DEVELOPMENT OF UNIFORM TESTING PROCEDURES FOR COMMERCIAL COOKING APPLIANCES PHASE 1: GRIDDLES

Dan Kaufman and Bettie Ferlin, Pacific Gas & Electric Company
Don Fisher, Consulting Engineer
Judy Nickel, Food Service Consultant

ABSTRACT

Commercial cooking equipment sales of $780 million per year comprise 24% of the total food service equipment sales. The fuel choice for this equipment has a significant impact on the utilities supplying energy to the food service industry, as well as on the cost to operate a restaurant. Utilities and their food service customers, however, have difficulty comparing the energy efficiency and operating characteristics of commercial cooking appliances because of the absence of universally accepted methods of performance testing for such equipment. The objective of the first phase of this research project is to develop a Uniform Testing Procedure (UTP) for measuring the energy efficiency and evaluating the overall performance of griddles.

Griddles were selected for the first phase of work, as they represent one of the more widely used appliances in the commercial kitchen. The scope of the investigation includes testing two gas and two electric griddles under controlled conditions within PG&E's Production-Test Kitchen. This research facility, integrated with the PG&E Learning Center in San Ramon, California, is a combination of a real food service operation and a testing laboratory. This specific appliance testing initiative is co-sponsored by the Electric Power Research Institute, the Gas Research Institute, and the National Restaurant Association.

The research paper compares the performance of the four griddles when tested in accordance with the developed UTP. Variables reported for each griddle include idle-energy consumption, cooking-energy consumption, cooking capacity, cooking-energy efficiency, water-boil efficiency, and the temperature uniformity of the cooking surface. Synthetic food models as an alternative to hamburger patties for the test food were investigated. The energy performance of the four griddles tested under the controlled, laboratory-style conditions is compared to the performance of the same griddles as they were used for menu production at the PG&E Learning Center.

DEVELOPMENT OF UNIFORM TESTING PROCEDURES FOR COMMERCIAL COOKING APPLIANCES PHASE 1: GRIDDLES

Dan Kaufman and Bettie Ferlin, Pacific Gas & Electric Company
Don Fisher, Consulting Engineer
Judy Nickel, Food Service Consultant

INTRODUCTION

It is not an easy task for the end-user of commercial cooking equipment to select an energy efficient appliance based solely on information presented in product specifications. But it is not hard for manufacturers to include the words "energy efficient" in their product literature. An easy claim to make, and a difficult one for the end-user to validate, is that a particular cooking appliance is actually more energy efficient than a model sold by another company.

The problem is compounded by a lack of uniform performance testing procedures that are applicable to both gas and electric appliances. There are numerous test kitchens or research laboratories in the United States that are capable of measuring the energy efficiency of an appliance under specified operating conditions. However, no common protocol has been adopted by the food service industry for comparing the performance of appliances within the same equipment category (e.g., griddles).

Standardized testing procedures for evaluating the performance of gas griddles in a laboratory environment have been documented by Southern California Gas Company.[1] These procedures subsequently were applied by the American Gas Association Laboratories (AGAL) for the performance evaluation of a 4-foot infrared griddle. This was done within the scope of the AGAL Market Introduction Program for innovative gas appliances.[2] It reported the energy performance of this griddle based on the quantity of energy consumed per pound of raw hamburger cooked (i.e., Btu/lb). Although a water-boil efficiency of 59% had been reported for this griddle, no correlation was drawn between the measured water-boil efficiency and the energy efficiency of the same griddle when it was used to cook hamburger patties under fully loaded conditions. For 2 six-load tests, comprising 36 one-quarter pound hamburger patties, the infrared burner griddle was reported to consume 968 Btu/lb for frozen patties and 701 Btu/lb for partially thawed patties, both cooked to a medium-done condition.

The large variation in the Btu/lb values for the two test conditions reported by AGAL suggested that the initial temperature of the test food has a significant effect on the quantity of energy consumed by the griddle. Thus, from the perspective of developing a Uniform Testing Procedure (UTP) for Griddles, it was recognized that the specification of the "raw" and "cooked" state of the hamburger patties would be an important aspect of the PG&E investigation.

In a more in-depth study of cooking appliance performance, the University of Minnesota[3] reported an energy efficiency of 46% for a gas griddle and 62% for an electric griddle used to cook thawed hamburger patties to a medium-done condition. The reported consumption of energy per unit weight of raw hamburger was 620 Btu/lb and 460 Btu/lb, respectively. Water-boil efficiencies for the two griddles tested by the University of Minnesota were not measured.

The correlation of the measured water-boil efficiencies (which represents the maximum thermal efficiencies of the griddles) with the actual energy efficiencies for four griddles when they were used to cook hamburger patties became a primary focus of the griddle investigation at the PG&E Production-Test Kitchen.

