Wok Water Saver Performance Test

Application of ASTM Standard F 1991 – 99
Test Method
FSTC Report 50130940

Food Service Technology Center
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Executive Summary

The Wok Water Saver is based on a standard double burner wok table with a maximum input rating of 200,000 Btu/hr. Unlike traditional wok ranges, which use continuous running water to cool the table, the Wok Water Saver utilizes a built in water re-circulation loop expanding from under the wok table surface to an external chiller. The system is designed to keep the wok table surface cool while running both burners. The Wok Water Saver design includes a waterfall, but is only used in an emergency (i.e. a power failure when the chiller is no longer able to maintain the in-loop water temperature below 75°F).

Food Service Technology Center (FSTC) researchers tested the Wok Water Saver under the tight specifications of the American Society for Testing and Materials' (ASTM) standard test method.[1] The wok performance was characterized by cooking-energy efficiency and production capacity.

As specified by the ASTM test method, cooking-energy efficiency is a measure of how much of the energy consumed by the appliance is delivered to the water and the pot during the cooking process. Cooking-energy efficiency is therefore defined by the following relationship:

$$\text{Cooking - Energy Efficiency} = \frac{\text{Energy to Water \& Pot}}{\text{Energy to Appliance}}$$

In addition to the standard test procedures, the Wok Water Saver testing included a one hour performance test. In restaurants, rarely does cooking require burners to remain on for more than 20 minutes at a time, but for lab testing, running the burners for a full consecutive 60 minutes allows the re-

[1] American Society for Testing and Materials. 2005. *Standard Test Method for Chinese (Wok) Tables.* ASTM Designation F 1991-99, in *Annual Book of ASTM Standards,* West Conshohocken, PA.

searcher to see possible limitations of the Wok Table in extreme cooking conditions. A summary of the ASTM test results is presented in Table 1-1.

Table 1-1. Summary of Wok Water Saver Performance Results.

Chiller Measured Cooking Energy Rate (kW)	1.571
Chiller Measured Idle Energy Rate (kW)	0.225
Control Energy Rate (W)	5.97
Burner Rated Energy Input Rate (Btu/hr)	200,000
Burner Measured Energy Input Rate (Btu/hr)	208,700
Waterfall rate (gpm)	4.0
Double Burner Cooking-Energy Efficiency (%)	10.5 ± 0.04
Production Capacity [c] (lb/h)	122 ± 1.9

The use of a closed-loop chiller to remove excess heat from the wok table may initially suggest a trade between saving water and saving energy. However, from the data collected using the ASTM Designation F 1991 – 99, the Wok Water Saver proved to save a significant amount of water. The additional energy use by the chiller is negligible in comparison to the gas burner's energy use.

Although the Wok Water Saver's cooking efficiency is similar to a standard wok table, the Wok Water Saver proved its effectiveness in keeping the table surface at safe operating temperatures while the burners are at full input for extended periods of time. The built in waterfall flows at a rate of 4.0 gallons per minute or 240 gallons per hour, which indicates a significant amount of water that can be saved. Compared to field study results, waterfall flow rates may be conservatively estimated to run at 1gpm per burner. When applied to the 2-burner Wok Water Saver table, operators can expect to save 2gpm or 120 gallons per hour, while adding 1.57 kW. By comparison, the chiller energy of 1.57kW, or 5.357Btu (1kW = 5.357Btu/hr) is equivalent to 2.31% of the overall equipment energy rate of 200,000Btu/hr.

Executive Summary

The Wok Water Saver provides an alternative to using tap water to cool the table top surface, but there is still a large amount of heat collected by the backsplash, which is cooled by the waterfall on a standard wok table. After a half hour of continuous burner use, the backsplash temperature can reach temperatures as high as 350°F. When the burners are turned off, temperatures drop rapidly from 350°F to 120°F. Some potential changes can be made to reduce or use this heat load effectively (ex. using a heat exchanger to preheat water).

