Urine Pretreatment for Distillation-Based Water Recovery

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Urine supports bacterial metabolism and creates solid precipitants. Currently, urine is pretreated with sulfuric acid and Oxone® to prevent fouling of the collection systems of human space habitats. Oxone® can create toxic gases and could be detrimental to astronaut health. The objective of this research is to identify a non-toxic pretreatment agent that prevents fouling and is compatible with a distillation-based recovery system. Laboratory tests were conducted to assess the pretreatment agents' ability to stabilize physical, chemical, and biological urine characteristics. The separabilty of the chemicals was determined with distillation software simulations. Laboratory tests results showed that the chemicals tested meet pretreatment requirements for short term storage but not for long term storage. Distillation simulation results showed that the chemicals are separable from water in the flash operating range of 25-50ºC. Preliminary simulations indicate that high percent chemical removal is possible.

Nomenclature

BSA	=	Bovine Serum Albumin
CDS	=	Cascade Distillation Subsystem
DO	=	Dissolved Oxygen
HMIS	=	Hazardous Materials Identification System
ISS	=	International Space Station
NASA	=	National Aeronautics and Space Administration
TSS	=	Total Suspended Solids

I. Introduction

THE National Aeronautics and Space Administration (NASA) has the goal of returning to the moon by 2020. Thus far, space exploration mission durations have not been long enough to require water reclamation. Water has been launched in the shuttle, and wastewater returned to earth or dumped into the vacuum of space. The Constellation program involves the development of a vehicle and other hardware necessary to return to the moon. The Orion crew module will be a vehicle used to transport four to six crew members to the moon. Urine will be collected in the crew module and water will be recovered using the Cascade Distillation System. Urine is a highly complex fluid that supports bacterial metabolism and quickly creates solid precipitants if left untreated. The constraints of a reduced gravity environment require the urine collection system to be composed of small diameter tubes susceptible to clogging. In order to prevent clogging of the collection system, urine is pretreated with a chemical agent upon urination to inhibit bacterial growth and solids precipitation. The current pretreatment method utilized by the US urine collection system in the International Space Station (ISS) uses a combination of sulfuric

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acid and Oxone®. Oxone® is a highly reactive oxidizing compound that is hazardous to human health. Oxone® destroys microorganisms by oxidation forming chlorine and other toxic gases[4]. The toxological effects of Oxone® have not been fully investigated, nor have the maximum allowable concentrations in potable drinking water. Thus, it is desirable to identify a non-toxic pretreatment agent that prevents clogging of the collection system and is compatible with the distillation system. This research aims to find an alternative pretreatment agent that is both non-toxic to humans and compatible with a distillation based water recovery system (Cascade Distillation Subsystem). The pretreatment chemical should be less toxic than the current pretreatment method that utilizes Oxone®. The pretreatment chemical should also buffer pH between 2 and 4.

II. Research Methodology

A. Selection of pretreatment agents

A set of criteria were established for the pretreatment candidates in order to be considered for testing. These criteria were set up in order to ensure that the pretreatment candidates would not be detrimental to the astronaut's health over an extended time period. The current pretreatment agents, Oxone® and sulfuric acid, do not meet this requirement. The candidates must also be compatible with the cascade distillation system adopted by NASA. Distillation based water recovery systems will likely be implemented in the near future aboard the International Space Station and on a lunar outpost.

Low toxicity chemical compounds were identified by investigating toxicity data, Hazardous Materials Identification System (HMIS), pKa, volatility, and solubility data. Solubility data was considered because the delivery system for solid chemicals depends on solubility. These pretreatment chemicals were boric acid, lactic acid, pthalic acid, sorbic acid, and fumaric acid. The listed pretreatment chemicals are shown to be less hazardous than Oxone®. Due to time constraints it was decided to only test boric acid, sorbic acid, fumaric acid, and sulfuric acid as a control.

B. Laboratory urine pretreatment tests

Pretreatment chemicals were tested using urine collected from eight individuals. The urine was collected and stored at 4ºC prior to testing experiments according to NASA Urine Collection Procedures[3]. At the start of the experiments, the collected urine was mixed in a carboy. Measured volumes of the mixed urine were poured into plastic polypropylene sample bottles and enough pretreatment chemical was added to achieve a concentration of 1 g/L as active ingredient. Experiments were carried out in triplicates in continuously stirred capped polyethylene bottles. Each experiment lasted one week. Samples were taken and analyzed at 0, 20, 40, 60, and 120 minutes the first day and every 24 hours for days 2 through 7.