OBJECTIVE

The objective of this research initiative was to develop a UTP for evaluating the overall performance of both gas and electric griddles. The scope of the project included :

1. Testing four griddles in accordance with the developed UTP for Griddles. Primary emphasis was placed on comparing the cooking-energy efficiency to the water-boil efficiency. Other factors considered were cooking-energy consumption, idle-energy consumption, and preheat-energy consumption.
2. Establishing the peak cooking capacity for each of the four griddles. This was measured in pounds of hamburger patties cooked per hour.
3. Evaluating the cooking-energy efficiency test as a procedure for comparing the energy efficiency of a single-sided griddle with that of a double-sided griddle.
4. Comparing the energy performance of the griddles when tested under laboratory-like conditions to the performance when used for the production of a real menu at the PG&E Learning Center.
5. Investigating the practicality of using a synthetic or alternative food model as a substitute for the hamburger patties in the determination of cooking-energy consumption and efficiency.
6. Assessing the distribution of heat across the cooking surface and the accuracy of thermostats in accordance with the developed UTP.

FACILITY AND EQUIPMENT

The development of a UTP for Griddles was based on the research experience and results from testing two gas and two electric griddles at PG&E's Production-Test Kitchen. This research facility, integrated with the PG&E Learning Center in San Ramon, California, is a combination of a real food service operation and a testing laboratory.

The cooking equipment in the Production-Test Kitchen is grouped on both sides of a utility distribution system (UDS). The equipment layout, shown in Figure 1, is ventilated by a double-sided canopy exhaust hood. The UDS functions as a central connection point, containing all plumbing, wiring, and natural gas distribution lines. The system has been designed to accommodate quick connection and disconnection of

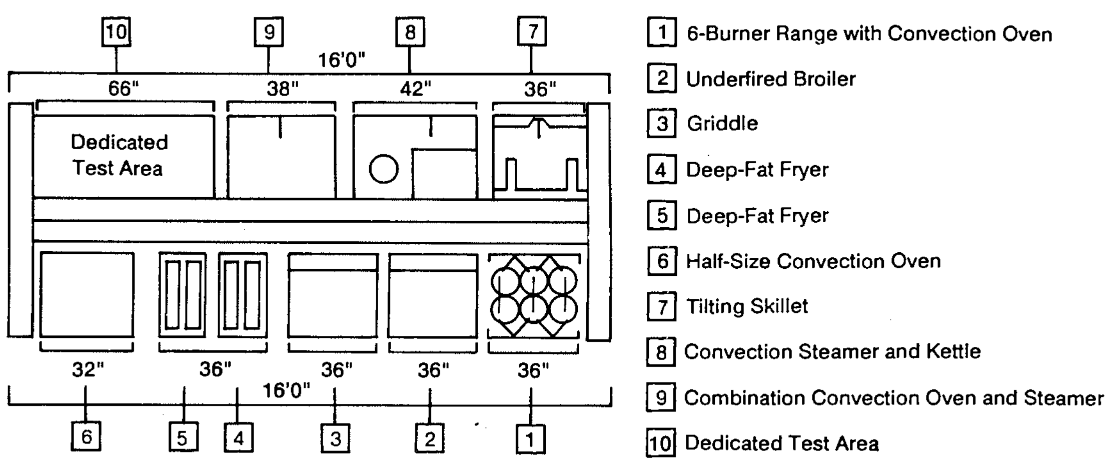


Figure 1. Production center appliance arrangement.

the appliances as they are rolled in or out of the equipment line. The production center has the flexibility to accommodate either a gas or an electric model in each appliance slot. Energy meters, installed as integral components of the UDS, permit the research team to monitor the energy consumed by the individual appliances.

Appliance slot 10, shown in Figure 1, was used by the research team during off-hours to conduct "dedicated" or laboratory-like testing on the four griddles (e.g., water-boil efficiency tests). This diversified use of the kitchen has permitted PG&E to compare the performance of a griddle tested under controlled conditions with the performance of the same griddle when it is used in an actual food service operation.

The griddles were installed sequentially in the "dedicated test" area slot 10. They underwent the laboratory-like testing in this slot in accordance with the UTP. The griddles were also installed in equipment slot 3, where they were used for routine menu production over several two-week menu cycles at the PG&E Learning Center.

