Induction Cooktop Analysis

Introduction

Induction, defined as the production of an electromotive force across an electrical conductor in a changing magnetic field, is a highly efficient method of transferring energy to electrical components like motors, generators, and other media like cookware. In the case of the later, a metal pan or pot becomes the actual heat source once placed in an induction appliance's electromagnetic field. The result is a highly energy efficient appliance when compared to those using conventional heating methods like resistive elements or natural gas flames. These traditional methods rely on conduction, convection and radiation which are inherently less effective at transferring energy to the cookware and ultimately the food being cooked.

First introduced to the American public in middle of the 20th century as a home appliance curiosity, and later in the 1970s for wider general consumption, induction cooktops did not gain any significant consumer uptake due to cost, durability and poor performance. Fortunately, European and Asian manufactures continued to develop induction cooking appliances for their respective residential markets as these homeowners faced energy, space and safety considerations that their American counterparts did not. While induction appliances, mainly small, low power countertop hobs kept a toehold in American commercial kitchens and buffet lines, it is in the most recent decade that a wider range of more powerful and versatile induction cooking and warming appliances have proliferated in these kitchens.

Today, commercial food service equipment manufacturers offer high power induction cooktops, as well induction griddles, Chinese woks, soup warmers, rethermalizers and buffet line hot food wells. Nowhere has the power increase in induction cooking appliances been more pronounced than in the cooktop category. To successfully compete with the traditional and entrenched natural gas-powered open burners, manufacturers have developed high power 208 volt/30-amp cooktops. These appliances produce 2.5 kW to 5 kW of power, making them comparable to a 20 kBtu/h to 30kBtu/h natural gas open burner. With regards to the physical cooking surface workspace, multiple 2 and 4 hob induction units can be grouped together to provide equivalent production capacity to the typical natural gas 6 burner open burner ranges.

Figure 1: Commercial Cooktop Appliances (left to right): Electric Resistance , Natural Gas and Electric Induction

Induction Market Adoption

Induction and Foodservice Perceptions/Barriers

A common opinion in the foodservice industry is that all electric cooktops are inferior to gas cooktops regarding performance and ease of use. This is generally true when comparing a gas cooktop to an electric resistance element cooktop. Electric resistance cooktops are slow to heat up, cool down, and modulate temperatures for precision cooking. Induction does not share these challenges - the cool down time and temperature modulation capabilities are similar to that of traditional gas cooktops and the heat up time can be considerably faster. However, outdated perspectives on electric cooktops caused by the weak performance of electric resistance units still hinder the perception and adoption of induction cooktops.

Boil & Simmer Test in Real Life

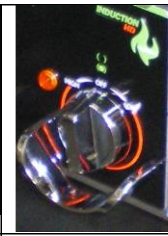
Why is it so hard for chefs and cooks to adopt something that would allow them to cook in a faster and sometimes more precise manner? One reason for this is visual feedback. We can separate most cooktop cooking into two categories, production and execution. Production is the preparation of food products and execution is the finishing portion. If a customer were to order soup at a restaurant, it is a reasonable expectation that the soup would be served within minutes. However, soup often takes much longer to make than a few minutes. Cooks prepare and hold key components of the recipe ahead of time, combining and reheating as needed to deliver the soup in a “reasonable” amount of time.

During the production process, cooks use gas flame size to visually gauge a desired temperature setpoint. This requires adjusting and readjusting the flame as the volume in the pot decreases from evaporation. From an execution perspective, this flame allows cooks to adjust quickly; in time this develops into muscle memory. If the flame visualization is removed from the cooktop, the cooks lose their reference point.

Induction employs a set of different reference points, one being the ability to cook by temperature. From a production standpoint, cooks can choose a desired set point temperature - this is particularly useful when the process requires a constant temperature. When performing this same process with a gas cooktop, constant monitoring is required since volume decreases as water evaporates, meaning cooks need to lower energy to maintain the desired temperature. Induction cooktops have sensors to maintain this temperature automatically, requiring much less effort from cooks.

During execution, the knob position replaces the flame feedback. Cooks often need to compensate for the slow pan preheat time associated with gas cooktops by turning the burner to 100% or near 100% ability to achieve timely preheat. Induction has much more stable temperature control and faster preheat times. This equates to less heat energy needed to achieve preheat and consistent preheat temperatures, with a knob position that can be easily memorized.

