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Energy efficiency analysis of different materials for cookware commonly used in induction cookers

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Abstract

The efficient use of energy is a priority when a technology migration plan is being executed. Several factors must be taken into account in order to achieve this goal. In this paper the migration from liquefied petroleum gas based cookers to electric induction cookers is analyzed, emphasizing on the selection of the best material to produce the cookware suitable for induction cookers in terms of energy saving and performance. To accomplish this study, several tests have been performed in three kind of pots made of different materials: stainless steel, cast iron and aluminium. These tests have allowed to evaluate some material properties as rust resistance, structural stability of pot bottom under thermal impact conditions, energy efficiency measurements in different body cookware materials, energy efficiency with different distances between induction zone and pot bottom, relation between energy efficiency and initial measurements of concavity/convexity and energy efficiency before and after thermal impact conditions. After completing this research, it has been found that the enameled cast iron and the stainless steel present higher efficiency in the same stove.

Peer-review under responsibility of Applied Energy Innovation Institute

Keywords: energy efficiency, induction cookers, cookware, pot, induction heating.

1. Introduction

Energy efficiency is the main component to achieve energy savings, allowing to obtain the same or better quality service or device with lower power consumption (Bertoldi, 2008). However, migration from conventional to more efficient technology involves a complex process. It is necessary to focus on the proper planning and taking the appropriate policies to ensure that migration produces the least possible impact on the population.

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Achieving a sustainable energy management system requires maximizing efficient use of energy resources, coupled with the preferential use of renewable energy sources. It is particularly necessary to introduce improvements in the policies of renewable energy and energy efficiency in homes (Milne & Boardman, 2000). Currently, Ecuador is running the migration from liquefied petroleum gas (LPG) based cookers to electric induction cookers plan for changing the energy matrix of the country from LPG and petroleum to electrical energy based on hydroelectric plants. A cookware manufacturing project for induction cookers is necessary to accomplish these policies. It is expected to fabricate and use around two to three million sets of induction cookware between 2014 and 2016; they would be formed by three pots with bottom diameters of 140, 160 and 180 mm respectively and a frying pan with bottom diameter of 180 mm (J. Martínez et al., 2014). In this context, it is really important to choose the material that has the best advantages in terms of energy efficiency and in cooking use.

The technique of heating by electromagnetic induction is well established and is an invaluable tool for industries engaged in heat treatment or hot working of metals, because of the high efficiency, precise control and low pollution properties. Since they were applied to home appliances in mid 1970s, much research into induction heating appliances has been performed. An induction cooker presents several advantages when compared with a traditional cooker. There are two major advantages of the induction cooker, namely, energy saving and safety enhancement (Barragan, et al., 2008).

The induction cookware must fulfill the principles of induction heating. Besides, it should also try to show good results in terms of energy efficiency; in these terms, it should allow a high speed of heating and dissipation. On the other hand, it is important that its price is as low as possible so that most of the people could afford a new cookware set, it cannot be made of a material that may have potential risks to human health and it should not rust or corrode during its lifetime (J. Martínez et al., 2014). The characteristics that the cookware material should have in order to be efficient are strictly related to good magnetic permeability to support the formation of a magnetic field, it must be made of a food grade material, and it should have a good thermal diffusivity, because they should be able to conduct heat quickly and evenly.

Several studies have been performed to improve energy efficiency opportunities in the residential sector in Ecuador (Orozco et al., 2014), studies in order to improve the energy efficiency in induction cookers (Riofrio et al., 2014), studies about convection or heat transfer during heating food (Houšová et al. 1985), but studies related to determine which material used for a pot have higher efficiency during the cooking process and have the fundamentals needed for an appropriate pot lifetime, have not been found.

Each one of the tests that have been performed in this research consist of evaluating the performance and behavior of stainless steel, enameled cast iron and aluminium pots, in order to validate their physical and mechanical properties when they are subjected to thermal impact and energy efficiency tests. In the end, a reduction in energy consumption in households is expected.

2. Materials and Methods

The following experiments were conducted using the observational method applied to three types of induction pots; each one is made from different materials as shown in Table 1. Each one of the pots was covered with a glass lid. The objective was to find pots with similar dimensions in order to obtain representative measures that could be compared. Several kinds of tests had been done using these pots in order to evaluate their characteristics and properties, as shown in Fig. 1. The following tests have been performed: a) Energy efficiency analysis of pots. b) Energy efficiency analysis of pots at different distance separations from the induction zone. c) Energy efficiency analysis of several stainless steel pots with different initial measurements of concavity/convexity. d) Structural stability of the pots bottom under thermal impact conditions. e) Energy efficiency analysis of pots before and after thermal impact test. It is important to notice that these tests were performed in the south of Quito (Ecuador), which is about 2800 meters above sea level, and has an atmospheric pressure of 728.4 hPa, which is the reason of the water boiling at 92 ° C.

