Induction cooking

Induction cooking uses induction heating to directly heat a cooking vessel, as opposed to using heat transfer from electrical coils or burning gas as with a traditional cooking stove. For nearly all models of induction cooktop, a cooking vessel must be made of a ferromagnetic metal, or placed on an interface disk which enables non-induction cookware to be used on induction cooking surfaces.

Top view of an induction stove

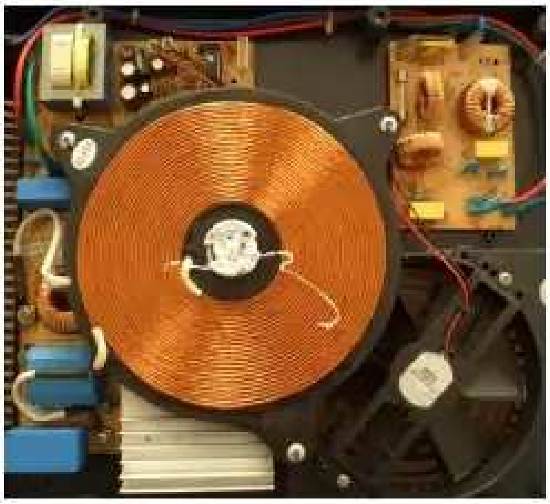
In an induction cooker, a coil of copper wire is placed underneath the cooking pot. An alternating electric current flows through the coil, which produces an oscillating magnetic field. This field induces an electric current in the pot. Current flowing in the metal pot produces resistive heating which heats the food. While the current is large, it is produced by a low voltage.

An induction cooker is faster and more energy-efficient than a traditional electric cooking surface. It allows instant control of cooking energy similar to gas burners. Other cooking methods use flames or red-hot heating elements; induction heating heats only the pot. Because the surface of the cook top is heated only by contact with the vessel, the possibility of burn injury is significantly less than with other methods. The induction effect does not directly heat the air around the vessel, resulting in further energy efficiencies. Cooling air is blown through the electronics but emerges only a little warmer than ambient temperature.

The magnetic properties of a steel vessel concentrate the induced current in a thin layer near its surface, which makes the heating effect stronger. In non-magnetic materials like aluminum, the magnetic field penetrates too far, and the induced current encounters little resistance in the metal. At least one high-frequency "all metal" cooker is available, that works with lower efficiency on non-magnetic metal cookware.

Design

An induction cooker transfers electrical energy by induction from a coil of wire into a metal vessel that must be ferromagnetic. The coil is mounted under the cooking surface, and a large alternating current is passed through it. The current creates a dynamic magnetic field. When an electrically conductive pot is brought close to the cooking surface, the magnetic field induces eddy currents in the pot. The eddy currents flow through the electrical resistance of the pot to produce heat; the pot then in turn heats its contents by heat conduction.



Inside view of an induction cooker: the large copper coil forms the magnetic field, a cooling fan is visible below it, and power supply and line filter surround the coil

The cooking vessel is made of stainless steel or iron. The increased magnetic permeability of the material decreases the skin depth, concentrating the current near the surface of the metal, and so the electrical resistance will be further increased. Some energy will be dissipated wastefully by the current flowing through the resistance of the coil. To reduce the skin effect and consequent heat generation in the coil, it is made from litz wire, which is a bundle of many smaller insulated wires in parallel. The coil has many turns, while the bottom of the pot effectively forms a single shorted turn. This forms a transformer that steps down the voltage and steps up the current. The resistance of the pot, as viewed from the primary coil, appears larger. In turn, most of the energy becomes heat in the high-resistance steel, while the driving coil stays cool.


