WASTE MANAGEMENT

LIQUID WASTES AND WATER POTABILITY

Speaker: DR. J. E. McKEE

Discussant: DR. GILBERT V. LEVIN

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DR. J. E. McKEE, Professor of Environmental Health Engineering, Division of Engineering, California Institute of Technology, Pasadena, California.

THE CHAIRMAN: We start on the next part of the program, and I would like to introduce Dr. J. E. McKee by saying that he has really been a good sport in connection with this program, because he started out as a discussant and suddenly found almost at the last meeting that he was given a major paper.

You see all the material on the board, this is the reason for it. Jack, I am very grateful for your understanding.

DR. McKEE: Ladies and gentlemen, at this stage of the Conference, it should be apparent to most of the participants that the problems of feeding and nutrition in space vehicles are both important and fascinating. But not really truly difficult of resolution.

The problems of water supply and waste management, on the other hand, are exceptionally critical and far from being solved. Indeed, they may be the factors that control the size and weight of the vehicle or the duration of the mission.

We have been told, for example, that the weight of dehydrated food will be only about .06 kilograms per man day, but the metabolic water requirement will be about 3 kilograms or about 3 liters per day, that is 5 times the weight of food. Consequently, it will be desirable, if not absolutely essential, to reclaim and reutilize waste water in space vehicles.

We have seen how food can be neatly packaged in advanced, stored in cabinets and containers, and readily prepared for appetizing and nutritious meals. But we have also learned that the handling of human waste will depend largely on the actions of the astronauts and the reliable hardware and techniques for waste disposal remain to be developed.

It is the intent of this paper to explore some of the ramifications of waste water reclamation in space vehicles and to describe some of the criteria that control the treatment of urine and other waste waters.

In assessing the problems of waste water management and reutilization, it is desirable to establish certain boundary conditions or limitations to the study. Accordingly, the following logical assumptions have been made:

1. That the flight duration will exceed 15 days but not six months, and that it will involve three men or more. For shorter flights and fewer men, sufficient fresh water can probably be carried aboard, and waste water can be stored. For periods longer than six months processes more complicated than those described in the paper may be indicated.

2. That feces will be kept separate from urine, that it will be packaged, disinfected and stored in used food containers. For voyages in excess of six months it may be desirable to utilize feces in photosynthetic processes, but I won't go into those today.

3. That zero gravity will prevail except during take-off and landing.

4. That occupants will be free to move about the cabin and to operate simple water-recovery apparatus, that is we will have a "short-sleeve" regime -- excuse me, shirt-sleeve regime will prevail.

5. That weight will be a controlling

factor but that power will be ample for the operation of simple functions.

6. That dehumidifying equipment will be provided to condense all excessive cabin moisture and make it available for reutilization.

And now we will go into recovery of water. Now let us discuss water quantities, that is, the daily quantity of water needed by each man. The quantities of water consumed by a man vary widely, depending on the level of his activity, temperature, diet, body weight and so on. The following average values from Hawk and others, and these have been used in several papers as shown on this tablation here. That is water intake consists of drinking water about 1200 millimeters per day. The water in the food, and this is using rehydrating food at a thousand millimeters per day, and that oxidized from food of 300 millimeters per day.

In the water output, urine 1400 -- these of course are average figures. Feces only 100 and respiration and perspiration 1,000.

This is one of the reasons why we are

not at this present time considering urine and feces, the water in feces, as a source of our water waste reclamation.

Now, from this table it can be seen readily that if all urine is reclaimed, and if the water of respiration and perspiration is recovered by dehumidification apparatus for drinking water and rehydration of food, the water oxidized from food exceeds that stored with the feces by 200 millimeters per day, that is from the food we oxidize 300 we only store 100. So, on a space voyage the total water available in the cabin will increase daily and may become a problem of ultimate disposal or storage. Instead of having a water storage we may end up with a water excess.

In addition to the water taken internally, man needs water for personal cleansing, laundry and perhaps cabin cleansing. In a prolonged voyage with zero gravity, bathing and cabin clearing will probably be limited to sponging operations. But the centrifugally operated washing machines for the cleaning of clothing should be easy to develop. Ingram has estimated these supplemental water needs at two and a half to five and a half liters per day. Now this water is capable of reclamation along with that from urine, respiration and perspiration. Indeed, the carbonaceous content of wash water may be advantageous in the biological stabilization of urine as discussed later.

