Fiscal Year:	FY 2008	**Task Last Updated:**	FY 01/13/2009
PI Name:	Sastry, Sudhir Ph.D.		
Project Title:	Reheating and Sterilization Technology for Food, Waste and Water		
Division Name:	Human Research		
Program/Discipline:	ADVANCED HUMAN SUPPORT TECHNOLOGIES		
Program/Discipline--Element/Subdiscipline:	ADVANCED HUMAN SUPPORT TECHNOLOGIES--Advanced life support		
Joint Agency Name:		**TechPort:**	No
Human Research Program Elements:	None		
Human Research Program Risks:	None		
Space Biology Element:	None		
Space Biology Cross-Element Discipline:	None		
Space Biology Special Category:	None		
PI Email:	sastry.2@osu.edu	**Fax:**	FY 614-292-9448
PI Organization Type:	UNIVERSITY	**Phone:**	614-292-3508
Organization Name:	Ohio State University		
PI Address 1:	206 Agricultural Engineering Bldg.		
PI Address 2:	590 Woody Hayes Dr.		
PI Web Page:			
City:	Columbus	**State:**	OH
Zip Code:	43210	**Congressional District:**	15
Comments:			
Project Type:	Ground	**Solicitation / Funding Source:**	2002 Space Biology 02-OBPR-01
Start Date:	07/01/2003	**End Date:**	09/30/2008
No. of Post Docs:	5	**No. of PhD Degrees:**	0
No. of PhD Candidates:	2	**No. of Master' Degrees:**	0
No. of Master's Candidates:	0	**No. of Bachelor's Degrees:**	1
No. of Bachelor's Candidates:	1	**Monitoring Center:**	NASA JSC
Contact Monitor:		**Contact Phone:**	
Contact Email:			
Flight Program:			
Flight Assignment:	NOTE: Received NCE to 9/30/2008 per PI (9/07)		
Key Personnel Changes/Previous PI:	Original contract had a subcontract with Virginia Tech. This was since cancelled, since the graduate student involved departed the university, stalling progress on that component.		
COI Name (Institution):	Yousef, Ahmed (The Ohio State University) Perchonok, Michele (NASA JSC)		
Grant/Contract No.:	NAG9 – 1508		
Performance Goal No.:			
Performance Goal Text:			

Long-duration space missions require high-quality, nutritious foods, which will need reheating to serving temperature, or sterilization on an evolved planetary base. The package is generally considered to pose a disposal problem after use. We propose herein the development of a dual-use package wherein the food may be rapidly reheated in situ using the technology of ohmic heating. We propose to make the container reusable, so that after food consumption, the package is reused to contain and sterilize waste. This approach will reduce Equivalent System Mass (ESM) by using a compact heating technology, and reducing mass requirements for waste storage.
Our objectives are to 1) develop and optimize a reusable container and system for processing food and waste products by ohmic heating; 2) test the device for efficacy in sterilizing plant foods and waste products; 3) test the device for efficacy in reheating packaged shelf-stable foods; 4) test the heating system for efficacy in heating water for crew use, when not being used for heating food; 5) establish the oxygen and moisture barrier requirements for longer-term food storage; and 6) develop procedures and test methods to ensure hermetic seal for thermostabilized food containers.

Our approach will involve the development of a package with two electrically conducting ends and an electrically insulating wall, which will serve as a combination package and ohmic heater. We propose to study properties of food and waste to ensure the appropriate process strategy; study the critical issues of elimination of electrolytic bubble formation and microgravity feasibility; verification via heat transfer and microbiological studies of the efficacy of sterilization; study the potential for using the same technology for heating water for personal use; and study the attributes of the container necessary for long shelf life.

Task Description:

1. Develop and optimize a reusable container and system for processing food and waste products by ohmic heating. This includes Optimization of package and enclosure to minimize ESM Optimization of power input conditions to eliminate gas production. Optimization of current density to eliminate arcing. Optimization for use under microgravity conditions.

