APPLICATIONS OF MICROWAVE AND RADIANT ENERGIES FOR FREEZE DEHYDRATION OF MEATS

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INTRODUCTION

MEATS are among the most difficult products to freeze dry using conventional processing. Their sensitivity to thermal degradation and low thermoconductivity limits the rate of dehydration and as a consequence, the processing times are lengthy and the costs are high. However, the advantages inherent in the simplified handling and storage of freeze dried foods have made it worthwhile to consider alternate methods for freeze dehydration.

It is well known that conventional freeze drying is limited by the rate at which heat can be conducted through the dried layer to the sublimation zone (1,2). For example, a 12 mm thick steak requires 12 to 15 hours to dehydrate.

A variety of methods have been explored in attempts to accelerate the drying rate. Of these methods, the use of microwaves, which generate heat within the frozen core, has been proven to be most successful. Jackson et al (3) demonstrated the potential of this process by reducing the drying time for sliced pears from 18 to 2 hours. Later attempts by Copson (4) and Copson and Decareau (5) proved that similar rates of drying could be obtained through the use of microwaves, but as in Jackson's work, they also encountered many difficulties in implementing the process.

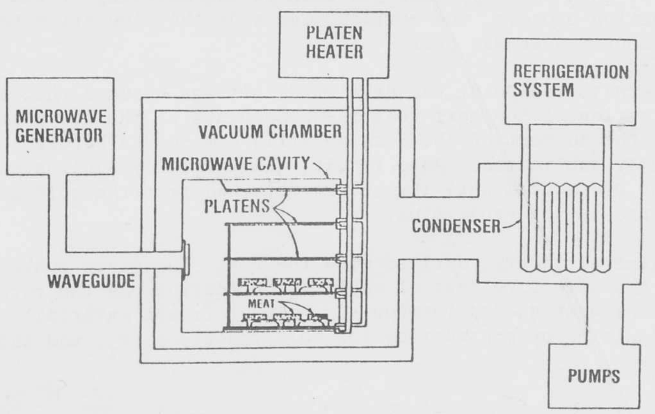
It was reported that the transmission of microwave power into low pressure environments was the cause of many of the problems. Under pressures normally encountered in freeze drying (.4 - .2 mm Hg) ionization or breakdown of the surrounding gas is triggered at low power levels, preventing transmission of power into the cavity. It has been found (6) that the breakdown electric field limit can be raised substantially by lowering the cavity pressure to below .1 mm Hg.

During the past 10 years at the US Army Natick Research and Development Command, a continuing research effort has been pursued in attempt to solve many of the problems that have inhibited the progress in developing the microwave freeze drying process.

In the first phase of the work, Ma and Peltre derived a theoretical description of the transient energy and mass transport processes encountered in microwave freeze drying (7). To test the theory, a series of experiments were performed on a small capacity (70 g) microwave freeze dryer (8).

This paper gives a summary of some of the more important aspects of the recent work including the analysis of data obtained from the operation of a large capacity microwave and radiant freeze dryer which has led to a substantial change in our understanding of the sublimation process.

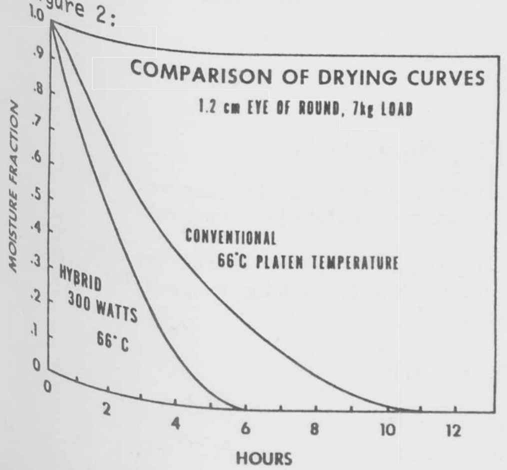
Figure 1: SCHEMATIC OF MICROWAVE-FREEZE DRYER



EXPERIMENTAL SYSTEM

THE CONFIGURATION of the experimental apparatus is shown in fig 1. The freeze dryer is basically a conventional system modified to facilitate utilization of the microwave power. This required installation of the coaxial cable through the bulk panel and constructing a screened microwave cavity which contained heating platens. Typically, the hybrid system processes a load of 7 Kg with a maximum input microwave power level of 400 watts and a platen temperature of 66°C. The average pressure during a run was .030 mm Hg which was maintained with a -50°C condenser temperature. Temperatures and pressures are monitored throughout the system while the weight of the bottom layer of product was recorded.

