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January 7, 1985

Mr. Daryl W. Chilcutt
Contracting Officer
R & T Procurement Branch
NASA-Johnson Space Center
Houston, Texas 77058

Dear Mr. Chilcutt:

Enclosed is the final report for contract NAS 9-11676.

Very truly yours,

Larry C. Witte

Larry C. Witte, Ph.D.
Professor of Mechanical Engineering

LCW/cw

Enclosure

cc: Susan Rhodes, UH OSP

(NASA-CR-171841) CHARACTERIZATION OF HEAT TRANSFER IN NUTRIENT MATERIALS Final Report, 30 Apr. 1971 - 31 Dec. 1984 (Houston Univ.) 6 p HC A02/MF A01 CSCL 06H

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FINAL REPORT

CHARACTERIZATION OF HEAT TRANSFER IN NUTRIENT MATERIALS

Contract NAS 9-11676
(4-30-71 to 12-31-74)

to

Department of Mechanical Engineering
University of Houston
University Park
Houston, TX
77004

from

NASA-Johnson Space Center
Bioengineering Systems Division
Houston, TX
77058

Larry C. Witte
Larry C. Witte
Professor of Mech. Engineering

Project Director

FINAL REPORT

NAS 9-11676

INTRODUCTION

This is the final report for NASA Contract NAS 9-11676 which supported technical activities related to the processing and storage of foodstuffs in zero-g environments such as the Skylab and the Shuttle. The contract began April 1, 1971 and ended Dec. 31, 1984. The project was directed by Dr. Jimmy E. Cox until 1980 when he left the University for a position in private industry. From 1980 to the present, the project has been under the direction of Dr. Larry C. Witte.

TECHNICAL ACTIVITIES

When the contract was initiated, the major thrust was to identify potential problems that would inhibit the efficient heating of foodstuffs in a zero-g, low pressure environment. Problems related to the lack of buoyancy currents in zero-g were identified and examined. The results of these studies provided input to industrial designers who were developing the hardware for food systems for Skylab and Shuttle.

Another major effort during the early years of the contract was to catalog and critique the thermophysical properties of various foodstuffs so that the most accurate properties could be used in heat transfer analyses of food-heating devices. During this period, several MS students examined various aspects of heating food in zero-g environments. Several reports were written that reflected the cumulative efforts of students and project directors during that period. These are listed in the next section.

Later in the contract, attention was directed toward the low-temperature storage of biological samples as well as foodstuffs during Shuttle flights. Various proposed systems for providing on-board refrigeration were examined. Eventually, a vapor-compression refrigerator was flown aboard the Shuttle and proved to be adequate to maintain small samples of foodstuffs in a stable, low-temperature state.

All during the contract, Dr.'s Cox and Witte provided technical consultation to the Project Monitors regarding vendor designs for zero-g food heating and storage systems.

PUBLICATIONS

The publications resulting from the contract are listed below:

Literature Papers-

1. "The Thermal Preparation of Foods in Space Vehicle Environments", R.B. Bannerot, C.K. Chen, N.D. Heidelbaugh, and J.E. Cox, presented at the 44th Annual Meeting of the Aerospace Medical Association, Las Vegas, May, 1973.

2. "Heating of Foods in Space Vehicle Environments", R.B. Bannerot, C.K. Chen, N.D. Heidelbaugh, and J.E. Cox, ASME paper 73-WA/HT-75, ASME/WAM, Detroit, Nov., 1973.

3. "Thermal Preparation of Foods in Space-Vehicle Environments", R.B. Bannerot, C.K. Chen, N.D. Heidelbaugh, and J.E. Cox, Aerospace Medicine, Vol. 45, No. 3, March, 1974, pp. 263-268.

4. "Thermophysical Properties of Foodstuffs", L.C. Witte, Y.T.E. Cheng, and J.E. Cox, ASME paper 76-HT-59, National Heat Transfer Conference, St. Louis, Aug., 1976.

MS Theses-

1. "A Study of the Effects of Cyclic (on-off) Heat Fluxes on Canned Food Heating Times During Skylab Space Flights", M.R. Mathias, MS Thesis, University of Houston, Department of Mechanical Engineering, 1972.

2. "Thermophysical Properties of Foodstuffs", Y.T.E. Cheng, MS Thesis, University of Houston, Department of Mechanical Engineering, 1974.

3. "Characterization of Heat Transfer in Nutrient Materials with Forced Convection Utilizing Convection Oven Design", B.C. Trivedi, MS Thesis, University of Houston, Department of Mechanical Engineering, 1976.

Reports-

1. "Characterization of Heat Transfer in Nutrient Materials", Report No. NAS9-11676-23, J.E. Cox, R.B. Bannerot, C.K. Chen and L.C. Witte, University of Houston, March 31, 1973, 66 pages.

2. "Characterization of Heat Transfer in Nutrient Materials", Report NAS9-11676-32, J.E. Cox, R.B. Bannerot, C.K. Chen and L.C. Witte, University of Houston, December 31, 1973, 66 pages.