Side view of an induction stove

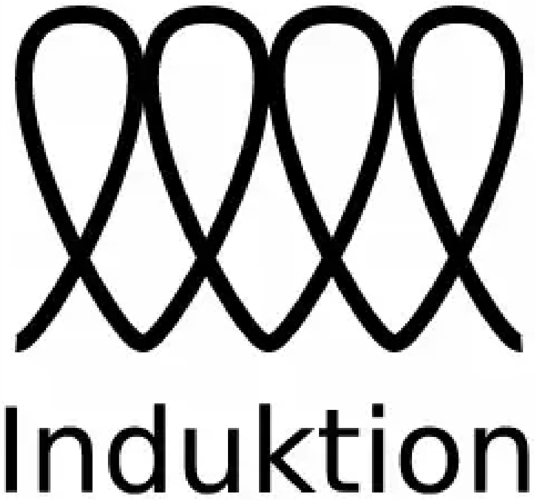
The cooking surface is made of a glass-ceramic material which is a poor heat conductor, so only a little heat is lost through the bottom of the pot. In normal operation the cooking surface stays cool enough to touch without injury after the cooking vessel is removed.

Units may have one, two, three, four or five induction zones, but four (normally in a 30-inch-wide unit) is the most common in the US and Europe. Two coils are most common in Hong Kong and three are most common in Japan. Some have touch-sensitive controls. Some induction stoves have a memory setting, one per element, to control the time that heat is applied. At least one manufacturer makes a "zoneless" induction cooking surface with multiple induction coils. This allows up to five utensils to be used at once anywhere on the cooking surface, not just on pre-defined zones.[1]

Small stand-alone portable induction cookers are relatively inexpensive, priced from around US$20 in some markets.

Cookware

Cookware for an induction cooking surface will be generally the same as used on other stoves. Some cookware or packaging is marked with symbols to indicate compatibility with induction, gas, or electric heat.



Cookware may carry a symbol that identifies it as compatible with an induction cooktop.

Induction cooking surfaces work well with any pans with a high ferrous metal content at the base. Cast iron pans and any black metal or iron pans will work on an induction cooking surface. Stainless steel pans will work on an induction cooking surface if the base of the pan is a magnetic grade of stainless steel. If a magnet sticks well to the sole of the pan, it will work on an induction cooking surface. An "all-metal" cooker will work with non-ferrous cookware, but available models are limited.

For frying, a pan with a base that is a good heat conductor is needed to spread the heat quickly and evenly. The sole of the pan will be either a steel plate pressed into the aluminum, or a layer of stainless steel over the aluminum. The high thermal conductivity of aluminum pans makes the temperature more uniform across the pan.

Stainless frying pans with an aluminum base will not have the same temperature at their sides as an aluminum sided pan will have. Cast iron frying pans work well with induction cooking surfaces but the material is not as good a thermal conductor as aluminum.

When boiling water, the circulating water spreads the heat and prevents hot spots. For products such as sauces, it is important that at least the base of the pan incorporates a good heat conducting material to spread the heat evenly. For delicate products such as thick sauces, a pan with aluminum throughout is better, since the heat flows up the sides through the aluminum, allowing the cook to heat the sauce rapidly but evenly [*citation needed*].

Aluminum or copper alone does not work on an induction stove because of the materials' magnetic and electrical properties.[2] Aluminum and copper cookware are more conductive than steel, and the skin depth in these materials is larger since they are non-magnetic. The current flows in a thicker layer in the metal, encounters less resistance and so produces less heat. The induction cooker will not work efficiently with such pots.

The heat that can be produced in a pot is a function of the surface resistance. A higher surface resistance produces more heat for similar currents. This is a "figure of merit" that can be used to rank the suitability of a material for induction heating. The surface resistance in a thick metal conductor is proportional to the resistivity divided by the skin depth. Where the thickness is less than the skin depth, the actual thickness can be used to calculate surface resistance. Some common materials are listed in this table.

Household foil is much thinner than the skin depth in aluminum at the frequencies used by an induction cooker. Here the foil has melted where it was exposed to the air after steam formed under it. Cooking surface manufacturers prohibit the use of aluminum foil in contact with an induction cooking surface.