Standards of water quality has been published by the United States Public Health Service and the World Health Organization. These standards are summarized in the Table I, and I might just point out that a few of these notes down here, are -- the mode A refers to the European standards of the World Health Organization. The World Health Organization also has what is called the International Standards which generally are not as strict as the European standards, and the second note, the subnote C refers to the Public Health Service Standards which are mandatory as contrasted with others which are merely recommended.

Some consideration should be given to the rationale under which these standards were established. In all instances, they are extremely conservative. They are designed to protect children from fluoride and nitrates. They protect aquatic life and goldfish in bowls with respect to chromates and lead. They meet the threshold limits of taste in the case of copper, iron, zinc and maganese. In short, they are standards of excellence, but not criteria of human health or limits for the maintenance of a healthful condition of man in space. They should definitely not be applied blindly to the determination of water quality to be met by reclamation systems in space, and I might say in reviewing literature onthe subject I found in several instances that these Public Health Service standards are accepted without any question. Since they came from Washington they are official and have to be used.

It is especially important to note that the Public Health Service and World Health Organization standards apply mostly to mineral constituents. Only in the case of carbon chloroform extract and phenolic compounds do true organic substances enter into the determinations. The Public Health Service and WHO standards were formulated largely on the basis of natural waters and the possible contamination by mineral wastes from industrial processes. They certainly did not envision the quality of water reclaimed directly from human wastes. For this reason the Public Health Service drinking water standards should not be applied blindly, as several researchers have done, to the quality of reclaimed water acceptable for space travelers.

What are some of the characteristics waste waters to be expected in space vehicles? Analysis of the water that may be recovered from sponge baths of astronauts, from cabin cleansing, from the laundering of clothing and from the condensates from dehumidifying operations have not been reported in the literature. We have values for laundry operations and commercial operations and home laundries, but we don't know just what this situation would be in the case of astronauts. It may be assumed to be, however, that such waste waters will contain sebaceous excretions, sweat, detergents and condensates that in combination will resemble domestic sewage with respect to biochemical oxygen demands, total organic solids, carbon-nitrogen parts ratios, and other perimeters of organic and mineral pollution. Such waste waters are amenable to biochemical treatment.

The other major waste water is urine, for which the approximate constituents are shown in Table II. Note especially that the total solids or residue on evaporation exceeds four percent, as compared with the Public Health Service recommended limit of 500 milligrams per liter or what I consider to be a more rational limit of about 1500 milligrams per liter. Note also that the levels of sodium, potassium, chloride and sulphur are too high to meet the Public Health Service limit for total dissolved solids. With respect to trace elements, however, no problem is involved, because in every instance the trace mineral output of urine is acceptable by rational or Public Health Service standards. Nevertheless, the mineral constituents of urine give us an important clue to the treatment that will be required. It is evident that no biological method such as activated sludge, trickling filters, or algal ponds will be sufficient for treatment because they will not remove the dissolved mineral solids. It will be necessary, therefore, to utilize an evaporative process, electrodialysis, and electrolysis fuel cell, or some similar method of separating water from the dissolved mineral solids in urine.

Let us look also at the organic solids in urine. Note especially that urea accounts for about 50 percent of the total dissolved solids, that is, 30,000 milligrams per person per day, and 21,400 milligrams per liter. Note also that the other nitrogenous compounds such as amino acid, creatinine, hippuric acid and uric acid are significant, and that lepids and organic acids account for important fractions also.

Indeed, many of these organic compounds are volatile enough to appear in the condensate from evaporative processes or the effluent from the electrodialysis units.

Considerable attention has been directed at processes for the recovery of drinking water from urine. The work prior to July 1962 has been summarized nicely by Slonim, Hallam, Jensen and Kammermeyer. The most promising systems utilize some force of distillation, with vacuum distillation being operationally most advanced. With all such processes, however, it is necessary to provde additional treatment of the condensate because volatile organic constituents of urine are carried over. Some of these compounds produce undesirable tastes. The after-treatment may consist of filtration to non-exchange resin or activated carbon, both of which become exhausted and must be replaced periodically.

In his opening remarks to this Conference, Dr. Konecci reminded us that we should search the literature and rely heavily on the experience gained by others, even in generations past. Sanitary engineers have had many decades of experience in the treatment of municipal and industrial wastes. Perhaps we should explore some of the systems that have been proven in such operations. It would seem logical, for example, to stabilize the organic constituents of urine prior to distillation by means of oxidative processes that convert organic compounds to mineral solids. For this purpose, sanitary engineers normally employ the activated sludge process, trickling filters or oxidation ponds. All of these systems, however, rely heavily on gravity forces, and indeed it is difficult to envision how they could operate in a zero-gravity condition.