3. "Characterization of Heat Transfer in Nutrient Materials", Report NAS9-11676-45, Y.T.E. Cheng, J.E. Cox and L.C. Witte, University of Houston, January 31, 1975, 110 pages.

4. "Characterization of Heat Transfer in Nutrient Materials", Report NAS9-11676-46, Y.T.E. Cheng, J.E. Cox and L.C. Witte, University of Houston, February 28, 1975, 118 pages.

Additional data and reports of technical activities can be found in the monthly reports that have been filed during the contract period.

FUTURE RESEARCH AND DEVELOPMENT REQUIREMENTS RELATED TO FOOD PREPARATION AND STORAGE ON THE SPACE STATION:

Considerable experience has been gained during the US space program about providing nutritious food to space travelers. From Apollo, Gemini, Skylab and the Shuttle, we have learned that we can indeed provide foodstuffs to astronauts that will nourish them up to several months.

The proposed Space Station opens new opportunities for man to stay in space for longer times than he has before. He will be able to conduct experiments in space, to observe the stars as never before, and to gain experience related to weightlessness that will tell us more about how the human body and mind work. However, he can only do this if he is healthy and enthusiastic about his activities. Nutritious and tasty foods will help astronauts maintain health and enthusiasm.

Although helpful, what we have learned about food preparation and storage during space activities so far will not be sufficient for the design of food systems for a Space Station. The Space Station will be much bigger than any system that has flown in space so far. It will remain in space for several years, so that on-board systems must stay in place and function for much longer lifetimes than those on the Shuttle or even the Skylab. More personnel must be fed, their tastes in food will probably be more diverse, and different modes of food preparation and storage might be required. Life in space should be made to resemble life on Earth as much as possible; one way to do this is to provide menus that are comparable to what one might have access to on Earth.

Currently most foodstuffs for astronauts are prepared on Earth, packaged and then heated or rehydrated for consumption. In more recent flights of the Shuttle, a freezer system has been available and ice cream has been provided. But the variety of foodstuffs is very limited at present. Green vegetables, fresh fruits, and many other types of food have not been provided because of transportation, storage and weight problems. Some prepackaging of foods will no doubt be desirable for the Space Station as well, but it is expected that when menus are expanded for palatability, alternative-means of food preparation must be provided.

Eventually, foods may be grown on-board the Space Station, which will require cooking of raw foodstuffs with the attendant problems. One of these problems will be the rate at which heating will be done; foods must be cooked fairly rapidly, otherwise they dry out and lose their nutritional value and flavor

In the absence of gravity, convection currents are not present so forced convection ovens and microwave ovens might be likely candidates for food preparation. Microwave ovens seem to be very desirable for such an application since they deposit heat directly in the material to be heated. There would be no appreciable heat loss due to convection during microwave heating so that heating should be more efficient and thus faster in zero gravity than in earth gravity. Forced convection ovens are commonplace and their operation in zero gravity would not appreciably differ from that in earth gravity. Matching the power requirements of forced convection and microwave ovens to that available in the Space Station would seem to be the only problem of note.

Many raw foodstuffs are cooked efficiently when immersed in boiling water. In zero gravity, however, the water would not stay in contact with either the heater or the foodstuffs that are being cooked. Assuming that this technique would be advantageous for processing food in space, the question is whether it can be adapted for zero gravity environments. One means of doing so would be to design a variation of the "pressure cooker"; i.e., an enclosed system containing water at a pressure elevated over the cabin pressure. This would not only contain the water but also create a higher boiling temperature; the latter would speed the cooking process. A device would be required to insure good contact between the saturated water and the cooking foodstuffs. A mechanical device or perhaps an acoustic or magnetic stirring system could be adapted for such a system. For best operation, the system should be operated a few degrees below the boiling temperature at the existing pressure. Then no pockets of vapor would be developed from active boiling sites in the system.

Frozen food retains its flavor and nutritional value for reasonably long periods of time. Frozen food, regardless of whether it is launched or whether it is grown onboard the Space Station and frozen there, requires a freezer system.

Vapor compression systems provide reliable and efficient refrigeration; because of its attractiveness, such a system has been developed for Shuttle flights. Ice cream has been launched and maintained in its frozen state satisfactorily on the Shuttle. However, the volume of freezer space for the Shuttle system is on the order of 1-3 cubic feet, but the requirements of the Space Station might be 10 to 20 times as much. When vapor compression systems are scaled up the flow dynamics in the condenser and the evaporator must be carefully scaled as well. If the flow passages are not sized properly, liquid and vapor tend to collect in the condenser and evaporator, respectively, and cooling capacity might be severely restricted. Research related to the proper operation of vapor compression refrigeration systems in zero gravity environments is needed.

Potential Problems for the Space Station:

1. Higher energy and power use for food preparation and storage.
2. Microwave baking and other methods for preparing foods.
3. Different methods for food storage, including vapor compression refrigeration on a larger scale.

SUMMARY

This final report for NAS 9-11676 contains a summary of the data and technical activities generated under the contract as well as some projected needs for future larger space vehicles such as the proposed Space Station.