1 Introduction

Background

Wok ranges employ high cooking temperatures to quickly sear food, locking in nutrients, and the high heat generated in the burner wells can spread across the table through conduction. Without cooling, the heat generated will be enough to warp the table surface and potentially cause serious injuries to the operator. Standard designs continuously run water across the table to remove the excess heat from the table. In addition, most standard wok tables include a utility faucet at the rear of the table for filling pots and pans. As most standard wok tables have excess heat, the faucet will typically run continuously throughout the day along with the table cooling water.

The manufacturer of the Wok Water Saver attempts to address the issue of water waste by utilizing a closed re-circulating loop filled with chilled water under the surface of the table. The water loop extends from the wok table to a separate chiller which maintains the water temperature at 45°F. The Wok Water Saver also has a built in safety feature in the case of a power failure, or if ever the in-loop water temperature exceeds a set temperature (for experimentation this was set to 75°F). The waterfall will turn on and the wok will operate as a traditional wok table.

The Wok Water Saver also includes a push button for the swing out utility faucet arm which actuates the timer to allow 0.5 gallons of water to flow in 15 seconds. A ceramic disk inside the faucet allows the water to stop flowing then the faucet is turned to either side, thereby indicating that it is not being used to fill cooking utensils. These designs are exclusive to the Wok Water Saver.

The glossary in Appendix A provided is a quick reference to the terms used in this report.

Introduction

Objectives

The objective of this report is to examine the operation and performance of the Wok Water Saver under the controlled conditions of the ASTM F1991-99 standard test method, and to document the performance of the Wok Water Saver's cooling strategies. The scope of this testing is as follows:

1. Verify that the appliance is operating at the manufacturer's rated energy input.
2. Document the cooking energy efficiency and production capacity of the burner wells when operated at their maximum settings.
3. Demonstrate the overall effectiveness of the Wok Water Saver cooling system under a one hour performance test.

Appliance Description

The Wok Water Saver is a standard double burner wok table with a maximum input rating of 200,000 Btu/hr. However, unlike traditional woks that use a waterfall, it utilizes a closed water re-circulating loop to cool the table surface which is attached to an external water chiller that maintains the water temperature at 45°F. Controls include an adjustable stainless steel gas control valve used to vary input to the burners and a push button timer on the faucet arm that allows 0.5 gallons of water to flow through in 15 seconds. Safety features include a waterfall system that turns on when the re-circulating water reaches a programmed temperature.

The Wok Water Saver is shown in Figure 1-1. Appliance specifications are listed in Table 1-2.

Figure 1-1.
Wok Water Saver.

Table 1-2. Appliance Specifications

Manufacturer	Wok Water Saver
Model	Wok Water Saver
Generic Appliance Type	Double Burner Wok table
Rated Input	200,000 Btu/hr (100,000 Btu/hr per burner)
Dimensions	43” x 67” x 40”
Controls	Thermostatic control for waterfall
	Push button to operate faucet

2 Methods

Setup and Instrumentation

FSTC researchers installed the Wok Water Saver under a 4-foot deep canopy hood that was 6 feet, 6 inches above the floor. The hood operated at a nominal exhaust rate of 300 cfm per linear foot of hood. There was at least 6 inches of clearance between the vertical plane of the wok and the edge of the hood. During testing the ambient room temperature was maintained at 75 ± 5°F. All test apparatus were installed in accordance with the ASTM test method.[1]

Power and energy from the water chiller were measured with a calibrated watt/watt-hour meter that generated an analog signal for instantaneous power and a pulse for every .0001 Wh. The voltage supplied to the chiller was maintained at 208V.

For the Wok Water Saver unit, thermocouples were used to monitor the ambient temperature of the testing area and inlet temperature of the natural gas. A pressure gauge was used to monitor the barometric pressure in the laboratory. Natural gas consumption was measured using a positive displacement-type gas meter that generated a pulse every 0.5 ft^3.

Water temperature was measured using a beaded-end, K-type thermocouple wire. The transducer and thermocouples were connected to an automated data acquisition unit that recorded data every 5 seconds. Surface temperature was also measured with a K-type thermocouple welded to the surface of the stainless steel plate. These probes were located on both the left and right sides of the pot, the rim of the burner, and the back wall of the wok table.