Skin depth at 24 kHz

Material	Resistivity (10^{-6} ohm-inches)	Relative permeability	Skin depth, inches	Surface resistance, 10^{-3} ohms/square (thick material)	Surface resistance, Relative to copper
Carbon steel 1010	9	200	0.004	2.25	56.25
Stainless steel 432	24.5	200	0.007	3.5	87.5
Stainless steel 304	29	1	0.112	0.26	6.5
Aluminum	1.12	1	0.022	0.051	1.28
Copper	0.68	1	0.017	0.04	1

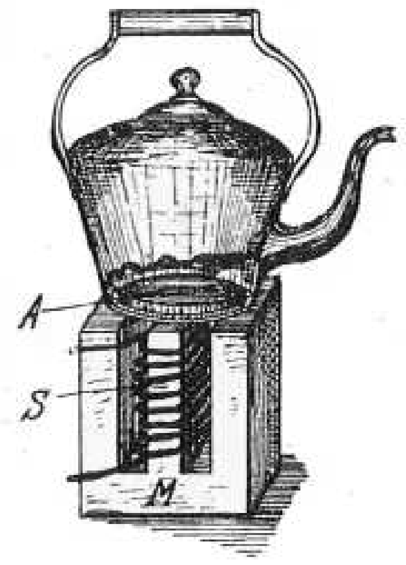
To get the same surface resistance as with carbon steel would require the metal to be thinner than is practical for a cooking vessel; a copper vessel bottom would be 1/56th the thickness of the carbon steel pot. Since the skin depth is inversely proportional to the square root of the frequency, this suggests that much higher frequencies (say, several megahertz) would be required to obtain equivalent heating in a copper pot as in an iron pot at 24 kHz. Such high frequencies are not feasible with inexpensive power semiconductors; in 1973 the silicon-controlled rectifiers used were limited to no more than 40 kHz. Even a thin layer of copper on the bottom of a steel cooking vessel will shield the steel from the magnetic field and make it unusable for an induction top. Some additional heat is created by hysteresis losses in the pot due to its ferromagnetic nature, but this creates less than ten percent of the total heat generated.

"All metal" models

New types of power semiconductors and low-loss coil designs have made an all-metal cooker possible, but the electronic components are relatively bulky.

Panasonic Corporation in 2009 developed a consumer induction cooker that uses a higher-frequency magnetic field, and a different oscillator circuit design, to allow use with non-ferrous metals.

History



An early induction cooker patent from 1909 illustrates the principle. The coil of wire S induces a magnetic field in the magnetic core M. The magnetic field passes through the bottom of the pot A, inducing eddy currents within it. Unlike this concept, a modern cooking surface uses electronically-generated high-frequency current

First patents date from the early 1900s.[3] Demonstration stoves were shown by the Frigidaire division of General Motors in the mid-1950s[4] on a touring GM showcase in North America. The induction cooker was shown heating a pot of water with a newspaper placed between the stove and the pot, to demonstrate the convenience and safety. This unit, however, was never put into production.

Modern implementation in the USA dates from the early 1970s, with work done at the Research & Development Center of Westinghouse Electric Corporation at Churchill Borough, near Pittsburgh, That work was first put on public display at the 1971 National Association of Home Builders convention in Houston, Texas, as part of the Westinghouse Consumer Products Division display.[*citation needed*] The stand-alone single-burner range was named the Cool Top Induction Range. It used paralleled Delco Electronics transistors developed for automotive electronic ignition systems to drive the 25 kHz current.

Westinghouse decided to make a few hundred production units to develop the market. Those were named Cool Top 2 (CT2) Induction ranges. The development work was done at the same R&D location, by a team led by Bill Moreland and Terry Malarkey. The ranges were priced at $1,500, including a set of high quality cookware made of Quadraply, a laminate of stainless steel, carbon steel, aluminum and another layer of stainless steel (outside to inside).

Production took place in 1973 through to 1975 and stopped, coincidentally, with the sale of Westinghouse Consumer Products Division to White Consolidated Industries Inc.

CT2 had four burners of about 1,600 watts each. The range top was a Pyroceram ceramic sheet surrounded by a stainless-steel bezel, upon which four magnetic sliders adjusted four corresponding potentiometers set below. That design, using no through-holes, made the range proof against spills. The electronic section was made in four identical modules cooled by fans.

In each of the electronics modules, the 240V, 60 Hz domestic line power was converted to between 20V to 200V of continuously variable DC by a phase-controlled rectifier. That DC power was in turn converted to 27 kHz 30 A (peak) AC by two arrays of six paralleled Motorola automotive-ignition transistors in a half-bridge configuration driving a series-resonant LC oscillator, of which the inductor component was the induction-heating coil and its load, the cooking pan. The circuit design, largely by Ray Mackenzie, successfully dealt with certain bothersome overload problems.