Figure 2:



EXPERIMENTAL RESULTS

THE PERFORMANCE of the system can be best illustrated through a comparison of the drying curves for a conventional and hybrid system. These curves, shown in fig 2, taken from the experimental freeze drying of 13 mm roast beef steaks, indicate that a minimum cycle of 12 hours was needed for conventional dryer operating with a platen temperature of 66°C. The hybrid system operating with an identical platen temperature and a microwave power input of 300 watts accomplished the drying in 6 hours. While the improvement in drying times was significant, the overall performance of the freeze dryer proved to be even more interesting.

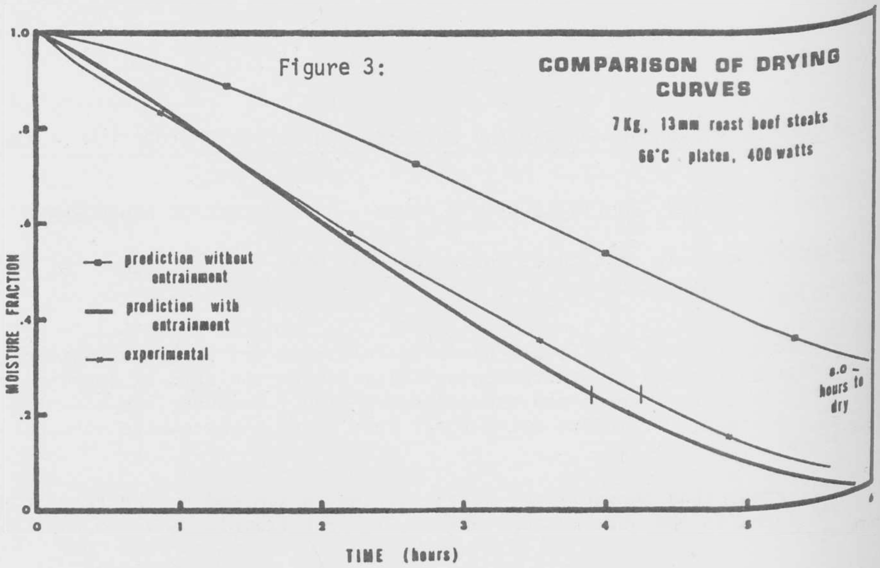


Figure 3: COMPARISON OF DRYING CURVES

A comparison, given in fig 3, of the data to the Ma-Peltre model of microwave freeze drying modified with a radiant boundry condition, indicated that dehydration was occurring at a faster rate than predicted, based on the energy input to the system. Such evidence would suggest that the energy required to remove the ice was reduced.

Another characteristic of the freeze drying process that appeared unusual was the effect of load size and power level on the drying time. It would be expected that the drying time would be improved with higher power levels and smaller loads. The operational surface given in fig 4, compiled from the collected data, indicated that within the range of conditions tested, the minimum drying time occurred with a 6 Kg load at 300 watts power.

DISCUSSION OF RESULTS

THE APPARENT REDUCTION in the heat of sublimation is the most difficult aspect to explain within the context of the current theories of freeze drying. Such an occurrence leads to the reassessment of the assumptions regarding the sublimation process.

Recent observations made by Luikov (9), in a study of low pressure sublimation, it was noted that a sizeable quantity of ice crystals accompanied the water vapor flux. The presence of unsublimated material in the vapor stream would tend to reduce the amount of energy required to remove the frozen core. Luikov suggested that the extent of entrainment was related to the velocity of the exiting flux, or in other words, that the phenomina was a result of a stripping effect of the high velocity vapor jet. It was found, however, when this approach was used in the modeling of the sublimation process, the correspondence of the simulation to the experimental data was poor.

An alternate viewpoint was developed. It was assumed that the vaporization of the most volatile components of the ice phase erodes the support of the less volatile components before these are fully sublimated. As a result, the partially sublimated regions of reduced activity become detached from the bulk and are entrained in the vapor flux.

In a general theory, derived with the reasoning given above, (10), the effective heat of sublimation (defined as the total amount of heat needed to remove a mole of frozen material), can be calculated by considering the mole fractions, X_i, and the