The following griddles, loaned to PG&E by manufacturers, were selected for testing:

1. GAS IR - 3-foot, infrared burner.
   Rated input: 60 000 Btu/h (17.6 kW)
   Cooking surface: 36 x 24 in

2. GAS ATM - 3-foot, atmospheric burner.
   Rated input: 60 000 Btu/h (17.6 kW)
   Cooking surface: 36 x 24 in

3. ELEC 1 - 3-foot, electric model.
   Rated input: 16.2 kW (55 300 Btu/h)
   Cooking surface: 36 x 24 in

4. ELEC 2 - 3-foot, electric model with an optional add on 1-foot "top" cooking section.
   Lower section rated input: 8.4 kW (28 700 Btu/h)
   Lower cooking surface: 33 x 24 in
   Upper section rated input: 3.3 kW (11 300 Btu/h)
   Upper cooking surface: 11 x 24 in

PROCEDURE

Water-Boil Test

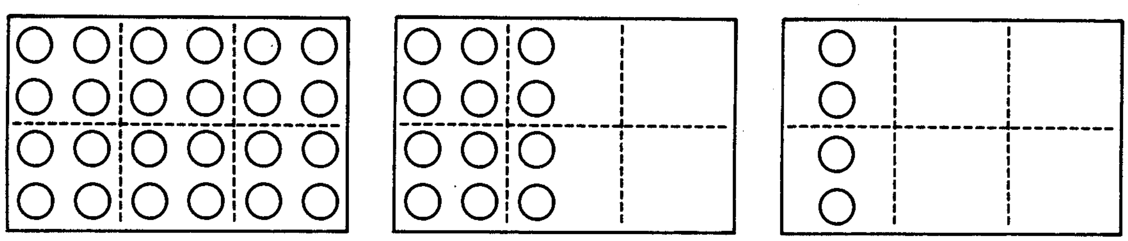
The first step of the water-boil procedure was to build a retaining wall around the entire griddle cooking surface. The wall consisted of existing griddle sides and back when usable. Aluminum plates were cemented to the griddle using high temperature silicone to form a complete containment for about a three inch depth of water.

Two legs of the griddle were placed on a load cell and the other two legs were leveled to match the load cell height. The output of the load cell was connected to an offsetting amplifier. The output of the amplifier was adjusted to zero when there was no water on the griddle. Water was weighed and added to the griddle surface in five pound increments to a total of 60 pounds. An equation was developed so that the output voltage from the load cell and amplifier was proportional to the weight of the water on the griddle. The output voltage was input to a computer equipped for data acquisition.

The input energy to the griddle was monitored throughout the test. Gas griddles had their gas supply, gas temperature, and gas pressure monitored continuously by the computer. The heating value of the gas for that day was also obtained. Electric griddles had their supply voltage, phase current, and power monitored by the computer. The griddle thermostats were set above 212°F so they did not cycle during the entire test. The water-boil efficiency was calculated by dividing the energy absorbed by the water by the energy input to the griddle.

Cooking Capacity and Energy Efficiency Test

The performance of each griddle was evaluated as it was used to cook quarter-pound, 20% fat (by weight), pure beef hamburger patties with a moisture content from 60% to 65% (by weight) and a nominal diameter of five inches. Laboratory analyses, based on procedures published by the Association of Official Analytical Chemists,[4] were used to determine the fat and moisture contents of the hamburger before and after cooking. The cooking-energy efficiency and cooking capacity were determined for each griddle by a "full-load" test, comprising 6 loads of 24 patties. This represented a loading density of four patties per nominal square foot of cooking surface. Pre-weighed, frozen patties (0°F +/-5°F) were sequentially placed on the cooking surface, cooked for a predetermined period of time on the first side, sequentially turned over, cooked for a predetermined period of time on the second side, and sequentially removed from the griddle surface. Hamburger patties were cooked to medium (i.e., no pink meat, internal temperature 165°F +/- 5°F, approximately 35% loss of weight). After removing the last patty of each load, the cooking surface was scraped for 30 seconds. If all thermostat lights indicated that the griddle plate temperature had recovered to the 375°F set point, the next load of 24 patties was placed on the cooking surface. If one or more of the thermostat indicator lights remained on after the 30-second period that was allotted for scraping, the time between loads was extended accordingly. Patty loading commenced immediately after the last burner or element had turned off. The cooking-energy efficiency was also determined for a medium- and light-load scenario, where the medium condition comprised 6 loads of 12 patties per load and the light condition comprised 6 loads of 4 patties per load. Placement of patties on the griddle cooking surface for the full-, medium- and light-load tests is illustrated in Figure 2.



FULL LOAD
All griddle sections on.

MEDIUM LOAD
Two griddle sections on.

LIGHT LOAD
One griddle section on.

Figure 2. Patty positions for three x two-foot griddle surface.

Cooking-Energy Efficiency Determination

Cooking-energy efficiency was defined as the quantity of energy gained by the hamburger patties during the cooking process expressed as a percentage of the quantity of energy input to the griddle, or:

$$\text{Cooking-Energy Efficiency} = \frac{\text{Energy Transferred to Food}}{\text{Energy Input to Appliance}} \times 100 \quad (1)$$

For the gas griddles, the actual quantity of energy (Btu) consumed during the cooking test was determined by multiplying the measured volume of gas (ft^3) input to the griddle (corrected for temperature and pressure to standard conditions) by the heating value (i.e., energy content, Btu/ft^3). For the electric griddles, the quantity of energy (Btu) consumed during the test was a direct conversion from the measured consumption of electricity in kWh.

