assumed to be maintained at comfort zone conditions, and the normal work is sedentary, sensible perspiration will be at a minimum. The water production per 24 hours per person under average conditions of temperature and humidity has been reported as 500 ml via skin (perspiration), and 350 ml in expired air.[105, 147]

Additional moisture in the atmosphere may come from hydroponic or biological growth systems which may be employed as a source of a supplemental food supply and as a method for balancing $CO_2 - O_2$.[91] There will be less moisture given off to the enclosed atmosphere if the systems are contained and kept separated from the main living atmosphere. The necessity of cleanliness and food preparation, no matter how minimal, will produce further water vapor in the contained atmosphere.

There are three general methods of reducing the moisture content of the air: by compression, by adsorption, and by cooling. Cooling below the dew point and condensing or freezing out the moisture is the most common method of dehumidifying. For this purpose the concepts employed in present day commercial equipment may be utilized to produce the desired effects within the closed ecological system. Modifications with respect to size and weight may have to be investigated.

Another possibility is the utilization of the temperature gradient across the hull of the cabin.[91] Exploratory investigations of the temperature suggest that at some location the cabin structure will have temperatures low enough to allow the use of freeze-out techniques. The engineering design of such a system requires more thorough investigation to determine its feasibility.

That dehumidification is necessary for comfort control is elementary, but more important is the fact that condensed water vapor from the enclosed atmosphere is one of the probable sources of water supply within the closed ecological system.

The water vapor that is condensed out of the contained atmosphere probably may be a purer and less contaminated source of water than any bodily waste. The question of utilizing the water vapor for drinking water will be discussed later.

Air Motion

Within this enclosed area where men are to exist for an extended period of time, certain parameters have been assumed; namely, that there is no gravitational force, and only one-half atmospheric pressure exists.

Normally the air surrounding a living and breathing body is carried up by its own warmth and consequent lightness, thus allowing fresh air to take its place. But in a gravitationless system neither fresh nor foul air have weight, and there can be no convection currents. Without air curculation, heat discharged from the body would hang against the body causing intense perspiration, which in a saturated atmosphere would not evaporate. Body cooling effect would therefore be minimal. Non-circulation effects would also hold for the expired air. In a non-circulating atmosphere a motionless human body would soon become enveloped in expired air, rich in CO_2 and water vapor.

Air motion imparted mechanically by a fan or other stirring mechanism to maintain the entire enclosed atmosphere in a state of turbulence or agitation is necessary.

Foreign Matter

In any confined area in which human activities transpire there are always to be found impurities or foreign matter in the air. These materials are usually particles of organic matter which come from nose, mouth, and skin, and particles derived from the attrition of surfaces. These particles tend to produce odors. The organic particles produce normal body odors which are usually preceived in unventilated or even poorly ventilated areas. Within the contained atmosphere these body odors are to be anticipated and others which are not normally considered must be added. Some odors which will become very marked in closed confined quarters are flatulence and outgassing from defecation and urination, odors of food preparation, sebaceous gland secretions and their subsequent breakdown, odors from equipment operation, odors from exposed hydroponic or biological growth systems, and odors from spillage of materials.

It has been stated that odors of themselves are not injurious to health, but indirectly they may affect health. As odors become extremely noxious, shallow breathing may induce an O_2 deficiency and its sequelae.

The above-mentioned sequence has been observed on study of body odors where some dilution has been present.(173) In a confined area with constant reuse of the same air otherwise minor quantities of noxious material may accumulate and become a source of toxic exposure.

At this time too little is known about the breakdown products and subsequent gasification of body oils, gland secretions, flatulence, halitosis, and bodily waste products to be certain of their non-toxic effects when accumulated in an atmosphere after cycles of reuse.

Winslow and other members of a commission undertook comprehensive studies of ventilation for the New York State Commission on Ventilation in 1923, and published a report.(171) This report contains many interesting details concerning the physiological significance of the various factors in ventilation with special reference to the effects of air conditions on health, comfort and efficiency. Among the several comments it was noted that a disagreeable odor existed in the experimental room supplied only with recirculated air. Odors were associated with higher humidity created by air washing operations.

Again it must be remembered that the water vapor in the air is being considered as a source of drinking water supply. Particulate matter or dust from the attrition of surfaces, as well as gaseous products, may be entrained or in solution in the water, and the effect of ingesting even minute quantities on the human system is a matter of surmise at present.

The air purification system is envisioned as a train of absorbents and adsorbents which will remove the contaminants from the air by physical processes, chemical reaction or electrostatic attraction. Solid state rather than liquid phase materials should be employed in order to prevent as much as possible additional pollutant carry-over in the air stream and subsequent condensation in the water supply.