Control electronics included functions such as protection against over-heated cook-pans and overloads. Provision was made to reduce radiated electrical and magnetic fields. There was also magnetic pan detection.

CT2 was UL Listed and received Federal Communications Commission (FCC) approval, both firsts. Numerous patents were also issued. CT2 won several awards, including Industrial Research Magazine's IR-100 1972 best-product award [5] and a citation from the United States Steel Association. Raymond Baxter demonstrated the CT2 on the BBC series *Tomorrow's World*. He showed how the CT2 could cook through a slab of ice.

Sears Kenmore sold a free-standing oven/stove with four induction-cooking surfaces in the mid-1980s (Model Number 103.9647910). The unit also featured a self-cleaning oven, solid-state kitchen timer and capacitive-touch control buttons (advanced for its time). The units were more expensive than standard cooking surfaces.

In 2009 Panasonic developed an all-metal induction cooker that used a different coil design and a higher operating frequency to allow operation with non-ferrous metal cookware. However, the units operate with somewhat reduced coupling efficiency and so have reduced power compared to operation with ferrous cookware.

Use

Induction equipment may be a built-in surface, part of a range, or a standalone surface unit. Built-in and rangetop units typically have multiple elements, the equivalent of separate burners on a gas-fueled range. Stand-alone induction modules are usually single-element, or sometimes have dual elements. All such elements share a basic design: an electromagnet sealed beneath a heat-resisting glass-ceramic sheet that is easily cleaned. The pot is placed on the ceramic glass surface and begins to heat up, along with its contents.

In Japan, some models of rice cookers are powered by induction. In Hong Kong, power companies list a number of models. Asian manufacturers have taken the lead in producing inexpensive single-induction-zone surfaces; efficient, low-waste-heat units are advantageous in densely populated cities with little living space per family, as many Asian cities are. Induction cookers are less frequently used in other parts of the world.

Induction ranges may be applicable in commercial restaurant kitchens. Electric cooking avoids the cost of natural gas piping and in some jurisdictions may allow simpler ventilation and fire suppression equipment to be installed.[6] Drawbacks for commercial use include possible breakages of the glass cook-top, higher initial cost and the requirement for magnetic cookware.

Benefits

An induction cooking surface boiling water through several thicknesses of newsprint. The paper is undamaged since heat is produced only in the bottom of the pot

This form of flameless cooking has certain advantages over conventional gas flame and electric cookers, as it provides rapid heating, improved thermal efficiency, and greater heat consistency, yet with precise control similar to gas. In situations in which a hotplate would typically be dangerous or illegal, an induction plate is ideal, as it creates no heat itself.

The high efficiency of power transfer into the cooking vessel makes heating food faster on an induction cooking surface than on other electric cooking surfaces. Because of the high efficiency, an induction element has heating performance comparable to a typical consumer-type gas element, even though the gas burner would have a much higher power input.

Induction cookers are safer to use than conventional cookers because there are no open flames. The surface below the cooking vessel is no hotter than the vessel; only the pan generates heat. The control system shuts down the element if a pot is not present or not large enough. Induction cookers are easy to clean because the cooking surface is flat and smooth, even though it may have several heating zones. Since the cooking surface is not directly heated, spilled food does not burn on the surface.

Since heat is being generated by an induced electric current, the unit can detect whether cookware is present (or whether its contents have boiled dry) by monitoring how much power is being absorbed. That allows functions such as keeping a pot at minimal boil or automatically turning an element off when cookware is removed.

Because the cook top is shallow compared to a gas-fired or electrical coil cooking surface, wheelchair access can be improved; the user's legs can be below the counter height and the user's arms can reach over the top.