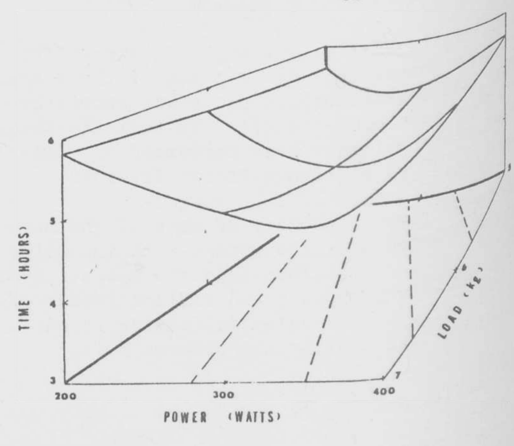
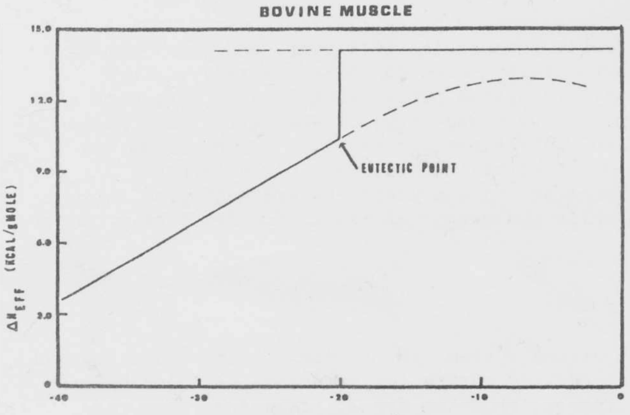


Figure 4: EXPERIMENTAL DRYING TIME TO .10 MOISTURE FRACTION

Figure 5: EFFECTIVE HEAT OF SUBLIMATION FOR BOVINE MUSCLE



vapor pressures P_i^o.

$$\Delta H_e = Q_T/N_T = \sum_i \Delta H_i \, x_i \, P_i/P_1$$

Here the subscript (i) denotes the component and (1) is assigned to the most volatile component.

When this definition is compared to the expression for the heat of sublimation for a homogenous solid with uniform activity.

$$\Delta H_s = \sum_i \Delta H_i \, x_i \, P_i/P_T$$

It is apparent that

$$\Delta H_e = \Delta H_s \; P_T/P_1$$

which simplifies the calculation of the effective heat of sublimation in the case of meat.

$$\Delta H_e = \Delta H_{s,meat} [P_{meat} / P_{pure\ ice}]$$

Because of the ratio of pressures in the definition, the heat of sublimation becomes a strong function of temperature as can be seen in fig 5.

The introduction of entrainment into the theory of the freeze drying process alters the coupling of the mass and energy balance in the dried layer to the equation of energy in the frozen core. As a result, the propagation of the sublimation interface is modified.

Referring back to fig 3, the effect of the addition of entrainment in the overall description of the process can be noted. As in the data, the simulation indicates the drying rates in the initial stages are most rapid. During this phase of the process, the interface temperature is at a minimum, substantially reducing the energy required to remove the frozen core.

In order to dehydrate most efficiently, it is necessary to maintain a low chamber pressure, thereby keeping the core temperature as low as possible. However, during processing, the diffusional resistance of the increasing dry layer causes the interface temperature to rise during the process. When the temperature passes through -20°C, the salt phase melts and entrainment stops. This results in a rapid increase in the energy required for vaporization and with a constant power input the drying rate slows proportionally. The simulation indicated that the core temperature reached -20°C in the 400 watt run at about 3.5 hours while with 300 watts the melting was delayed to about 5 hours. The subsequent rise in the effective heat of sublimation leads to a tailing of the drying curve apparent in the higher powered runs which can extend the cycle time.

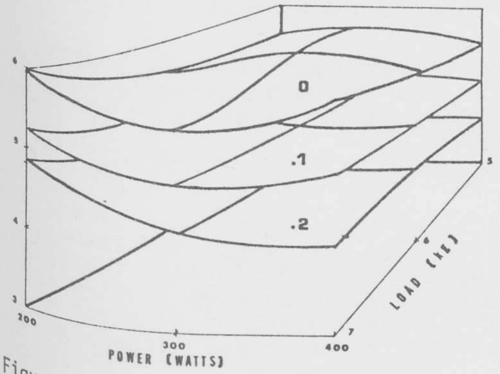


Figure 6: **SIMULATED DRYING TIME .2, .1, 0 MOISTURE FRACTION**

A performance surface was generated by the simulation and as can be noted in comparing figures 6 and 4 resulted in similar predictions. The trough of minimum drying times followed the lines of constant specific power, (defined as Kw/Kg, and is represented by the dashed lines in the drawing of the experimental surface). However, the curvature of the theoretical surface is less and appears to be shifted slightly to the left.

CONCLUSIONS

BY MAINTAINING a low chamber pressure and taking advantage of the entrainment phenomena, it has been found that acceptable drying rates can be obtained at relatively low power levels. This changes the emphasis in design of a hybrid system from one that is capable of high power microwave operation to one that can sustain a low pressure. The latter approach reduces the costs involved in the upgrading conventional freeze dryers since fewer modifications are needed.

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