For frozen patties, the energy gained by the hamburger during the cooking process was broken down into the following components:

$$E_{food} = E_{sens} + E_{thaw} + E_{vapor} + E_{melt} \qquad (2)$$

where:

E_{sens} = the sum of the sensible heat that was added to the components of the hamburger, including fat, non-fat, ice (below 32°F), and water (above 32°F), or:

$$E_{sens} = \sum(C_p)(W_i)(T_f - T_i) \text{ [Btu]} \qquad (3)$$

where: W_i = initial weight of component [lb]
T_i = initial temperature of component [°F]
T_f = final temperature of component [°F]
C_p = specific heat of component [Btu/lb F], as follows:
C_p(water) = 1.0 Btu/lb°F (Ref 5)
C_p(ice) = 0.5 Btu/lb°F (Ref 5)
C_p(fat) = 0.4 Btu/lb°F (Ref 6)
C_p(non-fat) = 0.2 Btu/lb°F (Ref 6)

E_{thaw} = the latent heat (of fusion) that caused the moisture contained in the patties in the form of ice to thaw when the temperature of the hamburger reached 32°F, or:

$$E_{thaw} = W_i\text{(water)} \times \text{Heat of Fusion [Btu]} \qquad (4)$$

where: W_i(water) = initial weight of water [lb]
Heat of Fusion = 144 Btu/lb (Ref 5)

E_{evap} = the latent heat (of vaporization) that causes a portion of the moisture contained in the patties to evaporate, or:

$$E_{evap} = W_{loss} \times \text{Heat of Vaporization [Btu]} \qquad (5)$$

where: W_{loss} = weight loss of water [lb]
Heat of Vaporization = 970 Btu/lb (Ref 5)

E_{melt} = the latent heat (of fusion) required to melt the fat contained in the hamburger patties, or:

$$E_{melt} = W_i\text{(fat)} \times \text{Heat of Fusion [Btu]} \qquad (6)$$

where: W_i(fat) = initial weight of fat [lb]
Heat of Fusion = 44 Btu/lb (Ref 7)

Production Energy Test

The energy performance of each griddle was evaluated as it was used by the Learning Center food service staff to cook breakfast and lunch menu items. Energy meters, interfaced with a remote data acquisition and processing system, permitted continuous, automatic recording of the energy used by the griddles for preheating, idling, and cooking. Energy-use profiles, showing daily griddle energy consumption patterns, were generated. From these, the daily hours of operation (griddle on-time) were determined and the average rate of "production" energy consumption (Btu/h) for a typical day calculated.

RESULTS

A UTP was developed and recommended as a valid method for evaluating and comparing the performance of griddles. The results of the griddle testing under both dedicated (laboratory) and production (real-use) conditions are summarized in Table I.

Correlation of Cooking and Water-Boil Efficiencies

The hamburger cooking-energy efficiency and cooking capacity determination were conducted under full-, moderate-, and light-loading scenarios. The thermal efficiency of each griddle was determined by a water-boil test. The water-boil efficiency reflects the maximum energy efficiency of a griddle. This is because essentially all the energy delivered to the cooking surface is absorbed by the water.

The measured water-boil efficiencies consistently overstated the cooking-energy efficiencies determined for the four test griddles. This was particularly true for the moderate- and light-load hamburger cooking efficiencies. However, a linear relationship between the water-boil efficiencies and the cooking-energy efficiencies was demonstrated. This is illustrated in Figure 3. It was concluded that, generally, the water-boil test is a valid procedure for comparing the relative energy performance of griddles. Water-boil efficiency values are not recommended as a basis for estimating the cost of operating a griddle in an actual food service operation.