Limitations

Cookware must be compatible with induction heating; glass and ceramics are unusable, as are solid copper or solid aluminum cookware for most models of cooker. Cookware must have a flat bottom since the magnetic field drops rapidly with distance from the surface. (Special and costly wok-shaped units are available for use with round-bottom woks.) Induction disks are metal plates—much like a skillet with no sides—that heat up non-ferrous pots by contact, but these sacrifice much of the power and efficiency of direct use of induction in a compatible cooking vessel. Further, cheap induction cookers regulate the transmitted power by simply powering the field on and off for specified times, like most microwave ovens do. If a pot with a thin bottom is used, the contained liquid boils intermittently. This does not occur with cookware that has a thicker bottom or with better induction cookers.

Manufacturers advise consumers that the glass ceramic top can be damaged by impact, although cooking surfaces are required to meet minimal product safety standards for impact.[7] Aluminum foil can melt onto the top and cause permanent damage or cracking of the top. Damage by impact also relates to sliding pans across the cooking surface, which users are advised against. As with other electric ceramic cooking surfaces there may be a maximum pan size allowed by the manufacturer.

A small amount of noise is generated by an internal cooling fan. Audible noise (a hum or buzz) may be produced by cookware exposed to high magnetic fields, especially at high power if the cookware has loose parts; better-grade cookware with welded-in cladding layers and solid riveting should not produce this type of noise. Some users may detect a whistle or whine sound from the cookware, or from the power electronic devices. Some cooking techniques available when cooking over a flame are not applicable. Persons with implanted cardiac pacemakers or other electronic medical implants are usually instructed to avoid sources of magnetic fields; the medical literature seems to suggest that proximity to induction cooking surfaces is safe, but they should always check first with their cardiologists. Radio receivers near the unit may pick up some electromagnetic interference.

An induction (or any electric) stove will not operate during a power outage. Older gas-stoves do not need electric power to operate; however, modern gas-stoves with electrical ignition require an external ignition source (e.g. matches) during power outages.

Efficiency and environmental impact

According to the U.S. Department of Energy, the efficiency of energy transfer for an induction cooker is 84%, versus 74% for a smooth-top non-induction electrical unit, for an approximate 12% saving in energy for the same amount of heat transfer.

Energy efficiency is the ratio between energy delivered to the food and that consumed by the cooker, considered from the "customer side" of the energy meter. Cooking with gas has an energy efficiency of about 40% at the customer's meter and can be raised only by using very special pots, so the DOE efficiency value will be used.

When comparing consumption of energies of different kinds, in this case natural gas and electricity, the method used by the US Environmental Protection Agency refers to source (also called primary) energies. They are the energies of the raw fuels that are consumed to produce the energies delivered on site.[8] The conversion to source energies is done by multiplying site energies by appropriate source-site ratios. Unless there are good reasons to use custom source-site ratios (for example for non US residents or on-site solar), EPA states that "it is most equitable to employ national-level ratios". These ratios amount to 3.34 for electricity purchased from the grid, 1.0 for on-site solar, and

1.047 for natural gas. The natural gas figure is slightly greater than 1 and mainly accounts for distribution losses. The energy efficiencies for cooking given above (84% for induction and 40% for gas) are in terms of site energies at the customer's meters. The (US averaged) efficiencies recalculated relative to source fuels energies are hence 25% for induction cooking surfaces using grid electricity, 84% for induction cooking surfaces using on-Site Solar, and 38% for gas burners.

Source-site ratios are not formalized yet in Western Europe. A common consensus should arise on unified European ratios in view of the extension of the Energy Label to domestic water heaters. Unofficial figures for European source-site ratios are about 2.2 for electricity, 1.0 for on-site solar, and 1.02 for natural gas, thus giving overall (referred to source energy) efficiencies of 38% and 84% for induction cooking surfaces (depending on source electricity) and 39% for gas burners.

These provisional figures need to be somehow adjusted due to the higher gas burner efficiency, allowed in Europe by a less stringent limit on carbon monoxide emission at the burner. European and US standards differ in test conditions. The US ANSI Z21.1 standard allows a lower concentration of carbon monoxide (0.08%), compared to the European standard EN 30-1-1 which allows 0.2%. The minimum gas burner efficiency required in the EU by EN 30-2-1 is 52%, higher than the average 40% efficiency measured in US by DOE. The difference is mainly due to the weaker CO emission limit in EU, that allows more efficient burners, but also due to different ways in which the efficiency measurements are performed.