A viable urine pretreatment agent would prevent changes in the biological, chemical, and physical characteristics of urine. Therefore, analytical measurements were performed to monitor the biological, chemical, and physical changes occurring in the stored urine following the addition of pretreatment agents. The biological conditions were monitored by protein assay, ammonia concentration, and dissolved oxygen (DO) concentration with a DO probe. A bovine serum albumin (BSA) protein assay kit manufactured by Pierce Biotechnology (Rockford, IL) was used to quantify biomass according to the method of Lowry (1951). Ammonia concentration was measured according to the methods 4500 F (Eaton, Clesceri et al. 2007)[1]. The chemical changes were monitored by pH measurements with an Orion probe. Any change in pH during storage indicates that the urine is not stable, and an increase in pH typically indicates urea hydrolysis. Physical changes, specifically the formation of precipitates, were quantified with turbidity according to method 2130 (Eaton, Clesceri et al. 2007) and total suspended solids (TSS) according to method 2540 D (Eaton, Clesceri et al. 2007)[1].

C. Simulation

In order to assess the compatibility of the laboratory tested pretreatment chemicals with the Cascade Distillation Subsystem (CDS), simulations were performed with the computer program Aspen. A large amount of background research was performed on the cascade distillation system, currently the primary candidate for the NASA wastewater recovery system on the lunar habitat, in order to determine simulation input data. The objectives of the simulation were to determine the percent water and acid recovery in the liquid stream and the percent acid recovery in the gas stream at the tested vacuum distillation operating conditions for the CDS. Simulation involved a one stage vacuum flash. The operating conditions included a pressure equal to zero and a temperature between 25-50°C (Figure 1)[2].

Feed Conditions	
Temperature °C	40
Pressure psi	14.69
Volume Fraction	
Chemical	0.04
Water	0.96

Flash Operating Conditions	
Temperature °C	25-50
Pressure psi	0

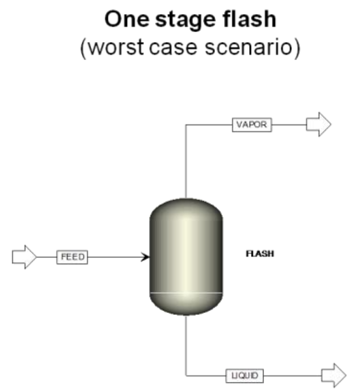

Figure 1. Distillation simulation operating and influent conditions

III. Results and Discussion

A. Laboratory test of pretreatment chemicals

Biochemical changes in urine are indicated by changes in pH. Any change in pH during storage indicates that the urine is not stable, and an increase in pH typically indicates urea hydrolysis. As Figures 2 shows, there was an increase in pH with time in the treated samples.

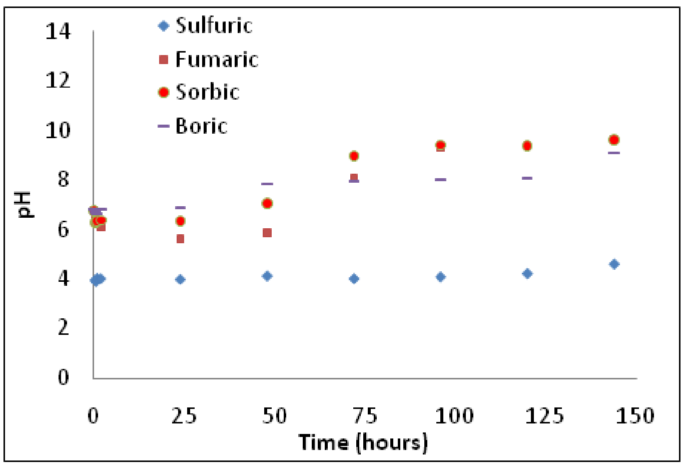

Figure 2. Chemical monitoring data: pH change (7 days)

TSS and turbidity were used to monitor that solid urine constituents remain in the dissolved phase and not form larger solids. An increase in either TSS or turbidity would indicate solid precipitation. Both TSS (Figure 3) and Turbidity (Figure 4) data show an increase with time in the treated samples indicating that all the chemicals were effective at stabilizing the urine for short term storage but not for long term storage.