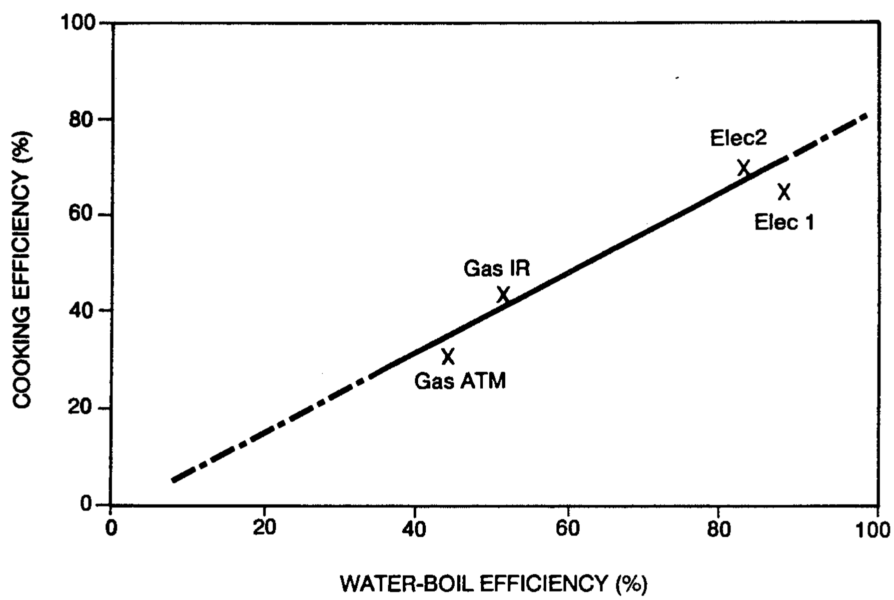


Figure 3. Relationship of water-boil and full-load efficiencies for 3-foot griddles.

The cooking-energy efficiency test was applied to one of the griddles with a 1-foot double-sided section (Elec 2). Results of the tests showed no significant difference in the cooking-energy efficiency between the double-sided and single-sided mode of operation. However, there was a significant difference in cooking times between the two modes of operation. Double-sided cooking time was 2 min., 40 sec., and single-sided cooking time was 7 min., 50 sec. for medium-done patties. It was concluded that the cooking-energy efficiency test is a practical alternative to the water-boil test for evaluating the performance of double-sided griddles. A considerable effort would be needed to develop a water-boil test for a double-sided griddle.

Table I. Summary of griddle test results.

Test/Condition		Gas IR	Gas Atm	Elec 1	Elec2*
Measured Input Rate	(Btu/lb)	60	59	51	27
Water Boil Efficiency	(%)	51	44	88	83
Full-Load Test:					
Energy-to-Food	(Btu/lb)	490	461	475	473
Energy-to-Griddle	(Btu/lb)	1148	1477	735	677
Energy Efficiency	(%)	42	31	65	70
Average Input Rate	(kBtu/h)	49	51	34	19
Minimum-Load Test:					
Energy-to-Food	(Btu/lb)	485	460	481	469
Energy-to-Griddle	(Btu/lb)	1556	2165	829	762
Energy Efficiency	(%)	31	21	58	62
Average Input Rate	(kBtu/h)	35	35	20	13
Light-Load Test:					
Energy-to-Food	(Btu/lb)	481	461	491	451
Energy-to-Griddle	(Btu/lb)	2679	3646	1151	906
Energy Efficiency	(%)	18	13	43	50
Average Input Rate	(kBtu/h)	20	19	9	6
Cooking Capacity:**					
Patty Cook Time	(min)	6.5	7.2	6.5	7.8
Recovery Time	(min)	1.8	3.3	1.3	4.6
Hamburger Output	(lb/h)	43	34	46	29
Idle Energy Rate at 375°F	(Btu/h)	17.1	19.5	8.1	6.1
Production Energy Performance:***					
Daily Consumption	(kBtu/day)	129	145	74.8	50.8
Average Input Rate	(kBtu/h)	17.7	21.8	10.1	7.6

* Elec 2 griddle used in single-sided mode.
** Based on full-load test.
*** Includes pre-heat energy.

Cooking Capacity

The cooking capacity (lb/h), or productivity, under full-load conditions varied among the four griddles. The regression in Figure 4 shows that cooking capacity is related directly to the energy input rate multiplied

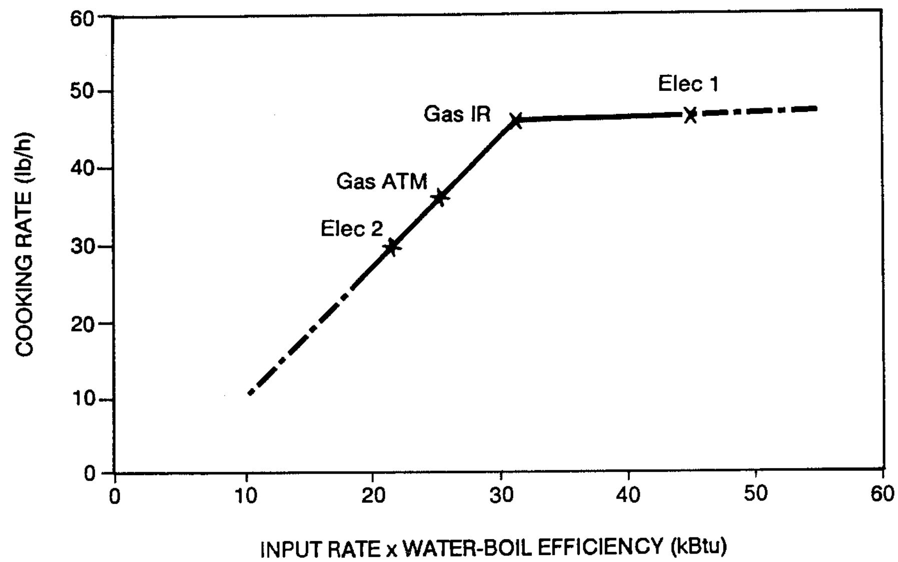


Figure 4. Hamburger cooking capacity compared to appliance input for 3-foot griddles.

