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PERFORMANCE EVALUATION OF HEAT PIPE GRIDDLE

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INTRODUCTION

A heat pipe is a superthermal conductor that transmits heat by evaporation and condensation of a working fluid. It has three basic elements: a hollow tube (or chamber), a capillary wick structure, and a working fluid. The wick structure is attached to the inside wall of the tube and is saturated with working fluid. The whole assembly is evacuated and hermetically sealed.

The working fluid is in equilibrium with its vapor phase at pressures corresponding to temperature. In the working temperature range, heating the evaporator section of the heat pipe vaporizes fluid. The hot vapor moves to the cooler working surface where heat is transferred to the load, condensing the vapor. The liquid is then drawn back to the evaporator section by the capillary wick structure to continue the cycle.

The development of a stainless steel griddle based on heat pipe vapor chamber design (instead of a metal tube), and used for surface cooking, was first reported by Basiulis (1973). In that version Dowtherm A (Anon. 1979a), which operates just below atmospheric pressure in the range of cooking temperatures, was selected as the working fluid, stainless steel 304 as the chamber material, and woven (60 mesh) stainless steel metal screen as the wick material. The bottom inside wall of the griddle chamber, covered with the wick material, functioned as an evaporator, while the top of the griddle chamber functioned as a condensor. Temperature controls and a pressure sensing bellows system (for positive protection) were also developed with the first stainless steel heat pipe griddle. Natural gas or liquid fuel was used as the heat source.

Subsequently, a number of heat pipe griddles using electricity as the heat source were manufactured and sold (Anon. 1979b; Cummings 1978).

The Natick Research and Development Command was requested by the DOD Food Service Facility and Equipment Board to conduct a performance evaluation on the heat pipe griddle. It should be noted that in selecting food service equipment there are other factors, such as initial

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costs, safety, and maintenance that have to be taken into consideration. These factors have not been included in the scope of this evaluation.

EXPERIMENTAL

Griddles Used for Evaluation

One stainless steel heat pipe griddle, 36 X 24 in., without a capillary wick structure, rated at 12 kW, with solid-state electronic sensing thermocouple for temperature control and adjustment, and using electricity as the heat source, was evaluated. One commercial electric griddle of the same size, 36 X 24 in. rated at 16.2 kW was used for performance comparison. The commercial electric griddle employed four Calrod heating units clamped to the bottom of the cooking surface and had four independent temperature control zones and four signal lights. The cooking surface was made of polished steel of ½-in. thickness.

RESULTS AND DISCUSSION

Energies Required to Heat Up and to Maintain Temperature

The heat pipe griddle and the commercial electric griddle were measured for the energy to heat from ambient temperature (68°F) to temperatures of 250°F, 300°F, 350°F and 400°F. The energy required to maintain each temperature without load was also determined. Results are shown in Table 1, indicating that the heat pipe griddle needs 33% longer time and 21% more energy to heat up than the commercial electric griddle. However, the heat pipe griddle requires 15% less energy to maintain a specific temperature.

Temperature Distribution Over the Cooking Surface

The griddle surface temperature uniformity was measured using 28 B&S gage copper-constantan thermocouples cemented to the cooking surface (Schoman 1960) using Dow Corning's Silastic 731 TRV adhesive. As shown in Fig. 1, 16 thermocouples at 16 points were used.

The commercial electric griddle had a uniformity of ± 30°F. Four isothermal areas of the commercial electric griddle can be identified as shown in Fig. 2. They are:

I — temperature over 410°F, center area of the griddle
II — temperature between 400 to 410°F, area outside of Area I
III — temperature between 390 to 399°F, area outside of Area II
VI — temperature below 390°F, four corners and one edge of griddle

Table 1. Energy required to heat up and to maintain griddle temperature without food load

	Heat Pipe Griddle (12 kW)				Commercial Electric Griddle (16.2 kW)			
Thermostat Setting ⟶	250°F	300°F	350°F	400°F	250°F	300°F	350°F	400°F
1. To Heat up:								
Time, Minutes: Seconds	6:53	7:56	10:57	12:21	5:10	6:21	7:36	9:29
Energy, kWh	1.55	1.91	2.25	2.72	1.23	1.57	1.91	2.30
2. To maintain one hour:								
Energy, kWh	0.88	1.26	1.62	2.08	1.07	1.45	1.96	2.39