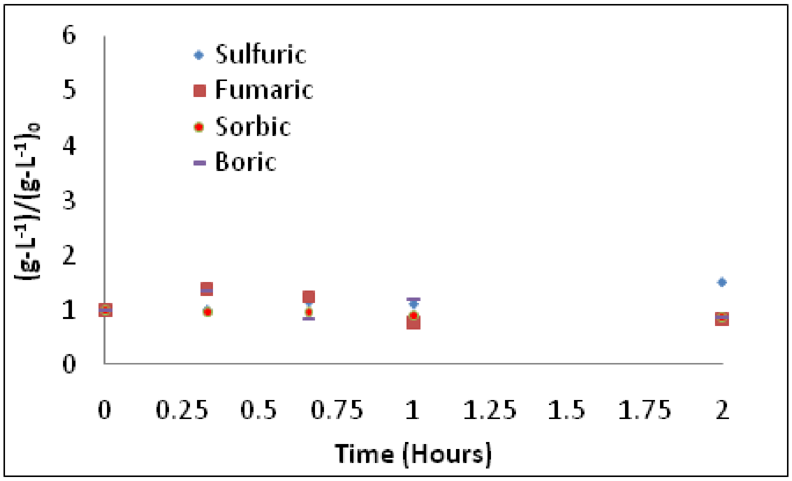

Figure 3. Total Suspended Solids (2 hours)

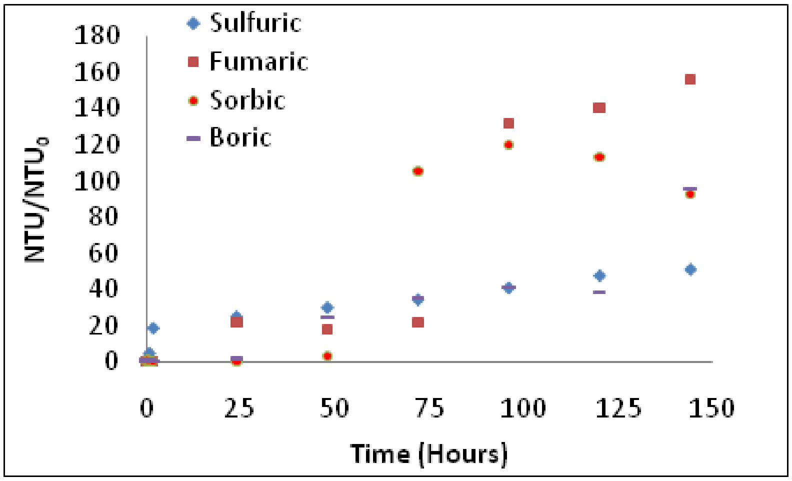

Figure 4. Turbidity (six days)

Ammonia concentration, protein concentration and DO were methods used to determine the presence of biological activity. If an effective pretreatment agent is added, the ammonia (Figure 5) and protein (Figure 6) concentrations will not increase and the urine will remain saturated with oxygen (Figure 7). Hence, a decrease in DO below saturated levels indicates biological activity and ineffective urine stabilization. Protein and ammonia concentration data indicate that the tested chemicals effectively stabilized the urine in the short term but not in the long term. DO data indicate that some biological activity is occurring in the first 2 hours.