by the water-boil efficiency. This direct relationship between the energy transferred to the cooking surface and the cooking time, however, is limited by the inherent resistance to heat transfer between the hamburger patty and the cooking surface. This is illustrated by the marginal increase in cooking time for the Elec 1 griddle over the Gas IR griddle, despite a 50% increase in energy actually transferred to the cooking surface (i.e., energy input rate x water-boil efficiency). The Cooking energy-efficiency of the four griddles is plotted against cooking capacity in Figure 5.

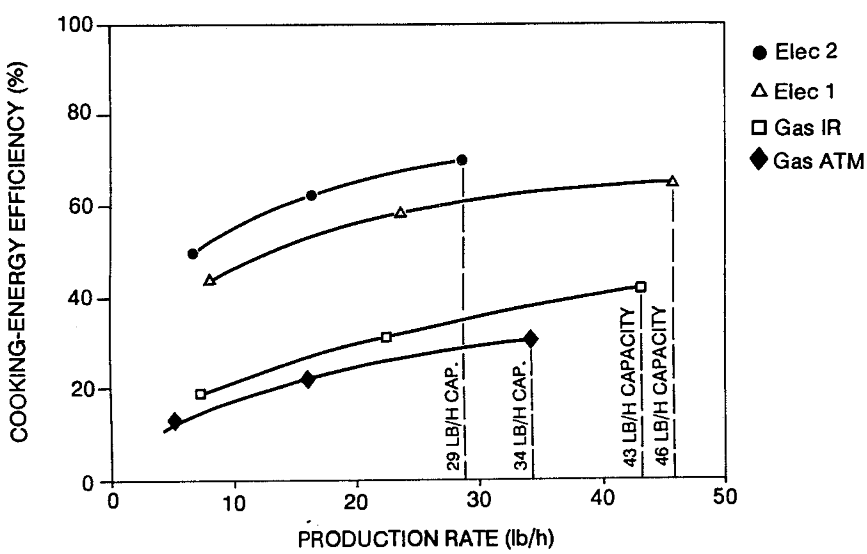


Figure 5. Cooking efficiency compared to throughput when cooking 1/4 lb. hamburger patties on 3-foot griddles.

Production Energy Performance

The energy-use profiles, presented in Figures 6 and 7, characterize the typical daily production-energy use for each of the griddles. Appliance operating time was approximately seven hours per day. The griddle was used for two distinct periods, a breakfast period, and a lunch period. The beginning of each of these periods shows a high energy usage, attributable to preheating the griddle. The remainder of the griddle on-

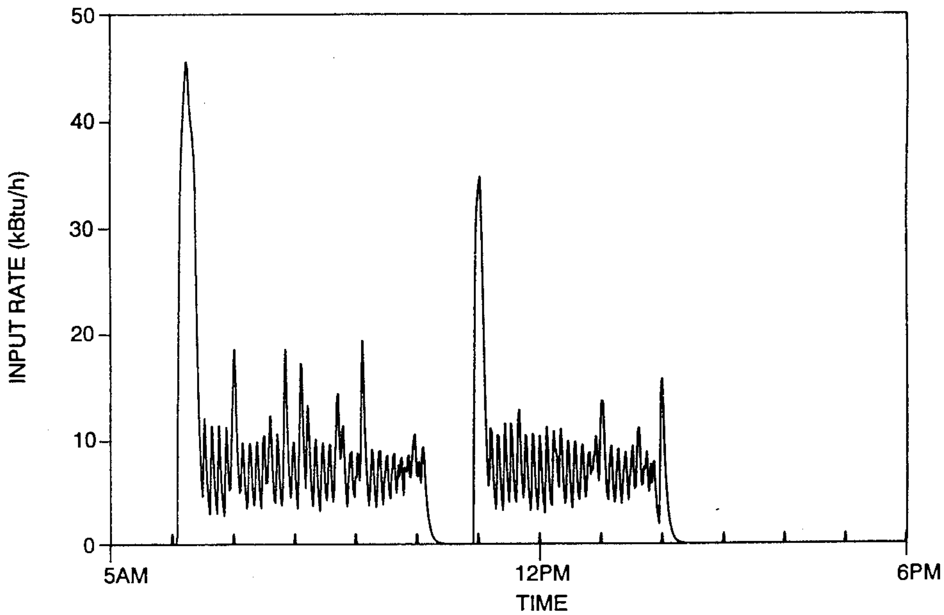


Figure 6. Energy input rate for 3-foot electric griddle (Elec 1).