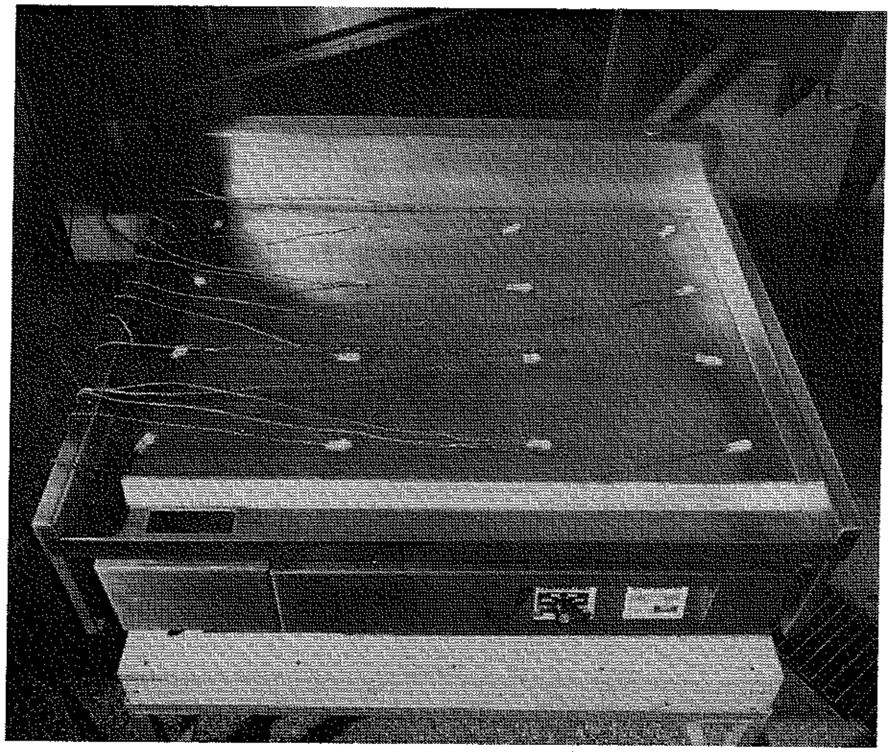

FIG. 1. MEASUREMENT OF TEMPERATURE DISTRIBUTION OF HEAT PIPE GRIDDLE

To determine if the temperature distribution pattern shown in Fig. 2 for a commercial electric griddle was typical, a smaller griddle (24 × 24 in.) was measured with the thermostat set at 400°F. Basically, the temperature distribution of both griddles was the same; both showed four isothermal areas with hot areas in the center and cold areas around the four corners and one edge of the griddle surface.

The temperature uniformity of the heat pipe griddle set at 400°F is shown in Fig. 3. A temperature spread of ± 5.5°F was observed over the entire surface. For all practical purposes, it represents only one isothermal area.

Griddle Temperature Cycling

To better understand griddle temperature cycling, the temperature of a typical and representative point on the surface of each griddle tested