Most induction cooktop manufacturers offer different control options. The less expensive controls mimic a gas input rate knob where the power to the HOB correlates to the position on the dial. More sophisticated controls are digital with button incremental temperature adjustment or additional analogue knobs or sliders for quick adjustment. Digital controls often have distinct visualization for the chef that indicate the level of power delivered to the HOB.

			
Digital Slider Controls	**Digital Knob Controls**	**Digital Touch Controls**	**Manual Controls**

Induction Cooktop Pros

Often the menu design and offerings require taking the kitchen’s output abilities into account; modular design associated with countertop induction units allows the cook line configuration to be changed as needed to meet business demands. Less radiant heat from an induction cooktop compared to gas or resistance heating results in less heat load to space, thereby saving on HVAC costs as well as creating a more comfortable work environment. Cooler surfaces of induction also decrease the potential for personal injury associated with burns. Faster preheat and cook times create potential for higher revenue potential. Increase in efficiency and decreased cook time may result in the need for less equipment to achieve the same capacity. Certain precision processes like melting chocolate or butter can be done more accurately by setting the temperature of the pan with certain induction cooktops. Cleanability is an advantage of induction cooktops, where a flat surface can be easily wiped down, whereas gas cooktops have more crevices where food can get stuck.

Induction Cooktop Cons

Challenges to adopting induction are the cost of the units being considerably more than their gas and resistance element counterparts. Installation can also prove to be costly as a retrofit into existing kitchens piped with a gas service would require electrical panel upgrades along with running wiring. To achieve maximum effectiveness, induction ready pans are required. This would exclude most aluminum pans on the market, though a few induction manufacturers are stating the ability to use aluminum pans. While the purchase cost of heavier duty induction pans can be considerably more than that of aluminum however, the total lifetime cost is lower since the pan lasts much longer before needing replacement.

The foodservice industry has been slow to adopt induction and other technologies designed to increase speed of service, reduce labor loads, and achieve effective energy use. Gas cooktops due to their simple and robust design have the potential to last much longer than induction tops. Induction hobs have an effective life which often requires for budgeted replacement, but the faster cook times can translate to higher throughput and thus higher revenue potential. The idea is that this will result in a profitable return on investment, but the industry is still uncertain of such claims.

Observations

More power is not always better - higher powered units at the 5kW level seem to be ideal for production, where pot boil volume is higher, or in high heat processes such as wok style cooking. For most western style sauté cooking, hobs ranging from 2.5-3.5kW seem to be ideal for most operations. One challenge with higher powered units is that, on a power scale from 1-10, the jump from 2-3 can be much more drastic than that of mid-powered units. Simmering and sautéing once the pot or pan is up to temperature is done at the lower power levels that are 10-30% of the maximum output. Lower input units have more precise power modulation at these lower input rates, giving controllability comparable to the infinitely adjustable manual gas valve.

Appliance Performance Characterization

Frontier Energy conduction a series of controlled laboratory tests to better characterize the operation and energy use of different induction cooktops. The American Standard Test Method for Performance of Range Tops (ASTM F1521) determines the appliance energy efficiency and production capacity with a water "boil" test. Through the application of this test method, natural gas or electrical energy consumption can be accurately measured and applied to operating energy use and cost models. Further, this performance data can help equipment specifiers better match an appliance's production capabilities with the output needs of the operation itself. Outside of the standard test method, a partial energy consumption load test, or "simmer" test helps to further characterize the appliance's ability to maintain a desired food product temperature integrated controls are employed to reduce the energy input of the appliance. Lastly, a fry pan, solid food product or "sauté" test is used to determine the energy use and production capacity of an appliance when cooking a solid food product like hamburger patties.

Maximum Energy Load/Efficiency Test - Boiling

The cooking energy efficiency test consists of bringing a pot filled with 20 lbs of room temperature water to a near boil temperature of 200°F while the appliance is set to its maximum control input. This "boil" test precisely measures the amount of energy the appliance consumes as it heats the contents of the pot.