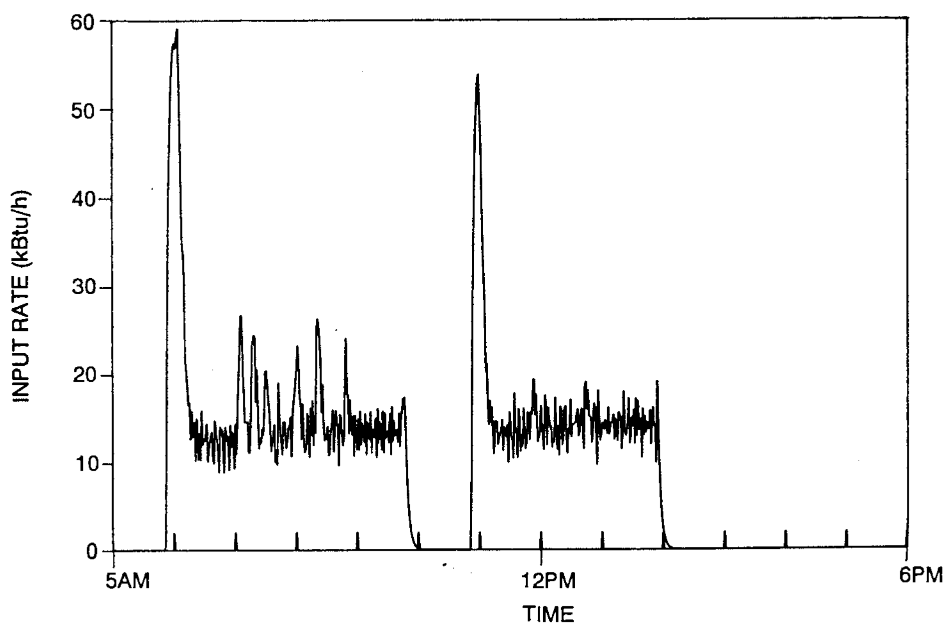


Figure 7. Energy input rate for 3-foot infrared burner griddle (Gas IR).

time is dominated by the energy used to maintain the griddle at an operating, or idle, temperature. The peaks above the idle range indicate actual cooking energy. This is considered to be a light-production level for griddle applications.

The bar graph in Figure 8 compares the average rate of production-energy consumption for the four griddles to the rate of energy consumption for the griddles when used to cook hamburger patties in accordance with the UTP. The rate of production-energy consumption compared most favorably with the rate of energy consumption under the light-load patty test, at least for this type of cafeteria-style food service operation. The bar graph in Figure 9 shows that the production-energy consumption rate for the 4 griddles is approximately 30% of the rated input.

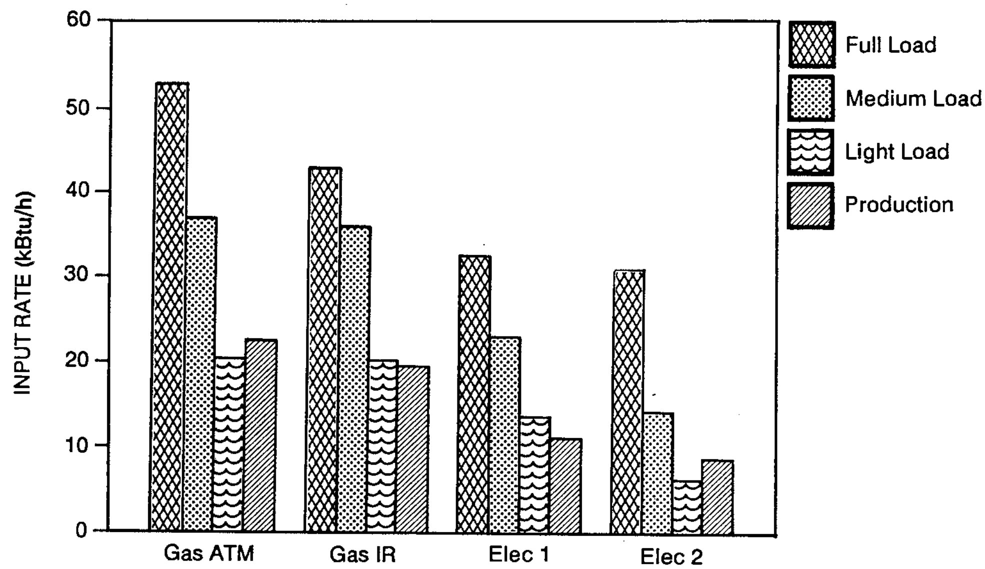


Figure 8. Rates of energy consumption for laboratory and production on 3-foot griddles.

