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Progress Report

Handling Air Contaminants Resulting from a Closed Ecological System

Part of

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

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Report on

HANDLING AIR CONTAMINANTS RESULTING FROM A CLOSED ECOLOGICAL SYSTEM

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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,

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.[1,2]

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 $CO_2 - O_2$. 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. 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 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 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 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. 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.[4] 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.[5] 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)[6] of various odors anticipated is over 50%. The absorption is practically instantaneous and continuous until the saturation point is reached. Experience reported[7] 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,[8] 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[9] 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[10] 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,[11,12] 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 milipore, 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,[2,13,14] 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[15] 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.[2,13] 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 residual brine, whereas in distillation, vapor passes over from 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[16,17] and Curran[18] 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 imparing 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.[19 to 29]

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.

References

Master File Reference

1. Specht, H., "Toxicology of Travel in the Aeropause," Physics and Medicine of the Upper Atmosphere, p. 171-180, University of New Mexico Press.

2. Mattice, C.E., Clinical Chemistry, Van Nostrand.

3. "Medical Problems of Space Flight", Special Report Air University, USAF School of Aviation Medicine, Randolph Field, August, 1955.

4. Yaglou, C.P., Riley, E.C., and Coggins, D.I., "Ventilation Requirements", Trans. A.S.H. & V.E., 1936.

5. "Ventilation", Report of N. Y. State Commission on Ventilation, E.P. Dutton & Co., 1923.

6. "Fan Engineering", Buffalo Forge Co., Buffalo, N. Y., 1948, p. 421 (according to Dorex).

7. "New Atomic Powered Submarine Equipped with Heavy Duty Cooling System", Industrial Refrigeration, Feb., 1957.

8. Turk, Amos, "Catalytic Reactivation of Activated Carbon in Air Purification Systems", Industrial and Engineering Chemistry, Vol. 47, No. 5, p. 966, 1955.

9. Barneby, H.L., "Quantity of Activated Charcoal Required for Air Purification", unpublished paper, Barneby-Cheney Co., Columbus, Ohio, May 1957.

10. Yaglou, C.P. and Wilson, U., "Disinfection of Air by Air Conditioning Processes", Aerobiology (Publication of the American Association for the Advancement of Science), No. 17, 1942.

11. "Filtration of Very Fine Dusts", Engineering, Vol. 179, p. 607, May, 1955.

12. Humphrey, A.E. and Gaden Jr., E.L., "Air Sterilization by Fibrous Media", Industrial and Engineering Chemistry, Vol. 47, No. 5, p. 924, May, 1955.

13. McFarland, Human Factors in Air Transport Design, McGraw-Hill, 1946.

14. Gradwohl, M.D., R.B.H., Clinical Laboratory Methods and Diagnosis, Volume 2.

Master File Reference

15. Stalley, R.H. and Fauth, E.H., "Treatment of Sewage Sludge by the McDonald Process", Public Works, Vol. 88, No. 3, p. 111, 1957.

16. Thompson, T.G. and Nelson, K.H., "Desalting Sea Water by Freezing", Refrigerating Engineering, Vol. 62, No. 7, p. 44, 1954.

17. Thompson, T.G., "Fresh Water from the Sea", Technion Yearbook, p. 96, 1957.

18. Curran, Brother Henry H., "Fresh Water Extracted from Salt Water", Refrigerating Engineering, Vol. 63, No. 9, p. 45, 1955.

19. "Freeze Drying", Report #7066 compiled by J. J. Berliner & Staff, 1956, New York.

20. Modern Refrigeration, March 18, 1943.

21. Food Manufacture, November, 1952.

22. Chemical Products, July - August, 1947.

23. Chemical Engineering Progress, June 1949.

24. Kirk, R.E. and Othmer, D.F., "Encyclopaedia of Chemical Technology", 1950.

25. Flosdorf, E.W., Chemical Engineering Progress 1947, Vol. 43, p. 343.

26. Bradish, C.J., Prain, C.M. and McFarlane, A.S., Nature 1948, 159, 28.

27. Greaves, R.I.N., "The Preservation of Proteins by Drying", Medical Research Council Special Report No. 258, 1946.

28. Greaves, R.I.N., Nature 1944, 153, 485.

29. Campbell, W.L., Proctor B.E. and Sluder, J.G., Research Reports on Quartermaster Contract projects, M.I.T. Food Technology Laboratories, Cambridge, Mass. (July 1, 1944 - Oct. 3, 1945).