Most odors due to organic origin are removed by a sorbent material, the most common of which is activated charcoal. The retentivity by activated carbon (% by weight)[102] of various odors anticipated is over 50%. The absorption is practically instantaneous and continuous until the saturation point is reached. Experience reported[10] with respect to new atomic-powered submarines shows that stale air is constantly freshened; and the odors from machinery and cooking as well as fumes are dissipated. Among the special provisions are odor absorbers of activated coconut shell charcoal, which act as absorber-filters. All of the ship's air is passed through these filters, and the charcoal removes all the undesirable odors. Special additional filters were built for the vent pipes from the kitchen and the lavatories.

A weight relationship, depending upon the type of absorbent and retention capabilities of the filter, are still to be investigated, as these filters cannot be easily reactivated,[164] and probably will have to be stored. Additional filters will have to be provided to replace those which become saturated. Quantity and sizing require further study.

H. L. Barneby in a paper discussing the activity of activated charcoal required for air purification[20] offers a table which gives some rough idea of the quantity of charcoal required per year for odor concentrations of difficult intensity. As a guess, an odor index of 2, 3, or 4 might be anticipated in the closed space. This corresponds to 0.1, 1.0, and 10 pounds of odor per million cubic feet. One pound per year of charcoal is required to treat 100, 10 or 1 cubic feet of space at the respective levels of concentration. Accordingly, for a space of 1,000 cubic feet the amount of charcoal required may be between 10 and 1,000 pounds. It should be noted here that this amount is only enough to provide for odor removal and is predicated on the assumption that some fresh air is available due to building leakage. It is also important that activated charcoal is not provided for CO_2 adsorption. Barneby points out that activated charcoal is relatively inefficient in removing CO_2 and should not be depended on for that action.

Microorganisms

The bacterial population in the air depends on many factors, principally the air distribution system and the number and activity of the occupants as well as the methods of housekeeping. A sneeze or a cough, blowing one's nose, expelling sputum--all these actions will cause distribution of microorganisms in the atmosphere. A turbulent air ventilation system, as was previously described, will keep the organisms in suspension. Experiments conducted in 1942[174] have shown that recycling of air in a closed room through air filters does little to change the overall room concentration, even though a large number of organisms are caught on the filter. Newer types of air filters of the millipore type, or the impregnated resin deep filters are capable of removing over 99% of the organisms from air drawn through the filter,[5, 82] but the residual concentration of microorganisms in the enclosed atmosphere may still be high.

The use of germicides, glycol sprays and other similar airborne materials may have a beneficial effect in reducing bacterial numbers, but their effect on humans under confined conditions with continuous inhalation and ingestion would require thorough study before they could be considered safe for use.

Air Conditioning

Air conditioning is herein assumed to mean the conditioning of the confined atmosphere with respect to temperature, humidity, air motion, the removal of foreign matter, and the return of the stale air in a freshened condition for reuse. The maintenance of the CO_2 - O_2 ratio with its attending problems is covered elsewhere in the report.

Temperature control, air motion development, removal of particulate matter, elimination of odors and control of microorganism populations seem feasible with modifications of present day commercial equipment. A train of materials can be established such that turbulent air from the confined cabin would be drawn through an activated carbon filter, a millipore, or deep bed filter, and chemical train for specific materials such as CH_4, H_2S, and any others that may become apparent as more analyses of breakdown products are conducted.

Last, but by no means least, is the dehumidification system with its condensing or freezing out of moisture. By the time the air has passed through the train most of the gross impurities have been removed. This leads to the assumption that this is the purest source of water available in the confined ecological system.

This supply of water developed from the water vapor would undoubtedly contain small amounts of entrained or dissolved gases. What the effect of these small amounts might be on the human system is not known, nor did any of the library references examined indicate study in this field.

It is conceivable that the human body, which is a well-organized purification unit, can receive these materials through inhalation, skin, or oral intake, and detoxify them, if necessary, passing them out as waste products. If this be the case, many problems of train contaminant removal are simplified by having the human body act as its own purification plant.

There is much needed further research in conjunction with the problem of air conditioning for a closed ecological system to ascertain the toxic limits for humans of the several material exposures by ingestion, by inhalation and by skin absorption.

Water Supply

In a closed ecological system the water supply must come from the wastes of the body. The sources of water are respiration, perspiration, urine, and feces. The water due to respiration and perspiration has been considered in the dehumidification process.