Table 1 Specifications of the three tested pots

N°	Body Material	Bottom Material	Diameter of the bottom [cm]	Diameter of the top [cm]	Thickness of the body [mm]	Thickness of the bottom [mm]
1	AISI 304 Stainless steel	AISI 430 Stainless steel	17.00	20.00	0.5	1.8
2	Enameled iron	Enameled iron	15.00	20.00	0.7	0.7
3	Aluminium	Aluminium and AISI 430 Stainless steel	14.00	20.50	2.0	2.5

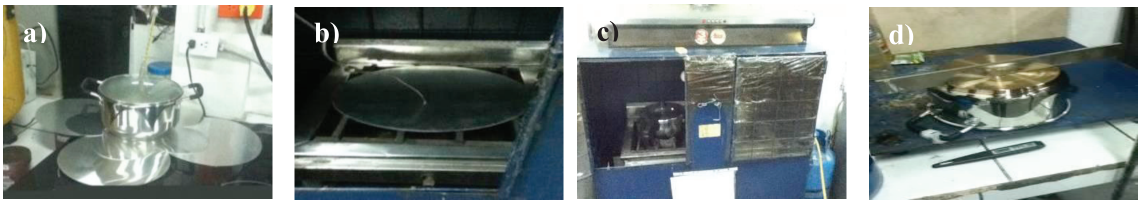

Fig. 1 a) Image of the discs used for the energy efficiency with different heights test. b) Image of aluminium disk over a heat source. c) Image of the pot under thermal impact conditions. d) Image of the concavity measurement process.

2.1. *Energy efficiency test*

In order to perform this test, it has been applied ASTM F 1521-03 and NTE 2851 standard test methods. Power was measured using the electrical parameters analyzer and through (1) the energy efficiency can be calculated:

$$\eta = \frac{(C_1 * m_1 + C_2 * m_2 + C_3 * m_3) * (T_f - T_o)}{P * t} * 100 \quad (1)$$

Where: η = Energy efficiency [%]; C_1 = Specific heat capacity of water, 4,18 kJ/kg; m_1 = Water mass [kg]; C_2 = Specific heat capacity of pot top and lid, 0,5 kJ/kg·°C, for stainless steel; 0,89 kJ/kg·°C, for aluminium and 0,45 kJ/kg·°C, for cast iron; m_2 = Total mass of pot [kg]; C_3 = Specific heat capacity of the glass lid, 0,876 kJ/kg·°C; m_3 = Lid mass [kg]; T_f= Final temperature [°C]; T_o= Initial temperature [°C]; P = Electrical power [W] and t = Time [s]. It was possible to calculate the error using the partial derivatives method, where $\Delta m_1 = \Delta m_2 = \Delta m_3 = 0{,}1g$; $\Delta T = 0.5°C$; $\Delta t = 1s$ and $\Delta P = 20W$ were measured during the test. Applying this method a 2.1 % error was determined.

2.2. *Energy efficiency with different heights test*

This test has two main objectives. On one hand, it is required to know the efficiency variation when separating the pot from the induction zone. On the other hand, it is important to see the effect that the concavity and convexity could have in energy efficiency. To obtain the measurements, the mentioned procedure for calculating the energy efficiency was followed; considering the same uncertainties, each test was done three times. In this case, aluminium discs with different thicknesses were added between the pot and the induction zone, using a configuration that allowed to get heights from 0.6 mm to 12.2 mm with a 0.05 mm uncertainty. Fig. 1 a) shows the discs configurations used for the test.

2.3. *Energy efficiency for several stainless steel pots with different initial measurements of concavity/convexity*

The objective of this test is to analyze the relation between the initial concavity/convexity measurements of 6 stainless steel pots with different diameters and their energy efficiency, in order to establish if the pot bottom shape changes would produce a variation on the energy efficiency. Firstly, the initial concavity/convexity measurements of each pot were taken using a feeler gauge; secondly, the mentioned proceeding for calculating the energy efficiency was followed.