Application of the water boil test at the Frontier Energy Food Service Technology Center (FSTC) on natural gas open burners, resistive electric element cooktops, and induction cooktops has resulted in a comprehensive characterization of the three-heating method's respective energy efficiency performance. Natural gas, resistive electric, and electric induction exhibited ranges of efficiencies between 25% and 40%, 65% and 75%, and 80% to 85%, respectively. Table 1 summarizes the water boil performance of several induction cooktops tested at the FSTC.

Table 1. Water Boil Test Results for Popular Commercial Induction Cooktops

Voltage	**120V**	**120V**	**120V**	**208V**	**208V**	**208V**	**208V**	**208V**
Model	A	B	C	D	E	F	G	H
Power Per HOB	1.8kW	1.4kW	1.8kW	2.5 kW	3.5 kW	3.5 kW	5 kW	5 kW
Boil Efficiency (%)	82.9	82.7	82.0	87.8	87.0	83.5	83.5	90.4
20lb Boil Time* (min)	33.6	42.1	35.4	22.2	17.2	16.7	13.9	10.5

*70°F to 200°F heat up time

Figure 2: Water Boil Test for Induction Cooktops

Partial Energy Load Test – Simmering

A simmer is a steady state of boiling without temperature increases or decreases. Although simmer is usually visually quantified by the formation of bubbles on the surface of the water, lab testing was conducted by adjusting the appliance controls to maintain 20lb of water at 210±2°F. This test characterizes how the induction cooktop operates at partial power conditions and its ability to maintain temperature. Higher-end induction cooktops feature multiple feedback temperature sensors which regulate simmer temperature based on setpoint.

Of the 6 induction cooktops for which the simmer test was conducted, 3 of the units had energy use rates of approximately 0.95 kW, while two others had moderately higher energy input rates of approximately 1.10 kW. The final and lowest energy consuming unit had an energy input rate of 0.88 kW. Table 2 summarizes the simmer performance of the induction cooktops tested at the FSTC.

Table 2: Simmer Test Results for Popular Commercial Induction Cooktops

Voltage	**120V**	**208V**	**208V**	**208V**	**208V**	**208V**
Model	B	D	E	F	G	H
Power Per HOB (kW)	1.4	2.5	3.5	3.5	5.0	5.0
Control Setpoint	220°F	220°F	215°F	Level 3	Level 3	Level 4
Average Simmering Power (kW)	0.94	0.88	1.10	1.08	0.98	0.95

Solid Food Energy Load Test – Sauté Test

ASTM F1275 Standard Test Method for Performance of Griddles quantifies commercial griddle performance and was used to assess the cooking appliances' energy efficiency and production capacity when tasked with cooking solid food product like hamburger patties. Sauté pans and griddle surfaces cook food in the same manner, via conduction between the food product and a flat heated surface. While the griddle test is conducted with multiple frozen burgers, the cooktop and accompanying 10" sauté pan cooked a single ¼ lb 80% protein/20% fat burger. The pan is first preheated to 375°F, then a frozen burger is placed in the pan, flipped when 60% of the cooktime elapses and cooked until it reaches a weight loss of 35% which correlates to a temperature of 175°F.

The sauté test captured a wide range of varying levels of performance from unit to unit, most notably with regards to fry pan pre heat times. Unsurprisingly, the higher the appliance's power input, the faster the accompanying pan's heat up time. Also notable was the average power consumption of the two 5.0 kW units with one having an average energy rate of 1.36 kW and the other with a power consumption rate 35% lower at 0.87 kW. Table 3 summarizes the sauté performance of several induction cooktops tested at the FSTC.

Table 3. Burger Sauté Results for Popular Commercial Induction Cooktops

Voltage	**120V**	**208V**	**208V**	**208V**	**208V**
Model	B	D	E	G	H
Power Per HOB (kW)	1.4	2.5	3.5	5.0	5.0
Cooking Efficiency (%)	42.5	39.5	38.3	34.8	39.5
Burger Cook Time (min)	5.96	5.28	5.75	5.24	5.48
Pan Preheat Time (min)	1.46	1.66	1.54	0.71	0.63
Cooking Power Level	30-50%	20-30%	20-30%	20-30%	20-30%
Average Cooking Power (kW)	0.67	0.78	0.77	1.36	0.87