2. Test the device for efficacy in sterilizing plant foods and waste products.

3. Test the device for efficacy in reheating packaged shelf-stable foods.

4. Test the heating system for efficacy in heating water for crew use, when not being used for heating food.

5. Establish the oxygen and moisture barrier requirements for longer-term food storage.

6. Develop procedures and test methods to ensure hermetic seal for thermostabilized food containers.

Research will help address the following Critical Path Roadmap Risks and Questions:

Risk No. 38. Crew nutritional requirements may not be met and crew health and performance compromised due to inadequate food acceptability, preparation, processing and storage systems.

38d. What food processing technologies are required when using crops and stored staple ingredients to ensure a system that is nutritious, safe and acceptable?

This study is the first step in developing better quality products. We will conduct informal tests to determine if quality is superior. Indeed, prior experience with ohmically heated products indicates this to be the case. However, the scope of the present project’s deliverables do not allow for Human Subjects testing, and this will have to be left for another project. 38e. What food packaging materials will provide the physical and chemical attributes, including barrier properties, to protect the food from the outside environment, and assure the 3-5 year shelf life?

We are currently working with military grade MRE pouches, which are designed to provide barriers compatible with a 3-5 year shelf life. We fully expect that a sterile product produced under these conditions will meet the shelf-life requirement.

38f. What food packaging will be biodegradable, easily processed, or be lighter in mass than the current packaging, and still provide the physical and chemical attributes including barrier properties to protect the food from the outside environment, and assure the 3-5 year shelf life?

In light of our current work, we believe that this question may be rephrased as:

What food packaging will be reusable, light in mass, still provide the physical and chemical attributes including barrier properties to protect the food from the outside environment, and assure the 3-5 year shelf life?

Risk No. 41. Crew health may be compromised due to inability of currently available technology to adequately process solid wastes reliably with minimum power, mass, volume. Inadequate waste management can also lead to contamination of planetary surfaces.

Specific questions addressed include:

41a. What system will meet the storage and/or disposal requirements for specified missions?

Our study indicates that a system for ohmic heating within packages will enable storage and disposal for long-duration (Mars) missions.

41e. What system will meet the requirements for managing residuals for planetary protection?

Biological residuals may be contained and sterilized within spent food packaging materials, as indicated by our preliminary studies. We expect to address this question further during the coming year.

41i How do partial and microgravity affect biological waste processing?

We will be addressing this subject in part within this study, but cannot verify it without a flight experiment. For the moment, we have been looking into bubble generation within our package/heater system.

41o. What resources are required to manage waste disposal as an environmental risk during long and remote missions (from EH)?

Capability for containment and sterilization is necessary. This capability may be met by reusable food packaging, and our system fits this need. The mass balance on a human being (Hanford and Ewert, 2002) also indicates that the total mass of fecal waste is far smaller than the total food intake. Thus, over time, we would expect a surplus of containers. Those containers not used for waste containment could be reused for packaging of food produced on an evolved planetary base.

41s. How should wastes be handled or stored to avoid perception such as bad odors or unsightly appearance that would adversely affect crew quality or life and consequent degradation in performance?

Our project addresses this issue, since we intend to contain and sterilize human wastes within reused packaging material. Since food packaging is designed with barrier properties in mind, it should be effective in waste containment as well. Our preliminary tests indicate that this is feasible, but further tests in the coming year will verify this finding.

41t. What waste management systems will prevent release of biological material (cells or organic chemicals that are signs of life) from contaminating a planetary surface, such as the Martian surface, and compromising the search for indigenous life?

As discussed above. Our system offers this capability. Once adequately sterilized, the waste can no longer contaminate its environment.

41w. What is the probability that microorganisms in biological wastes such as food scraps or feces could be altered or mutated by the space environment radiation to become harmful or pathogenic? What can prevent this?