All instrumentation was connected to an automated data acquisition system that recorded every 5 seconds. A Cutler-Hammer gas calorimeter was used to determine the gas heating value during each test. All gas measurements were corrected to standard conditions.

Energy Input Rate

The input rate was measured with the unit operating at full input in order to verify that the Wok Burners were operating properly and within ± 5.0% of the manufacturer's rated input.

Cooking-Energy Efficiency and Production Capacity

After a 30 minute stabilization period, the cooking energy efficiency and production capacity were determined by heating 3.75 ± 0.0375 lbs of water in a Wok from 70°F to 200°F, using the maximum burner setting. The cooking container used for the cooking-energy efficiency tests was a 14"-inch diameter iron wok, weighing 2.95 pounds. Three cooking tests were performed in accordance with the ASTM test method, which ensured that the reported cooking energy efficiency and production capacity result had an experimental uncertainty of less than ± 10.0%. The results from each test run were averaged, and the absolute uncertainty was calculated based on the standard deviation of the results.

Appendix C contains the ASTM results reporting sheets for the Wok Water Saver.

3 Results

Energy Input Rate

The input rate was measured at 208,720 Btu/hr with the unit operating at full input in order to verify that the burners were operating properly and within ± 5.0% of the manufacturer's rated input.

Cooking-Energy Efficiency and Production Capacity

Three test runs were performed at full input to determine the cooking-energy efficiency and production capacity. The results are reported in Table 3.

Table 3-1. Double Burner Cooking-Energy Efficiency and Production Capacity Results

Test Time (min)	3.69
Production Capacity (lb/h)	122 ± 1.9
Cooking Energy Rate (kBtu/h)	170.2 ± 1.03
Cooking-Energy Efficiency (%)	10.5 ± 0.04

Test Results

Cooking-energy efficiency results for the four tests were 10.50%, 10.49%, 10.52%, and 10.47%, yielding an uncertainty of 0.04%.

The hour long performance test yielded results which demonstrated the overall effectiveness of the Wok Water Saver system. Figure 3-1 shows that the gas energy rate starts high, and then drops off to a consistent level after 30 minutes. With an initial input energy rate of 208,720 Btu/hr, the energy rate levels off to an average of 174,000 Btu/hr, even though burner settings are not changed. The cooking-energy efficiency and production rate were performed during this period of consistent burner levels.