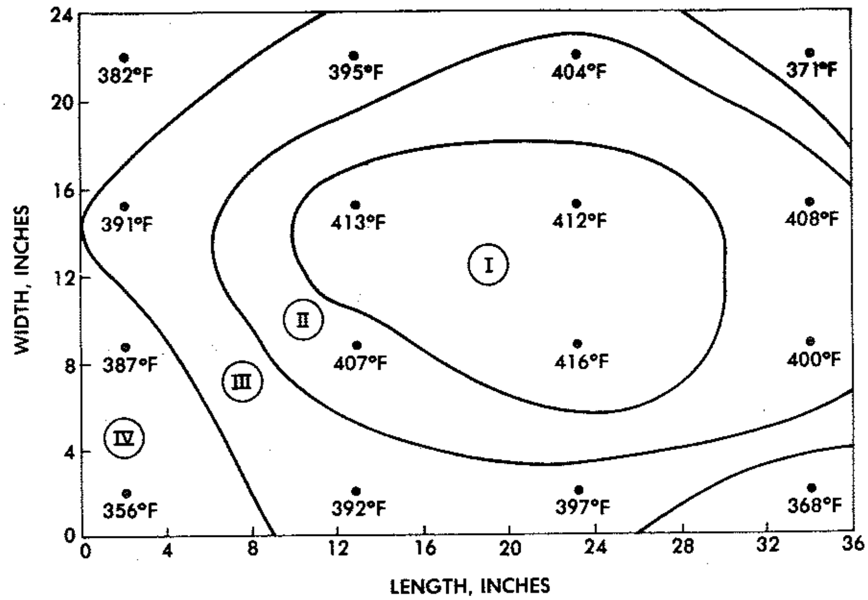

FIG. 2. CONVENTIONAL ELECTRIC GRIDDLE — TEMPERATURE DISTRIBUTION THERMOSTAT SETTING: 400°F

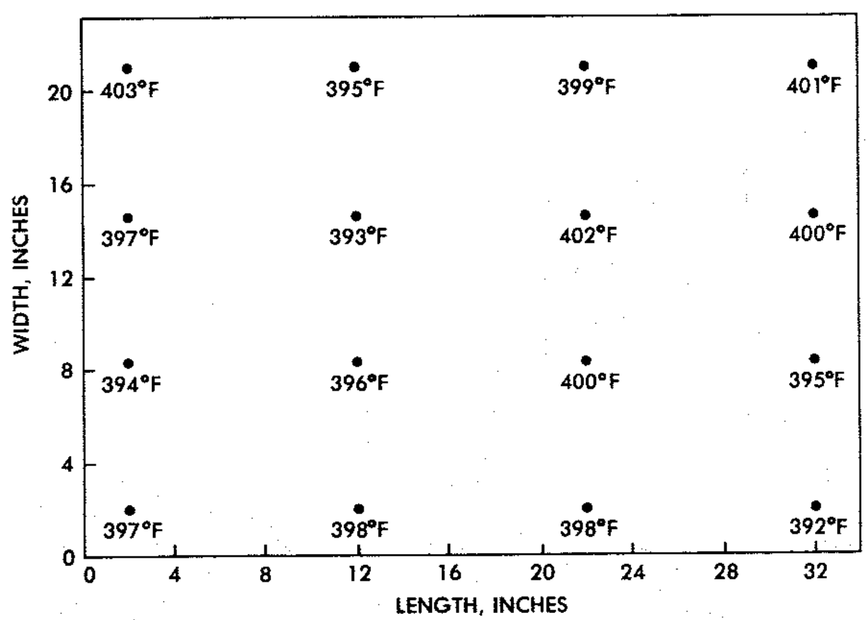

FIG. 3. HEAT PIPE GRIDDLE — TEMPERATURE DISTRIBUTION THERMOSTAT SETTING: 400°F

was followed. The pattern is shown in Fig. 4 with the thermostat set at 350°F. During the period of heating, the temperature of the heat pipe griddle overshot the 350°F thermostat set point by 15°F while the commercial electric griddle overshot by 65°F. Furthermore, the temperature fluctuation of a single point on the heat pipe griddle was ± 5°F while that of the conventional electric griddle was ± 10°F.

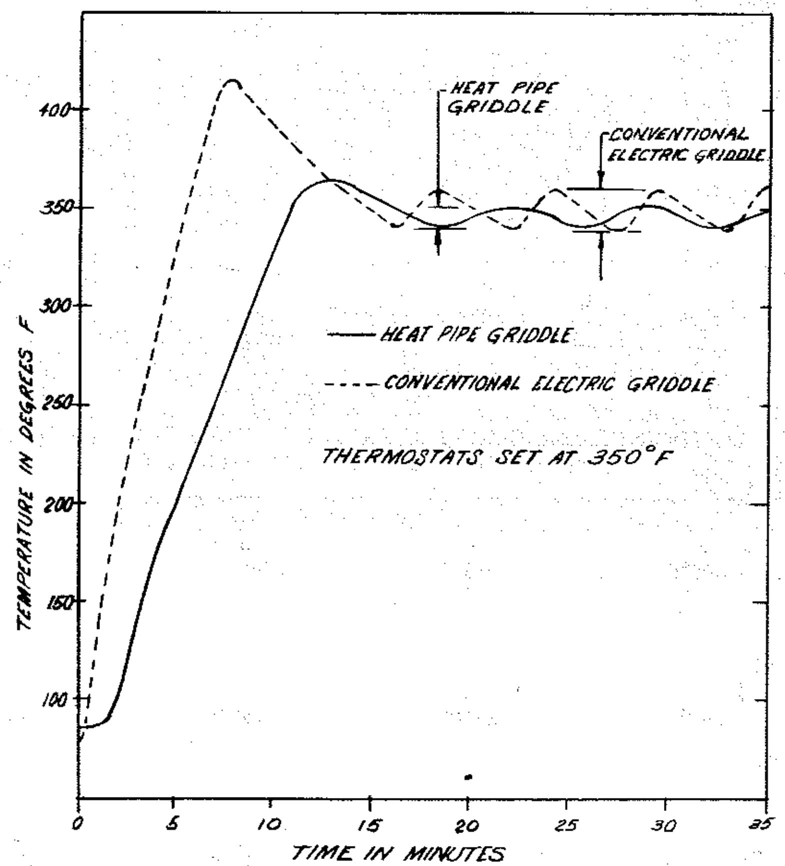

FIG. 4. GRIDDLE HEATING, START-UP AND CYCLING

There was a pronounced delay after the heat pipe griddle was turned on before its surface began to heat up. This was caused by the lack of direct thermal contact between the heating elements and the cooking surface. Also, in a heat pipe griddle, a quantity of heat has to be absorbed by the working fluid, amounting to 128 BTU/lb (latent heat of evaporation of Dowtherm A), before the heat transfer can take effect on the griddle surface.