Again, adequate containment and sterilization, both of which are being addressed in this project. If waste is sterile, no such problem will exist, and the question will no longer be relevant.

41x. What containment vessels will be sufficient to prevent escape of stored waste at various mission locations such as planetary surfaces or crew cabins?

Containers of the MRE-type will answer such issues. Again, the assurance of sterility and container integrity are key.

Rationale for HRP Directed Research:

Research Impact/Earth Benefits:

The pouch concept has been shown to heat foods uniformly, which is a first step to improved product quality, whether for earth-based processing or for processing harvested products on a planetary base. Further, the pouch shows improved stackability and reduced ESM compared to current heater concepts.
Work on this project has also resulted in the development of a universal cell for determination of microbial inactivation kinetics under alternative processes such as ohmic heating, which has shown that ohmic heating accelerates the inactivation rate of G. stearothermophilus over and above that of heat alone.

The concept of an electrode-equipped pouch is currently being investigated by a private company for potential commercialization as a beverage warming device. We are working with them to help develop the concept further.

Long-duration space missions require high-quality, nutritious foods, which will need reheating to serving temperature, or sterilization on an evolved planetary base. The package is generally considered to pose a disposal problem after use. We developed a dual-use package wherein the food may be rapidly reheated in situ using the technology of ohmic heating. We container was intended to be reusable, so that after food consumption, the package could be reused to contain and sterilize waste. This approach will reduce Equivalent System Mass (ESM) by using a compact heating technology, and reducing mass requirements for waste storage.
The food pouch, made of multilayered laminate was developed for this purpose. The first prototype of the ohmic technology was fabricated by pasting aluminum foil electrodes inside a Meals Ready to Eat (MRE) packet. The pouch had two extended portions of electrode coming out of the top seal, serving as tabs for making electric connection with an external circuit. Three different electrode configurations were tested with a two dimensional heat transfer model using Fluent computational fluid dynamics software (v 6.2, Fluent Inc., Lebanon, New Hampshire). CFD codes with User Defined Functions (UDFs) for electric field equations were used for the transient model. Simulation of the electric field potential inside the pouch concluded that V-shaped electrodes configuration was best out of the three options and had the cold zones reduced to 2% of the cross-sectional area. Tomato soup was successfully heated to the serving temperatures (up to 80°C) inside the V-shaped electrodes pouch.

To improve understanding of heating profile inside an ohmic pouch, a three dimensional model was also developed. The simulated heating pattern was verified by inserting thermocouples inside the pouch and was found to be in good accordance with the actual temperature profile. Details have been described in published work.

The second generation of the ohmic pouch had electrodes coming out through the sides instead of the top seal. Aluminum foil electrodes were changed with stainless steel foil electrodes which eliminated any visible gas production at the electrode-food interface.

An important aspect of the ohmic pouch technology is reuse of the used food pouches to contain and stabilize waste. Depending on the mission protocol waste may be jettisoned or stored. In case of jettison the waste will be stored the appropriate time, for which sterilization of the biological waste should be done to prevent risk of pathogenic outbreak. The ohmic pouch presents a promising solution to this problem by using the used food pouches (which currently accounts for 50% of the total trash dry mass generated on ISS and Shuttles) to contain the remaining waste including biological and sterilize it. A simple mass balance calculation based on the metabolic interface values for crew members [6] suggested that total food dry matter intake (0.617 kg/CM-d solids and 3.909 kg/CM-d water) is more than the potential solid waste load (0.2 kg/CM-d), with the remaining water being recycled. Thus, over time, even when used for waste containment and sterilization, an excess of containers would be available for other uses, for example, containing and sterilizing foods grown on planetary surfaces.

Solid human waste was successfully sterilized inside a V-shaped electrodes pouch with tabs through the sides. The sterilized pouch was stored at normal room temperature conditions for more than 2 years without any visible gas production due to surviving micro-organisms.