Results

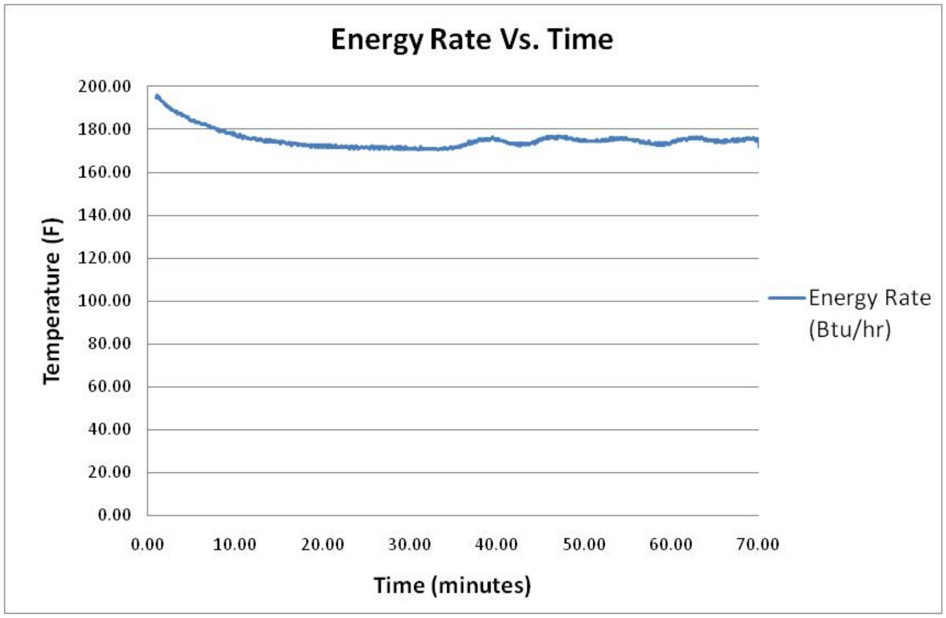


Figure 3-1.
Energy Rate vs. Time

The drop off in the energy rate of almost 30,000 Btu/hr should not raise concerns as this is a natural process due to the thermal expansion of the gas prior to entering the burner tip. With each pot burner having a total of 24 burner tips, this thermal expansion makes for a dramatic change in the energy output.

Figure 3-2 shows the rise in table top and backsplash surface temperatures during the hour performance test. From the graph, measured table top temperatures on both the left and right side climb to a high of 120°F in the first 30 minutes and continue to increase at a lower rate. During the 60 minute interval, the burners remain on and the table top temperatures reached a maximum of 130°F. It is important to note that while the surface temperature reached 130°F, the internal water loop temperature was still at 50°F and not high enough to activate the emergency waterfall system on. The absence of the waterfall presented a higher surface temperature reading of 350°F in the backsplash area which is neither cooled by water nor the closed water loop. After the first 63 minutes, the burners were turned off and the system was allowed to cool with the chiller and water loop running.

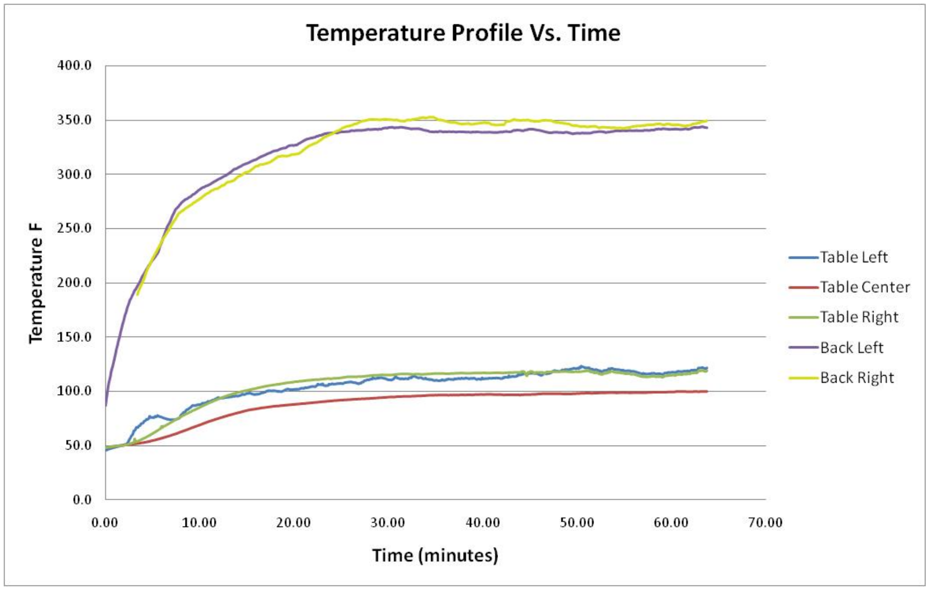


Figure 3-2.
Wok Table Temperature Profile vs. Time using Chiller

It is important to note that while this experiment is a performance test, it does not entirely reflect normal cooking operations, as the burners are rarely operated continuously at maximum input for an hour or more at a time. This test is to observe the threshold behavior of the Wok Water Saver after an hour of continual maximum burner setting and determine whether it is still safe for operation.

Figure 3-3 shows the temperature profile of the wok table with the water chiller off and the waterfall enabled. In this test run, the wok table was allowed to operate without cooling methods (chiller, waterfall) for the first ten minutes to create a heat load onto the table. The waterfall was intentionally activated via temperature controls and 4gpm of water flowed from the waterfall, over the table surface, and into the drain. There was an immediate surface temperature drop, and the table surface adopted the water temperature.