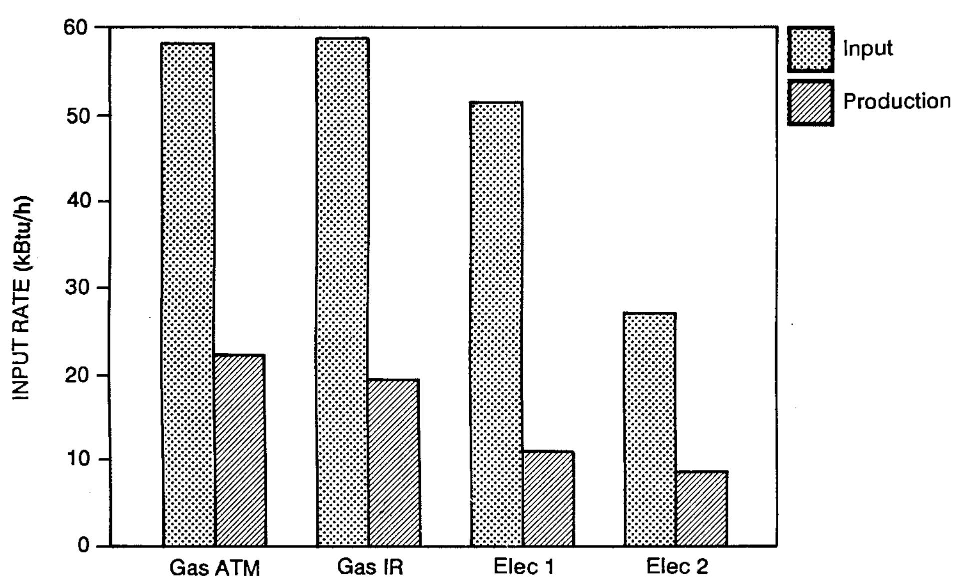


Figure 9. Peak input rate and average production input rate for 3-foot griddles.

Hamburger Modeling

Formulations for two model food systems were developed and evaluated. The first approach was to develop a model that, from a functional standpoint, would behave in a similar fashion to the hamburger. The second approach was to develop a very simple model system that would contain the same amount of water and solids as a 20% fat hamburger and could be shaped into patties. Although the development of a model system (based on soy protein powder) proved viable, it was felt that its application within the recommended UTP would not compete with the practicality of using real hamburger patties under tightly controlled specifications.

Cooking Surface Temperatures

Surface temperature uniformity of the griddles was evaluated by infrared thermography. The infrared camera system produces a digitally encoded video image of the griddle surface. The digital video image can be played through instrumentation to produce a color picture on a monitor of the griddle surface. The colors of the picture correspond to different temperature zones of the griddle surface. The image can be recorded on videotape to show the surface temperature changes during griddle thermostat cycling. Temperature uniformity studies showed that temperature variations on the griddle surfaces were about +/- 25°F from the thermostat set point.

ACKNOWLEDGEMENTS

Through PG&E's national Advisory Group, support for this project has come from both researchers and end users within the food service industry. Organizations that previously had not participated jointly in appliance testing are working together on this project. These organizations include the Gas Research Institute, the Electric Power Research Institute, American Gas Association Laboratories, and the National Restaurant Association. Other participants include Underwriters Laboratories, Pennsylvania State University, McDonald's Corporation, Marriott International, and ARA Services. The ongoing commitment of these professionals to the PG&E Production-Test Kitchen Project and their technical contribution to this griddle investigation is noteworthy.

REFERENCES

1. Southern California Gas Company, Standardized Test Procedures for Griddles, Revision Date: August, 1983

2. American Gas Association, Performance Test Report - Gas Foodservice Equipment Market Introduction Program: Wolf Infra-Red Griddle with Solid State Controls and Electric Ignition, July 24, 1985

3. O.P. Snyder, D.R. Thompson, J.F. Norwig, Comparative Gas/Electric Food Service Equipment Energy Consumption Ratio Study, University of Minnesota, March, 1983

4. Association of Official Analytical Chemists, *Official Methods of Analysis of the Association of Official Analytical Analytical Chemists*, Pub. by the Association of Official Analytical Chemists, Washington, D.C.

5. ASHRAE Handbook of Fundamentals (1981), pp. 39.6 & 39.7

6. R.T. Toledo, *Fundamentals of Food Process Engineering*, AVI Publishing Company, 1981, pp. 132

7. S.L. Polley, O.P. Snyder, and P. Kotnour, "A Compilation of Thermal Properties of Foods," *Food Technology*, Nov. (1980)