A polycarbonate enclosure was developed to facilitate application of external pneumatic pressure during sterilization at temperatures above 100°C. The enclosure also had a provision for water based cooling, to cool the sterilized food (or waste). Separate enclosures are expected to be used for sterilization of food products and waste, for sanitary and psychological reasons.

Task Progress:

The pulsed power supply system was able to minimize gas bubble formation inside the pouch with stainless steel electrodes. A supporting electronic system was also developed to facilitate pulsed ohmic heating (square waves at 10 kHz with a duty cycle of 0.2). Analysis of metal ions such as Cr, Fe, Ni, Mn and Mo (constituents of stainless steel) showed that metal ion concentration in food was below the upper level daily dietary exposure limits.

An uneven heating pattern was not a hindrance for waste sterilization as quality was not an issue, but uniform temperature profile is critical for food sterilization in order to obtain high quality products. Ideally flat and parallel electrodes present a homogeneous electric field resulting in uniform heating of an ohmic reactor. The initial V-shaped electrodes pouch was redesigned into a parallel flat electrode shape to obtain uniform electric field and heating pattern. The pouch thus obtained had rectangular prism geometry. Stainless steel foil electrodes were folded at the top to pass through the top seal. A pouch of dimensions 11.8cm x 10.7cm x 2cm was found best to hold a standard meal of 8 oz. (227 g) at high temperature-pressure conditions. The rectangular prism geometry also improved the stack-ability of the pouches inside a stowage tray.

An inoculated pack study using 107 cfu/ml of Geobacillus stearothermophilus spores (ATCC 7953) in potato soup base was done to validate sterilization. Duplicate samples at four different holding times (0, 6.0, 8.0 and 10.0 min) were taken at a temperature of 121°C. A maximum log reduction of 1.6 obtained at 6.0 min holding time predicted presence of under processed zones and warranted a further investigation of the pouch design.

The error analysis showed that folding of electrode tabs and presence of a triangular prism extending outside cross-sections of the electrodes were the reasons behind under processing. Folding of the electrode tabs brought them closer creating points of low potential difference and subsequently forming cold zones in folded corners. Presence of a triangular prism shaped area outside of the electrodes created cold zones at the non-electrode sides of the pouch.

Zones of underprocessing from a rectangular prism geometry pouch were finally removed by sealing of the shoulder flaps, thereby eliminating the triangular prism part and forming a flat portion on non-electrode sides. Two slide-in tabs were integrated at the backside of electrodes on outer part of the pouch. An electrical connection between the electrode and tab was made through the laminate material instead of passing via seal. Theoretically, the rectangular prism geometry with slide-in tabs removed all zones of uneven heating possible inside an ohmic pouch. The new tab design made the pouch compatible to a slide-in type enclosure. This greatly improved ease of placing the pouch in the enclosure and removal after the end of treatment. The pouch showed minimal deformation at 145°C (under 45 psi) and at 90°C (at atmospheric conditions). This pouch design and method of connection has been disclosed as an addendum to our original invention disclosure. The concept is currently under consideration for commercialization by an external company.

Sterilization of food was tested through an inoculated pack study using tomato soup with 107 cfu/ml of Geobacillus stearothermophilus spores (ATCC 7953), for which the generally reported D-values are 20 times more than that of Clostridium botulinum spores. A log reduction of 3.65 obtained at 130°C for a holding time of 2 minutes confirmed a kill equivalent to commercial sterilization.

A lighter version of the ohmic technology for food warming was developed and compared with the existing suitcase type food heater currently used by NASA. Equivalent system mass (ESM) for the ohmic system (without accounting for the reusability feature) was much lower (839 kg) than the suitcase type heater (3475 kg) for the Mars Transit Vehicle of the Independent Exploration Mission. ESM of the ohmic technology for the Orion spacecraft (CEV) of the Near-Term Exploration Mission was calculated to be 89 kg.

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