The feasibility of using feces as a source of water has been investigated. Feces consist of the indigestible and undigested portion of food mixed with bacteria and water. The amount of feces produced by a human under normal diet varies widely. Averages have been reported by many investigators,[69, 105, 108] and there is some agreement that 0.5# per day is a maximum value with 0.25# per day being about average. The water content is from 60 to 85% with an average of about 70%. This means that the feces contain about 70 to 100 cc of water per day per person.

Because feces is composed of organic matter having the same basic elements as coal or petroleum, a search of the literature was undertaken to find a thermal cracking process or procedure which might have application. There were no pyrolytic procedures available in either the coal or petroleum technologies which might indicate a means of extracting useful products and separating the water from feces. The search was conducted in Chemical Abstracts, Biological Abstracts, the Industrial Arts Index, the Engineering Index, and all engineering journals published during the past twenty years. No supporting information was found.

Stolley and Fauth[152] have reported on a solvent extraction process wherein extraction, dehydration, and treatment of raw sewage sludge are accomplished simultaneously. The process requires the use of a solvent to extract the oils and fats from the sewage and then application of heat to the solvent-sludge mixture to drive off the water. The water present in feces is primarily trapped and bound water. Sewage sludge dewatering cannot be accomplished by centrifuging without premixing with a solvent. This, together with other findings of the authors on the usefulness of sludge for food, fertilizer, fuel, and other by-products leads to a conclusion that feces might just as easily be stored at below 0°C and not be considered as a source of usable material.

If, as has been mentioned previously, the human body can act as its own purification system and eliminate as part of its solid wastes small quantities of ingested or inhaled pollutants, these contaminants would be eliminated from the cycle. If the feces are to be stored and not considered as a source of any usable material, possible contaminants of the atmosphere entrained or trapped in the feces would be removed and the air conditioning train would be less complex.

Another probable source of water remaining to be considered is urine. The urine produced by a person in 24 hours is approximately 1,500 ml.[105, 108] Urine is approximately 95% water and the remainder salts.

The possibility of using urine as a source of water is apparent. The means by which a safe and potable water can be extracted from the urine has two approaches: distillation or freezing. The freezing method of extracting fresh water from the urine and the distillation method are similar in that both require a change of state by the application of suitable heat transfer processes. The methods differ in that the formed ice remains in contact with residue and condenses separately.

It should be pointed out that any distillation process under conditions of one-half atmosphere has the possible disadvantage of outgassing. Unless closed system methods are used, these additional gases added to the closed atmosphere will require additional air purification material and possible additions to the length or complexity of the decontamination train.

In the distillation of sea water the precipitating salts permit use of up to 50% of the brine. A single run experiment on urine indicated a distillation of 60% to 70% before odor and color carryover became intense.

The literature has reported several attempts to secure fresh water from the sea by freezing. The use of ice formed in the sea as a source of fresh water has been known to the inhabitants of the Arctic regions since prehistoric times.

In work reported by Thompson[162, 163] and Curran[46] it is stated that about 80% of the total salts in the original water were concentrated in 20% of the original volume; that 50% of the liquid contained 20% of the solids originally in the sea water; that the yield of pure water can be enhanced by reprocessing the partially desalted water; and that self washing of the ice results in practically salt free water.

In the freezing of sea water it has been found that fresh water precipitates in the form of ice crystals which mechanically retain some salt. The density of the material immediately adjacent to the ice crystals increases and sinks being replaced by less dense, less saline material. Under laboratory controlled conditions the brines were all collected at the bottom of the vessel. The ice formed from the freezing of sea water is of a porous nature due to the entrapment of some salt. When the ice is removed from the freezing vessel and is permitted to melt, the first ice to melt would be that immediately adjacent the interstitial salts and brine retained in the ice. The resulting liquid, gravitating through the ice, would have high salinity, while the remaining ice would have only a small fraction of salts. The process of permitting the ice to melt and wash out the entrapped brine is referred to as auto-washing, or self washing. Water formed by the later melting of the residual ice would be fresh water.

A freezing process under controlled conditions (within a closed ecological system) might be employed to separate the water in urine from the salts. A safe, usable drinking water might be recovered from the urine through fractional freezing and auto-washing. Since this process must be conducted at reduced temperatures, it might be associated in methodology and equipment with the dehumidification process to remove moisture from the air, or with some part of temperature control. As temperatures drop, solubility of gases increases. This phenomenon might be advantageous in preventing outgassing from urine during its conversion to a usable drinking water.

A corollary study which requires further investigation is the feasibility of using the thickened urine brine as a sorbent for contaminants in the air.

The urine brine residual would have to be stored at or below 0°C, and volumetric consideration must be given to quantities involved.