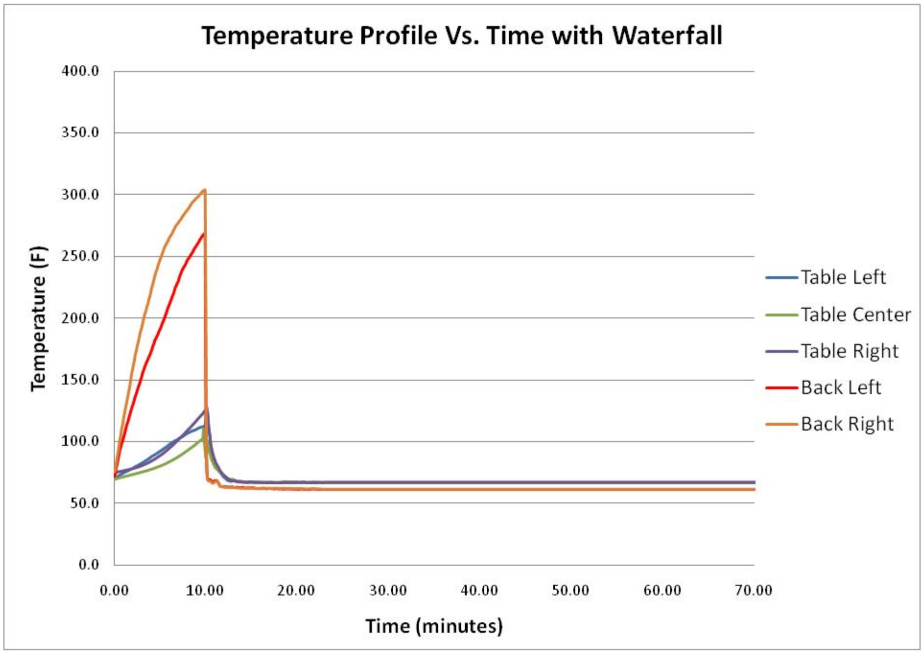


Figure 3-3. Waterfall Temperature Profile vs. Time

Using results from field research and controlled laboratory testing, researchers developed operating cost models to project the Wok Water Saver's annual operating costs. The projected annual water savings associated with the installation of the Wok Water Saver is estimated to be 641 units of water. A conservative estimate of 2gpm of water flow is used for each 2 burner wok table. This cost model includes the cost used to chill the table surface and does not include the burner operating costs.

Table 3-2. Annual Operating Cost Model.

	Annual Water use (units)	Annual Energy Use (kWh)	Water Cost	Energy Cost	Total Cost
Typical Industry Wok Table (2 burners)	641	-	$5,125	-	**$5,125**
Wok Water Saver w/ Chiller	-	3,405	-	$436	**$436**

A few of the cost model assumptions are listed in Table 3-3. In addition to these assumptions, it was assumed that burners used in the Wok Water Saver and other wok tables are all 100,000 Btu/hr burners, with the same efficiency and cooking volume. In the average restaurant using a wok table, it is assumed that the waterfall is on for all of the operating hours. It also assumed that cooking is done for 5 hours out of the operating day, and that the chiller will be on idle for the remainder.

Table 3-3. Cost Model Assumptions.

Hours of Operation	Operating Days/ Year	Cooking Hours/ Day	$/Unit of water	$/kWh
11	363	5	$8	0.13

The average cost per unit of water for a food service operation currently is $8 in California. Restaurants pay an elevated fee for additional food pollutant sewer waste when compared to other commercial facilities. This value is based on the weighted average for the most populous cities across California. See Appendix E.

4 Conclusions

The Wok Water Saver with the water chiller gave a solid performance during the cooking-energy efficiency/performance test by allowing the burners to maintain maximum temperature while keeping the table top relatively cool. Utilizing the closed re-circulating water loop, the Wok Water Saver prevented the waterfall from turning on, thus reducing water waste. Although the cooking efficiency test yielded results that were in the range of traditional woks, the water saved by the Wok Water Saver is a significant improvement.