Whenever local electricity emits less than 435 grams of CO2 per kWh, the greenhouse effect of an induction cooker will be lower than that of a gas cooker. This again comes from the relative efficiencies (84% and 40%) of the two surfaces and from the standard 200 (±5) grams CO2/kWh emission factor for combustion of natural gas at its net (low) calorific value.Wikipedia:No original research#Synthesis of published material that advances a position

Gas cooking efficiencies may be lower if waste heat generation is taken into account. Especially in restaurants, gas cooking can significantly increase the ambient temperature in localized areas. Not only may extra cooling be required but zoned venting may be needed to adequately condition hot areas without overcooling other areas. Costs must be considered on an individual situation due to numerous variables in temperature differences, facility layout or openness, and heat generation schedule. Induction cooking using grid electricity may surpass gas efficiencies when waste heat and air comfort are quantified.

Vendors

The market for induction stoves is dominated by German manufacturers, such as AEG, Bosch, Fissler, Miele, and Siemens. The Spanish company Fagor, Italian firm Smeg, Sweden's Electrolux, and Slovenia's Gorenje are also key players in the European market. Prices range from about GB£250 to 1,000 within the United Kingdom. In 2006, Stoves launched the UK's first domestic induction range cooker at a slightly lower cost than those imported.

The European induction cooking market for hotels, restaurants and other caterers is primarily satisfied by smaller specialist commercial induction catering equipment manufacturers such as Adventys of France, Induced Energy of Brackley in the UK, Control Induction and Target Catering Equipment of the UK and Scholl of Germany.

Taiwanese and Japanese electronics companies are the dominant players in induction cooking for East Asia. After aggressive promotions by utilities in HK like Power HK Ltd, many local brands like UNIVERSAL, icMagIC, Zanussi, iLighting, German Pool also emerged. Their power and ratings are high, more than 2,800 watts. They are multiple zone and capable of performing better than their gas counterpart. The efficiency is as high as 90% and saves a lot of energy and is environmentally friendly. Their use by local Chinese for wok cooking is becoming popular. Some of these companies have also started marketing in the West. However, the product range sold in Western markets is a subset of that in their domestic market; some Japanese electronics manufacturers only sell domestically.

In the United States, as of early 2013 there are over five dozen brands of induction-cooking equipment available, including both build-in and countertop residential equipment and commercial-grade equipment. Even restricting to build-in residential-use units, there are over two dozen brands being sold; residential countertop units add another two-dozen-plus brands to the count.

The National Association of Home Builders in 2012 estimated that, in the United States, induction cooktops held only 4% of sales, compared to gas and other electric cooktops.[9]

In April 2010, *The New York Times* reported that "In an independent survey last summer by the market research company Mintel of 2,000 Internet users who own appliances, only 5 percent of respondents said they had an induction range or cooktop. . . . Still, 22 percent of the people Mintel surveyed in connection to their study last summer said their next range or cooktop would be induction."[10]

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[4] *Kitchen of the Future has Glass-Dome Oven and Automatic Food Mixer*, Popular Mechanics Apr 1956, page 88

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[6] Roger Fields, *Restaurant Success by the Numbers: A Money-Guy's Guide to Opening the Next Hot Spot*, Random House of Canada, 2007 ISBN 1-58008-663-2, pp. 144–145

[7] Hans Bach, Dieter Krause, *Low thermal expansion glass ceramics*, Springer, 2005 ISBN 3-540-24111-6 page 77, lists IEC, UL, Canadian, Australian and other standards with impact resistance requirements

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[9] http://www.nahb.org/generic.aspx?genericContentID=183725&fromGSA=1 *Kitchen Appliance Upgrades that Shine*, retrieved 2012 Aug 15

[10] http://www.nytimes.com/2010/04/07/dining/07induction.html?pagewanted=all *Is Induction Cooking Ready to Go Mainstream?* , retrieved 2013 Jan 31

External links

- Technical Support Document for Residential Cooking Products (http://www.eere.energy.gov/buildings/appliance_standards/residential/pdfs/cookgtsd.pdf)
- Video (http://www.finecooking.com/videos/induction-cooktop-action.aspx) demonstrating how an induction cook top works

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