Evaporation directly from the solid state to remove better than 85% of the water content of the wastes has some feasibility. Work has been done on biological materials, serums, food stuffs and other easily decomposing substances to dry them without impairing their usefulness. In each case the residue was the material of interest. In the case of the closed ecological system, the water would be of prime importance and the residue secondary.

The advantages of a sublimation process - or freeze drying as it is called - are manifold. The wastes would be rapidly frozen thus entraping and entraining the malodorous compounds; all wastes might be treated together at one time; the entire process might be made a portion of the temperature control equipment of the closed space; and the water obtained might be less polluted than water obtained by other processes.

Basically the process requires that the material in question, that is the liquid wastes of a closed ecological system, be rapidly frozen in thin layers to a temperature below the eutectic point.

In any sublimation process the solid substance is vaporized under a vacuum so that no intermediate liquid phase develops. The vapor developed is removed rapidly from above the solid substance and condensed elsewhere. This recondensed material, in the case of the wastes of the closed ecological system would be the water, and presumably would be free of the non-subliming dissolved impurities of the original solid substance.

Descriptions of the various types of apparatus which have been employed in laboratory and pilot plant investigations are given in the list of references.(6, 25, 28, 29, 58, 70, 71, 92, 120, 141)

It has been indicated in the research work on food stuffs that about 85% of the water can be removed directly by this process. Since temperature during the entire process is held below 0°C, all impurities would remain in the solid state.

More work is definitely required before a conclusive statement can be made about the merits of this process for the recovery of a potable water but the reference material was encouraging.

The water derived from the urine may contain some trace amounts of impurities. What effect these small amounts might have on the human system after cycles of reuse is not known. Further study is imperative to ascertain toxic limits for humans of trace material exposures by ingestion. In a closed ecological system constant accumulation of minor quantities of pollutants may result in equilibria above safe levels of toxic exposure.

Appendix 5

Report on

THERMAL ENERGY EXCHANGE WITH SPECIFIC APPLICATION TO WASTE HANDLING IN A CLOSED ECOLOGICAL SYSTEM

Prepared by

Lawrence Slote

One of the basic methods proposed in treating human waste is the application of thermal energy to the cracking of the waste with by-product recovery. In order to accomplish this feat, both high temperatures for the cracking and low temperatures for the condensation of the by-products must be available. Another possible technique is the purification of urine by freezing, which becomes possible only if the temperature is low enough. The specifics of the abovementioned techniques will be discussed in a separate paper.

As a first approach to this problem of insolation, the biosatellite will be assumed to have an elliptical orbit about the earth with its perigee of 300 miles and its apogee of 1000 miles. For purposes of this paper, the geometry of the biosatellite will be spherical. It should be noted that the geometry of the satellite is important in the determination of the thermal energy exchange. The sphere is the easiest three dimensional body to investigate and therefore all results will be specific to the sphere.

The temperature of the biosatellite is the resultant of the sum of radiations from the following sources:

1. directly from the sun
2. solar radiation returned from the atmosphere and the earth

3. low temperature radiation from the earth

The following theoretical discussions are based essentially on articles listed in the Author Index as Nos. 33, 62, 140, 144, and 170.

The ranges of maximum and minimum temperatures may be calculated assuming the various characteristics of the biosatellite. These characteristics are:

1. absorptivity of the surface
2. geometry of the satellite
3. mass
4. specific heat
5. orbit trajectories - distance of perigee and apogee
6. duration of insolation
7. duration in shadow of earth
8. internal heat generated

A configuration of the mean surface temperature for the case of perfect heat conduction, or a spinning vehicle is readily made from a consideration of the total energy received and emitted.

$$q_s + q_r + q_e + q_a + q_E = q_{out} \qquad (1)$$

where q_s energy received directly from the sun

q_r solar irradiation returned from the atmosphere and the earth

q_e low temperature radiation from the earth

q_a aerodynamic heating or cooling

q_E internal heat produced by equipment and men

q_{out} energy emitted by the surface of satellite

Assuming negligible aerodynamic heating or cooling and neglecting internal heat generation since we have no idea as to size and contents of the biosatellite, equation (1) can be written as follows:

$$q_s + q_r + q_e = q_{out} \quad (2)$$

The value of the terms on the left hand side of Eq. (2) are as follows:

$$q_s = 2.00 \text{ gm cal cm}^{-2}\text{min}^{-1}$$
$$q_r = 0.36 \text{ gm cal cm}^{-2}\text{min}^{-1}$$
$$q_e = 0.32 \text{ gm cal cm}^{-2}\text{min}^{-1}$$