The Wok Water Saver has proven its effectiveness in keeping the table surface at safe operating temperatures while the burners are at full input for extended periods of time. The built in waterfall flows at a rate of 4.0 gallons per minute, or 240 gallons per hour, a decent amount of water that can be saved. Field study results show that on average, waterfall flow rates may be conservatively estimated to run at 1gpm per burner. When applied to the 2-burner Wok Water Saver table, operators can expect to save 2gpm or 120 gallons per hour, while adding a scant 1.57 kW. By comparison, the chillers energy rate of 1.57kW, or 5.357 Btu, is equivalent to 2.31% of the overall equipment energy rate of 200,000Btu/hr.

The Wok Water Saver provides an alternative to using tap water to cool the table top surface, but there is still a large amount of heat collected by the backsplash, which is cooled by the waterfall on a standard wok table. After a half hour of continuous burner use, the backsplash temperature can reach temperatures as high as 350°F. When the burners are turned off, temperatures drop rapidly from 350°F to 120°F in about 30 minutes. Some potential changes can be made to reduce or reuse this heat to effectively preheat water using a heat exchanger.

Conclusions

The Wok Water Saver also integrated a faucet push button which provides 15 seconds of running water, equivalent to 0.5 gallons. Chefs can now easily turn on the water and fill up containers hands free without worrying about turning off the faucet. Overall, when compared to traditional wok tables found in the field, the Wok Water Saver saves 60 gallons of water per hour per burner with the waterfall off and operating a chiller at 1.57kW. This adds up to a potential savings of $4,689 per year for a two-well unit, based on $8/unit of water (water and sewer combined) and $0.13/kWh for electricity.

5 References

1. American Society for Testing and Materials, 2003. *Standard Test Method for Performance of Range Tops*. ASTM Designation F1991-99. In Annual Book of ASTM Standards, West Conshohocken, PA.

Appendix A Glossary

Cooking-Energy (kWh or kBtu)

The total energy consumed by an appliance as it is used to cook a specified food product.

Cooking-Energy Consumption Rate (kW or kBtu/h)

The average rate of energy consumption during the cooking period.

Cooking-Energy Efficiency (%)

The quantity of energy input to the food products; expressed as a percentage of the quantity of energy input to the appliance during the heavy-, medium-, and light-load tests.

Duty Cycle (%)
Load Factor

The average energy consumption rate (based on a specified operating period for the appliance) expressed as a percentage of the measured energy input rate.

$$\text{Duty Cycle} = \frac{\text{Average Energy Consumption Rate}}{\text{Measured Energy Input Rate}} \times 100$$

Energy Input Rate (kW or kBtu/h)
Energy Consumption Rate
Energy Rate

The peak rate at which an appliance will consume energy, typically reflected during preheat.

Heating Value (Btu/ft^3)
Heating Content

The quantity of heat (energy) generated by the combustion of fuel. For natural gas, this quantity varies depending on the constituents of the gas.

Idle Energy Rate (kW or Btu/h)
Idle Energy Input Rate
Idle Rate

The rate of appliance energy consumption while it is holding or maintaining a stabilized operating condition or temperature at a specified control setting.

Idle Temperature (°F, Setting)

The temperature of the cooking cavity/surface (selected by the appliance operator or specified for a controlled test) that is maintained by the appliance under an idle condition.

Idle Duty Cycle (%)
Idle Energy Factor

The idle energy consumption rate expressed as a percentage of the measured energy input rate.

$$\text{Idle Duty Cycle} = \frac{\text{Idle Energy Consumption Rate}}{\text{Measured Energy Input Rate}} \times 100$$

Glossary

Measured Input Rate (kW or Btu/h)

Measured Energy Input Rate
Measured Peak Energy Input Rate

The maximum or peak rate at which an appliance consumes energy, typically reflected during appliance preheat (i.e., the period of operation when all burners or elements are "on").

Pilot Energy Rate (kBtu/h)
Pilot Energy Consumption Rate

The rate of energy consumption by the standing or constant pilot while the appliance is not being operated (i.e., when the thermostats or control knobs have been turned off by the food service operator).