It appears, however, that no one has given consideration to an ancient method of stabilization of organic solids, namely the intermittent and unsaturated percolation through fine-grained media such as soil.

I have a sketch here, of a very simple operation which would consist of fine grained forest media, and this is just fancy words for soil, 20 centimeters in diameter and 100 centimeters long, that is in it alone.

Now, with porous plates at either end. The waste water such as urine could be injected through a one-way valve, assuming that it is collected, through one of the systems that you have seen already into a tube here with a piston operation, and after the urine is inserted into the tube here the piston would drive it through this (indicating). Again one-way valve into the fine-grained porous media.

Now, it is essential in such operations that we have unsaturated flow, that is that the water does not fill all the intersities of the soil, instead that the water move through the soil largely by capillary forces, and for that reason we would want to put compressed air in, also through a one-way valve and after the piston is brought back, that is after the urine has been pushed into the fine grained porous media the piston withdrawn then the compressed air would flow in through the one-way valve and would percolate also through the porous media.

The flow-up here then would be stabilized to a very large extent, to what extent I can't say at this time because this system to the best of my knowledge has never been studied with urine. We have studied percolation of municipal sewage through fine-grained soil and know quite a bit about that, but urine represents an entirely different situation because it doesn't have the same balance with respect to carbon, nitrogen and phosphorus.

However, we do know that urine is

stabilized rather successfully, and I am sure as I will show you on equation that comes up that we get a higher degree of stabilization so that almost all of the organic matter then will be converted over to nitrates, carbonates , phosphates and so on.

As I say, this method has not been studied and it certainly ought to be investigated thoroughly.

One of the important advantages of this thing is that it doesn't require gravity. That is normally when we percolate water through soil we think about putting the water on and it goes down through gravity forces through the soil, but actually the capillary forces involved are much greater in this case than the gravity forces and this thing can be made to operate in any position, regardless of gravity.

Now, after a bed of such media has been ripened or acclimated to a given organic waste, it will function effectively to convert carbonaceous and proteinaselus substances to oxidized end-products such as carbon dioxide, nitrates, sulphates and phosphates and water. Now the oxidation of urea, for example, is shown by these equations. Here we have urea with water and decomposes very rapidly in the presence of water to protoplasm and this represents biosynthesis, we get bacteria forming and these would particularly form on a fine-grained soil and that's end protoplasm. So, this is two minus -- if we add oxygen to this system we get a certain amount of additional protoplasm formed because the bacteria will form on fine-grained soil. Then we get nitrates, hydrogen, hydrogen iron, water and the same carbon dioxide. This is not an additional carbon dioxide. Now, how much of this we get depends again on how much protoplasm is formed and how much end products occur. Consideration must be given to the fact that stabilization of organic matter utilizes oxygen and produces CO_2, both of which are critical factors in space travel.

Now, let us examine the magnitude of the oxygen utilization. If all of the urea in urine were converted to nitrates, carbon dioxide and water without any biosynthesis, the oxygen requirement would be approximatelytwice the weight of the urea, or about 64 grams per man day, which is equal to 10 grammoles of oxygen or 45 liters per day at standard temperature and pressure. The oxygen demand for man's respiration, however, is in the order of 610 liters per day, it's reported by Breeze, and as you heard in the conversation the other day, the total oxygen utilization would probably be twice this amount because of cabin leakage. Hence the complete oxidation of the organic solids in urine would add only 7 percent to the oxygen demand. The carbon dioxide production would be even less significant because the respiration, respiratory quotient for oxidation of urea is only 30.25.

Now, from this brief dissertation, it is apparent that considerable work needs to be done to determine many of the factors related to the recovery of waste water in space vehicles. I have not got into the mechanics of the various methods of vapor compression percolation, for example, vacuum distillation. The electrolysis fuel cell method and many others. They have been written up in reports which are available.

However, attention should be directed

especially to some of the following matters:

First we should establish realistic criteria or standards for the necessary quality of the water recovered from urine. We should not use the Public Health Service drinking water standards, but establish reliable qualitative data that would apply to adults only in the environment of the space vehicle.

Secondly we need more research on the oxidation of urine by intermittent percolation through fine-grained media, especially in the absence of gravity.

Well, Dr. Mrak, I've hurried through this. I expect that in the written papers in the proceedings there will be a little more detail on the mechanics of these processes. Thank you.