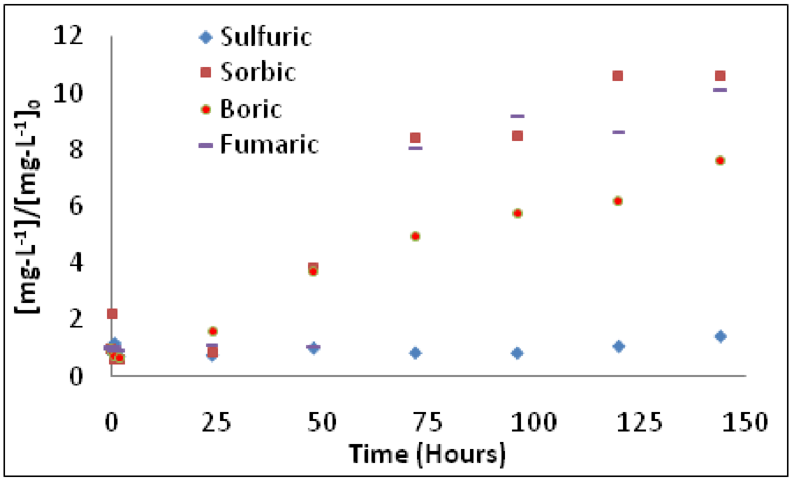

Figure 5. Ammonia concentration (six days)

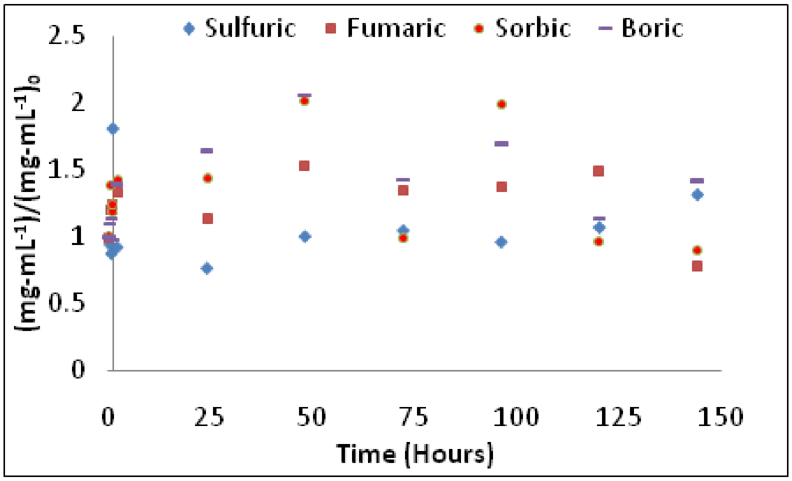

Figure 6. Protein (six days)

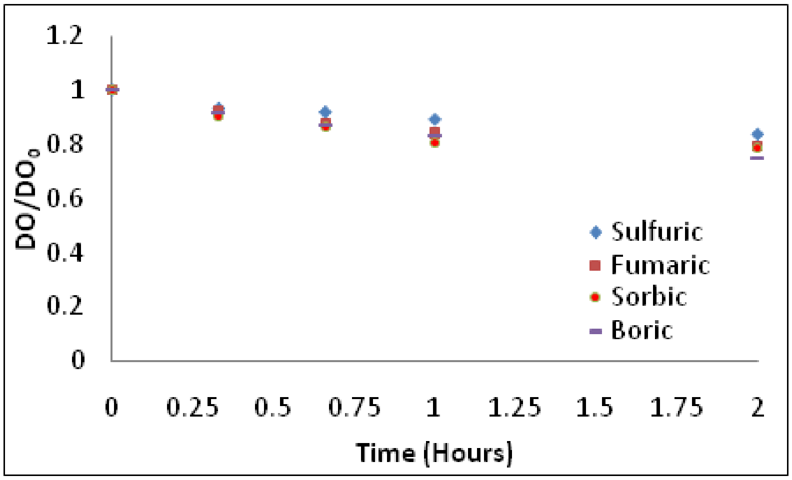

Figure 7. Dissolved Oxygen (2 hours)

B. Simulations

Sulfuric, fumaric, and boric acids were found to be separable from water in the flash operating range of 25-50°C (Table 1). Sorbic acid was not simulated due to program data constraints.

Pretreatment Chemical	Fumaric Acid	Sulfuric Acid	Boric Acid
% water recovery	98.49	96.94	99.97
% chemical recovery	99.59	99.98	81.97

Table 1. Simulation Results

IV. Conclusions

Laboratory tests results indicate that the chemicals tested meet pretreatment requirements for short term storage but not for long term storage. Distillation simulation results show that the chemicals are separable from water in the flash operating range of 25-50°C. Preliminary simulations indicate that a water stream with low percent of acids is possible.

Acknowledgments

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