Preheat Energy (kWh or Btu)
Preheat Energy Consumption

The total amount of energy consumed by an appliance during the preheat period.

Preheat Rate (°F/min)

The rate at which the cook zone heats during a preheat.

Preheat Time (minute)
Preheat Period

The time required for an appliance to "preheat" from the ambient room temperature (75 ± 5°F) to a specified (and calibrated) operating temperature or thermostat set point.

Production Capacity (lb/h)

The maximum production rate of an appliance while cooking a specified food product in accordance with the heavy-load cooking test.

Production Rate (lb/h)
Productivity

The average rate at which an appliance brings a specified food product to a specified "cooked" condition.

Rated Energy Input Rate
(kW, W or Btu/h, Btu/h)
Input Rating (ANSI definition)
Nameplate Energy Input Rate
Rated Input

The maximum or peak rate at which an appliance consumes energy as rated by the manufacturer and specified on the nameplate.

Recovery Time (minute, second)

The average time from the removal of the cooked food product from the appliance until the cooking cavity is within 10°F of the thermostat set point and the appliance is ready to be reloaded.

Test Method

A definitive procedure for the identification, measurement, and evaluation of one or more qualities, characteristics, or properties of a material, product, system, or service that produces a test result.

C Results Reporting Sheets

Test Oven Description

Manufacturer:	Wok Water Saver
Model Number:	Wok Water Saver
Date:	December 2009

1. Test Apparatus (11.1)

Type:	Gas Burners, Water Chiller
Rated Input:	200,000 btu/hr
Controls:	Thermostatically controlled waterfall temperature

Description of operational characteristics:

The Wok Water Saver is a dual pot wok table with the capacity to run a chilled re-circulating water loop internally cooling the table surface allowing the waterfall to remain off. Temperature adjustments for the emergency waterfall temperature, as well as the chiller water temperature can be adjusted.

2. Apparatus (11.2)

_√_ Check if testing apparatus conformed to specifications in Section 6.

Deviations: Pot used was 13-inch diameter, 20 quart capacity, induction-ready stainless steel pot.

3. Energy Input Rate (11.4)

Test Voltage	208
Gas heating value (Btu/ft^3)	1028
Measured (Btu/h or kW)	208,729
Rated (Btu/h or kW)	200,000
Percent difference between measured and rated (%)	4.36

4. Chiller Idle Energy Rate (11.4)

Test Voltage	208
Chiller Idle Energy Rate (W)	225

5. Pilot Energy Consumption (11.5)

Gas heating value (Btu/ft^3)	1030
Pilot energy rate (Btu/h or kW)	3,485

6. Cooking-Energy Efficiency and Production Capacity (11.7)

Test voltage for chiller (V)	208
Gas heating value (Btu/ft^3)	1025
Test time (min)	3.69
Production rate (lb/h)	122 ± 1.9
Burner Cooking energy rate (Btu/h)	170,201
Cooking-energy efficiency	10.5 ± 0.04

D Cooking-Energy Efficiency Data

Table D-1. Specific Heat.

Specific Heat (Btu/lb, °F)	
Water	1.00
Cast Iron	0.11

Table D-2. Cooking-Energy Efficiency Test Data.