Cooking Foods

Pancakes and frozen hamburger patties were cooked both on the heat pipe griddle and on the commercial electric griddle. The pancake batter was prepared from pancake mix regular Type II, Class 2, Style C, as listed in Federal Specification (Anon. 1978a). The hamburger patties were prepared according to USDA Specification for Frozen Ground Beef (Anon. 1978b). The cooking procedures are summarized in Table 2, and the cooking of pancakes is shown in Fig. 5.

Table 2. Cooking procedures for heat pipe and commercial griddles

Factor	Product: Pancakes	Product: Frozen Hamburger Patties
Griddle surface temperature	375°F	400°F[1]
Griddle surface preparation	Oil lightly between batches	Scrape the surface clean between batches
Number of products in one batch	20 pancakes per batch	30 patties per batch
Weight of product	Approx. 60 g batter per cake	Approx. 68 g per frozen patty
Cooking time for one batch	Approx. 3 min, 8 s (2 sides of pancakes)	Approx. 8 min, 45 s (2 sides of hamburger patties)

[1] Note: the grilling temperature of 400°F was selected because the frozen hamburger patties were used without tempering. High grilling temperature shortens grilling time and avoids stewing effect of lower temperature

Pancakes were uniformly brown cooked on the heat pipe griddle, using first on/first off procedures. Frozen hamburgers also were uniformly done. No difficulties were experienced in cooking on the heat pipe griddle.

On the commercial electric griddle, pancakes cooked on the four corners, first on/first off, were distinctly lighter brown than those in the center. When the procedure was changed to first on/last off (batter was dropped on colder areas first and removed last), the color was satisfactorily uniform. Similarly, following the procedure, first on/first off, hamburger patties on the corners (cold spots) were rare and those on the center (hot spot) were well-done. Changing to first on/last off loading from the cooler to the hotter areas of the griddle surface, hamburgers were uniformly done.

The energy consumption in cooking pancakes and frozen hamburger patties is shown in Table 3. Results show that there was an energy savings in cooking food on the heat pipe griddle compared with the commercial: 20 Wh savings per batch of pancakes and 170 Wh savings per batch of hamburger patties. This amounts to 7 to 14% energy savings.

FIG. 5. COOKING PANCAKES ON HEAT PIPE GRIDDLE

Table 3. Energy consumption in cooking foods

	Heat Pipe Griddle	Conventional Electric Griddle
1. Cooking pancakes — Energy/Batch of 20 cakes	0.27 kWh	0.29 kWh
2. Cooking frozen hamburger — Energy/Batch of 30 patties	1.05 kWh	1.22 kWh

Needless to say, the total amount of energy saved depends on the quantity of food cooked each day.

Griddle Power Cycling

During these evaluation tests the importance of power cycling on the energy consumption data of cooking foods was realized, especially with pancakes with their very short cooking time.

A simplified Temperature/Power Cycling curve is shown in Fig. 6. As the falling griddle temperature reaches the lower limit of the thermostat control band, the heater is turned on. Due to thermal capacity and time