In the case of the spherical biosatellite, at heights less than several thousands of miles from the earth:

$$-q_r = 0.36 \times 2 \left[1 - \frac{\left[(h - r)^2 - R_r^2\right]^{\frac{1}{2}}}{(h - r)} \right] \pi \tau^2 \quad (3)$$

$$q_e = 0.32 \times 2 \left[1 - \frac{\left[(h - r)^2 - R_e^2\right]^{\frac{1}{2}}}{(h - r)} \right] \pi \tau^2 \quad (4)$$

where h height of satellite above earth, miles

r radius of the earth 3960 miles

R_r radius of the effective reflecting hemisphere, equal to 3960 miles plus 5 miles

R_e radius of the emitting sphere, equal to 3960 miles plus 20 miles

τ radius of biosatellite, cm

The biosatellite emits radiant energy in accordance with the Stefan law:

$$q_{out} = \epsilon \sigma T^4 \qquad (5)$$

where T surface temperature of biosatellite, °K

σ Stefan constant 81.35×10^{-12} gm cal cm^{-2}min^{-1}

ϵ surface emissivity coefficient at temperature T

Eq. (2) can be written as follows:

$$\epsilon T^4 = \frac{1}{\sigma} A_p/A_t \left(\alpha_s q_s + \alpha_r q_r + \alpha_e q_e\right) \qquad (6)$$

where α coefficient of absorptivity for the given wavelengths

A_p/A_t ratio of projected to total area of sphere, 1/4

For an elliptical orbit having a perigee of 300 miles and an apogee of 1000 miles, the following values are obtained:

q_r = 0.46 gm cal min^{-1} 300 miles

q_r = 0.288 gm cal min^{-1} 1000 miles

q_e = 0.415 gm cal min^{-1} 300 miles

q_e = 0.258 gm cal min^{-1} 1000 miles

Assuming a gray body surface which is uniformly absorbing and emitting from wavelengths 0.2μ to 25μ, Eq. (6) becomes:

Sunlight

$$T^4 = \frac{(q_s + q_r + q_e)}{4\sigma} \qquad (7)$$

T = 307°K or 34°C 300 miles

T = 298°K or 25°C 1000 miles

Shadow

$$T^4 = \frac{q_e}{4\sigma} \qquad (8)$$

T = 189°K or -84°C 300 miles

T = 168°K or -105°C. 1000 miles

The characteristic of the surface becomes very important in determining the equilibrium radiation surface temperature. This can be shown for a polished nickel surface having the following characteristics:

$$\alpha_s = \alpha_r = 0.3$$

$$\alpha_e = 0.05$$

$$\epsilon = 0.05$$

Sunlight

T = 472°K or 199°C 300 miles

T = 456°K or 183°C 1000 miles

Shadow

T = 189°K or -84°C 300 miles

T = 168°K or -105°C 1000 miles

The following table shows the comparison between a gray body and a nickel body for the given altitudes and conditions of irradiation.

		Altitude	
Surface		300 miles	1000 miles
Sunlight			
	gray	34°C	25°C
	nickel	199°C	183°C
Shadow			
	gray	-84°C	-105°C
	nickel	-84°C	-105°C

For the given elliptical orbit with a perigee of 300 miles and an apogee of 1000 miles, the biosatellite would have a period of 106 minutes. The time spent in the sunlight and in eclipse shadow is shown in the following table.

Condition	Illuminated Minutes	Shaded Minutes	Total Period Minutes
1. illuminated at perigee, shaded at apogee	73.2	32.8	106
2. illuminated at apogee, shaded at perigee	69.0	37.0	106
3. illuminated at right angles to axis: perigee - apogee	70.8	35.2	106

To arrive at estimates of the likely temperatures of a spherical biosatellite, values for the dimensions of the input and outgo areas, the weight, and the thermal capacity must be known. It therefore becomes imperative that this information be determined accurately for the various geometric shapes and for the various conditions of irradiation to be encountered. Having this information, it is possible to determine the transient temperature response of the biosatellite by programming this information on a high speed digital computer.

The previous analysis has attempted to show the variation in the total surface temperature of a perfect heat conducting or spinning biosatellite for a given orbit and for various conditions of irradiation. As the thermal capacity of the satellite is reduced we obtain a temperature distribution about the surface of the sphere. Therefore, it becomes evident that various temperatures can be obtained depending upon the geometry, surface and trajectory of the biosatellite. With this in mind, it seems feasible to use thermal energy sources in connection with processes for cracking of human waste and for the purification of urine by freezing, if these processes are used.

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