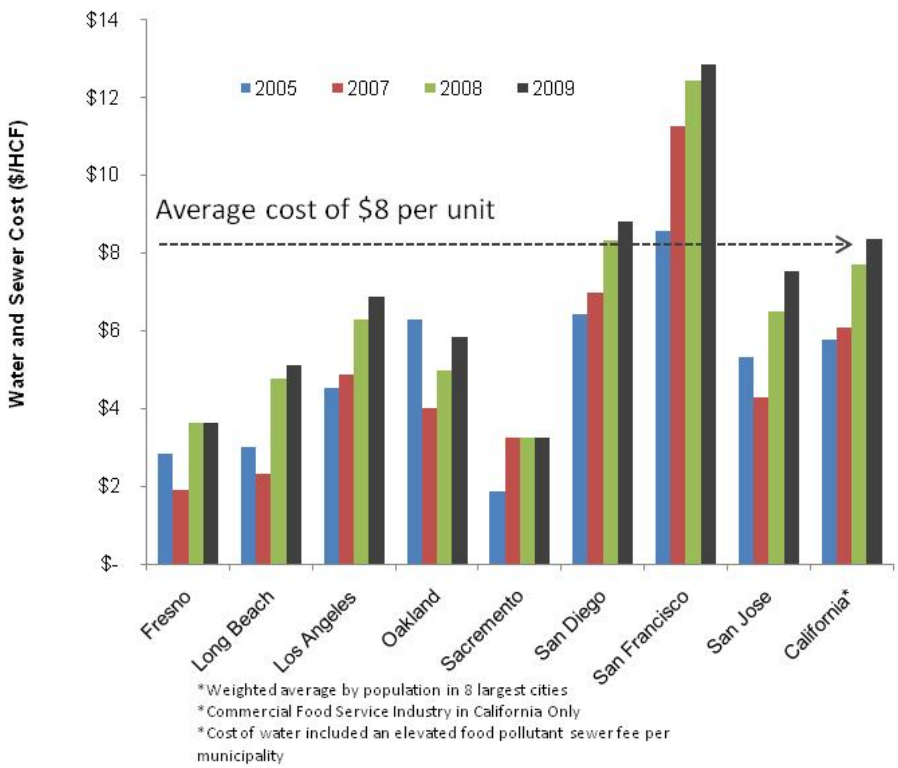
	Test #1	Test #2	Test #3	Test#4
Measured Values				
Total Energy to Wok table (Btu)	10,446	10,446	10,496	10,396
Cook Time (min)	3.67	3.70	3.69	3.67
Weight of Water (lb)	7.56	7.51	7.55	7.39
Weight of Cooking Container (lb)	2.955	2.955	2.955	2.955
Initial Temperature of Water (°F)	68	65.7	65.7	65.2
Final Temperature of Water (°F)	202.6	200.3	200.5	200.5
Calculated Values				
Energy to Water (Btu)	1,010	1,008	1,017	1000
Energy to Cooking Container (Btu)	86.9	87.3	87.6	88.0
Energy to Wok Table (Btu)	10,446	10,446	10,496	10,396
Cooking-Energy Efficiency (%)	10.50	10.49	10.52	10.47
Cooking Energy Rate (Btu/hr)	170,780	169,395	170,671	169,959
Chiller Cooking Rate (kW)	1.571	1.571	1.571	1.571
Production Rate (lb/h)	123.6	121.8	122.7	120.8

E California Commercial Food Service Water Rates

Table D-3. Cooking-Energy Efficiency and Production Capacity Statistics.

	Cooking-Energy Efficiency (%)	Production Capacity (lbs)
Replicate #1	10.50	123.6
Replicate #2	10.49	121.8
Replicate #3	10.52	122.7
Replicate #4	10.47	120.8
Average	10.5	122.2
Standard Deviation (%, lbs)	0.02	1.19
Absolute Uncertainty (%, lbs)	0.04	1.9
Percent Uncertainty (%)	0.36	1.6

E California Commercial Food Service Water Rates



FSTC Researchers compiled information from different sources including:

1) Black and Veatch Corporation. "50 Largest Cities: Water/Wastewater Rate Survey". 2008. Web.

2) California's largest cities local municipalities' utility rates:
   a. Los Angeles: http://www.ladwp.com/ladwp/homepage.jsp
   b. Oakland: http://www.ebmud.com/
   c. Sacramento: http://www.cityofsacramento.org/utilities/water/
   d. San Diego: http://www.sandiego.gov/water/rates
   e. San Francisco: http://sfwater.org/mc_main.cfm/MC_ID/13
   f. San Jose: http://www.sanjoseca.gov/esd/rates.asp
   g. Fresno: http://www.fresno.gov/Government/DepartmentDirectory/PublicUtilities/Watermanagement/Default.htm
   h. Long Beach: http://www.lbwater.org/