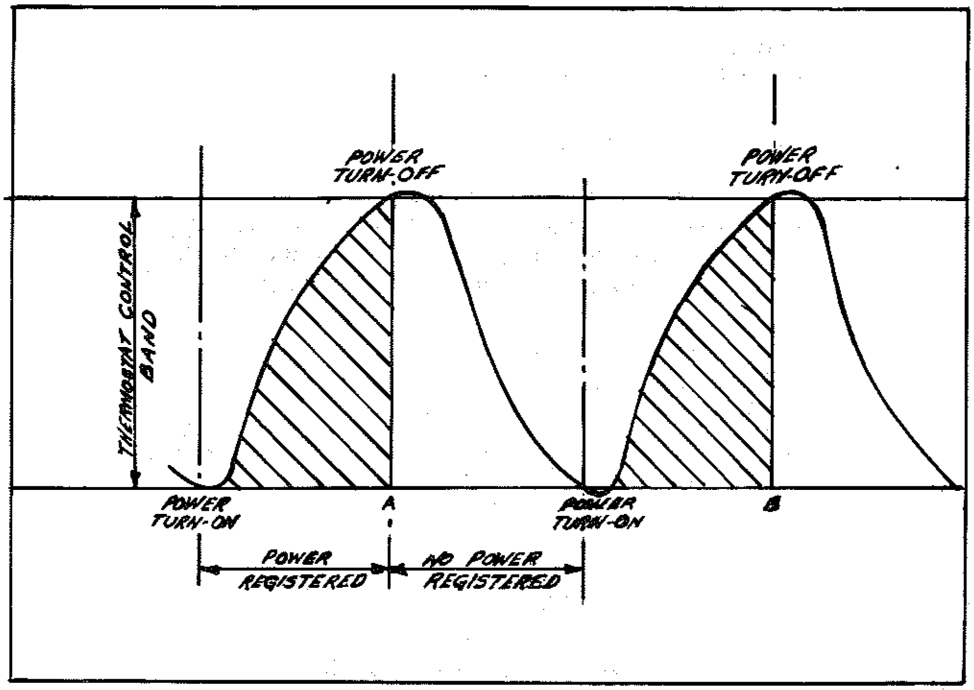

FIG. 6. A TYPICAL POWER CYCLING CURVE

lag, the griddle temperature drops slightly further before increasing. The temperature then increases at a decreasing rate (exaggerated in shaded area of Fig. 6) until the upper control limit is reached. The thermostat turns power off; the temperature coasts slightly higher before falling in a decreasing rate (clear area in power cycle of Fig. 6). A load on the griddle may lengthen the power part of the cycle and/or shorten the no-power part. The time required for cooking does not usually correspond with this cycle. The griddle at the end of the cooking time is not in the same thermal condition as at the start. Figure 6 represents the temperature swings that would be produced by "square waves" of energy.

To assure close correspondence of initial to final thermal conditions of the griddle, cooking tests were started (packing the product on the griddle batchwise) when the thermostat signal light turned on after a period of no power. The test time was concluded when the product was considered done for the batch. Another batch was started when the thermostat light turned on again after a period of no power. This was repeated for six batches. Averaged data for these six batches represented the energy consumption for cooking the product. These procedures help in obtaining more consistent and reproducible data on energy consumption in cooking foods.

Recovery Time

The "recovery time" is defined as the time required to regain the cooking temperature after a cooking load is placed on the griddle. It is an important point to be considered in evaluating a griddle, since the shorter the recovery time, the shorter the cooking time, and the production rate is, therefore, increased.

Attempts have been made to gather data on recovery time by placing a frozen hamburger patty directly above a thermocouple tip cemented on a griddle. The degree of contact between the hamburger patty and griddle surface was not always constant because of the interference of the thermocouple wire and the rigidity of a frozen hamburger patty. No reproducible data have been collected.

CONCLUSIONS

The heat pipe griddle was found to take 30% longer time and to use 21% more energy to heat up to a specific temperature than a commercial electric griddle. However, the heat pipe griddle required 15% less energy to maintain.

The heat pipe griddle exhibits improved temperature distribution uniformity as compared to the commercial electric griddle. When the thermostat was set at 400°F, the temperature variation over the entire cooking surface of the heat pipe griddle was ± 5.5°F, whereas the variation over the commercial electric griddle was ± 30°F.

The heat pipe griddle showed less temperature overshoot during the heat-up and a narrower temperature range during idle time than the commercial electric griddle.

When the first on/first off procedure is followed in cooking, the heat pipe griddle will produce more uniform foods in color or in doneness as compared to the commercial electric griddle. However, if the first on/last off procedure is followed, the commercial electric griddle could also produce a uniform batch of products.

The results of a laboratory cooking test showed a 20 Wh energy savings per batch of pancakes and a 170 Wh savings per batch of hamburger patties when cooking food on the heat pipe griddle compared with the commercial electric griddle. This amounts to 7 to 14% energy savings in favor of the heat pipe griddle.

To ensure a consistent data collection of energy consumption, the selection of the point of the power cycle at which the food is put on the griddle is important when cooking cycles are short as in the case of pancakes. In this study the point when the power was first turned on after a period of no power as indicated by the signal light was used as the point to start putting foods on the griddle. The test time was conducted when the product was considered done for the batch.

For a thorough evaluation of the heat pipe griddle, a long-term evaluation at the production line is necessary.

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