Figure 3. Frozen Burger Sauté Test

Conclusions

Application of the regimented ASTM test method, simmer test and sauté test demonstrated notable performance differences across induction models, often correlating with the maximum input rate of the appliance. Boil efficiencies generally increased with the input power of the unit. Higher power leads to quicker boiling times, which minimizes the time for the pot to lose heat to the ambient air. However, simmering and sauté cooking efficiencies were generally higher among the lower powered units. Higher powered units can sometimes have larger gaps between their available power settings, so this difference may be due to the ability of lower powered units to more precisely find the optimum rates for simmering and sautéing. Frontier Energy recommends that the ASTM methodology for testing cooktops be modified to include the simmer and sauté test, which more fully characterize the possible uses and advantages of different cooktop designs. The boil test alone is not sufficient for characterizing energy efficiency, especially for cooktops with advanced energy saving control algorithms.

Despite the differences across units though, the test results indicate that induction cooktops are consistently energy efficient when compared to traditional heating methods, which have a boil efficiency in the 70 – 80% range. Once the hurdles of adequate electrical service, proper cookware and operator perception are overcome, induction cooktops can offer significant benefits. Induction cooktops cook more efficiently and consistently, reduce heat gain to the kitchen, reduce burn risks, simplify cleaning and improve indoor air quality. Together, these qualities help to overcome the initial purchase price premium and potential infrastructure costs of induction appliances.

Frontier Energy recommends further testing to characterize how induction compares to other cooktop technologies during sautéing and simmering, to more fully characterize the energy efficiency differences. Additional research to determine whether different cookware affects the energy test results could also better inform more comprehensive kitchen design optimization. The focus is often placed on the appliance, but the cookware paired with the equipment might also prove to have a significant impact.

Appendix A: Test Methodology

1. Install cooktop according to manufacturer's specifications
2. Use the same cookware set for all ranges tested
    a. Stainless steel large 20-quart pot with lid: 20lb of water, covered
    b. Stainless steel pan medium 10" top diameter, 2 ± 0.2 lb: ¼lb 80/20 frozen hamburger, uncovered
3. Attach thermocouples to each cooking vessel:
    a. Pot:
        i. Geometric center 1" from the bottom
        ii. Geometric center 1" submerged in liquid from the top lid
    b. Pan:
        i. Welded to cooking surface, 1" from handle joint, not to interfere with hamburger cooking
    c. Freezer:
        i. Monitor temperature for the last hour of burger holding with a thermocouple logger and a thermocouple inside the burger box
4. Verify the test voltage at full burner input is within 5% of specification
5. Verify the tested input rate is within 5% of specification during water boil test
6. Water boil test conducted with the pot and water volume specified in section 2a.
    a. Initial water temperature 70±2F
    b. Record pot weight and material
    c. Burner input rate set to maximum
    d. Final water temperature 200F per DAQ, needs to get higher for simmer
    e. Conducted as a single replicate
    f. Record temperature, time, energy and voltage
    g. Leads to simmer test
7. Simmer test conducted after the boil test with the pot and water volume specified in section 2a.
    a. Achieve 212F±2
    b. Set burner input level to maintain simmer
    c. Record temperature, time, energy and voltage during simmer for 15 mins
    d. Verify simmer conditions are steady throughout the 15-minute test
    e. Adjust input rate and repeat if 7d not met
8. Sauté test conducted with the pan and product specified in section 2b.
    a. Use frozen product stabilized in a 0F±5F environment for at least 12 hours, do not have product out of freezer for more than 1 minute prior to cooking
    b. Record pan weight and material
    c. Record initial food product weight using a high-resolution scale
    d. Preheat pan to 375F±5F per welded thermocouple
    e. Record temperature, time and energy to preheat pan
    f. Place frozen hamburger patty in the hot pan and adjust controls as needed to maintain pan temperature at 375F±25F throughout sauté test
    g. After 60% of estimated sauté time elapses, flip the patty with a spatula
    h. Remove patty after estimated sauté time and stop recording temperature, time and energy to cook burger.
    i. Record final product weight using a high-resolution scale
    j. Verify cooked weight loss was 35±2%, adjust cook time or setting if not
    k. Conduct additional tests until three completed tests meet the 8j conditions