2.4. Structural Stability of the pots bottom under thermal impact conditions test

The main objective of this test is to analyze how the cookware structural stability reacts to heat and in this way, getting to know the dimensional variations of cookware during the test. This test allows checking if a configuration would tend to be more concave or more convex with the action of heat. In order to perform this test the following tools were required: a) an indicator with 0.01 mm uncertainty, b) a feeler gauge with 0.05 mm uncertainty, c) an aluminum disc, d) a wood block, e) a heat source or a gas burner, f) a thermocouple and g) a chronometer. The procedure was the following: a) the initial pot concavity was measured and registered using the comparative indicator. b) The aluminium disc was put on the heat source until it reached a temperature of 350 ± 25 ºC, as shown in Fig. 1-b). c) The empty pot was put on the heated disc until it reached a temperature of 200 ºC, measured in their bottom center, (Fig. 1-c)). d) The pot was placed on the wood block and immediately, a quantity of water equal to 50 % of its capacity was added. e) The pot was kept on the wood block during 30 s. f) The pot was removed and was cooled down immersing it in water until the temperature dropped to 25 ºC. g) The pot bottom concavity was measured using a spirit level and a feeler gauge (Fig. 1-d)). h) This procedure was performed 40 times.

2.5. Energy efficiency after thermal impact conditions test

This test pretends to analyze what kind of pot configuration would gain or lose energy efficiency during its use and their concavity/convexity variations. To obtain the measurements, the mentioned proceeding for calculating the energy efficiency was followed. Each test was done three times.

3. **Results**

The obtained results allowed establishing: the relation between energy efficiency and pots bottom concavity/convexity, evolution of concavity/convexity of several pots, energy efficiency of several pots before and after structural stability of the pots bottom under thermal impact conditions test and finally, the behavior of energy efficiency with different distances between pot bottom and induction zone.

3.1. Energy efficiency with different heights test

Fig. 2-a) shows the behavior of energy efficiency according to the distance between pots bottom and the induction zone. When increasing the separation between induction cooker and cookware bottom the energy efficiency of the three kinds of pot materials decreases presenting a logarithmic curve fitting. It is important to mention that the aluminium pot worked properly until a 7.1 mm height, while stainless steel and enameled iron worked until a height of 15 mm. It can be observed that drops in energy efficiency are important when increasing distance, being the most important the aluminium efficiency drop and showing similarities between the cases of enameled iron and stainless steel.

3.2. Relation between energy efficiency and pots bottom concavity/convexity

Fig. 2-b) shows the relation between concavity/convexity measurements and energy efficiency of 6 stainless steel pots with different diameters. The results allowed concluding that with a higher pot

concavity, energy efficiency increases until concavity reaches a value of 0.90 mm.

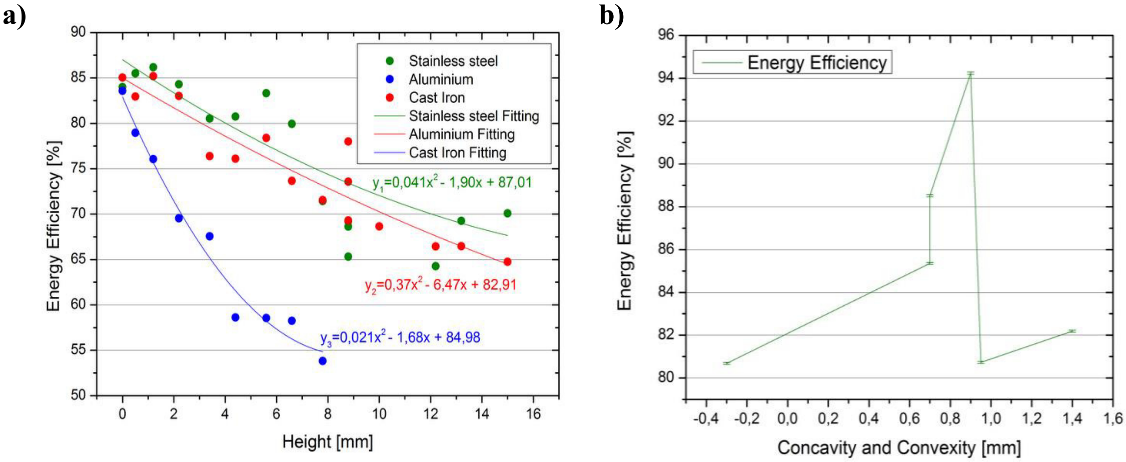

Fig. 2 a) Energy efficiency with different heights. b) Relation between concavity/convexity and energy efficiency.

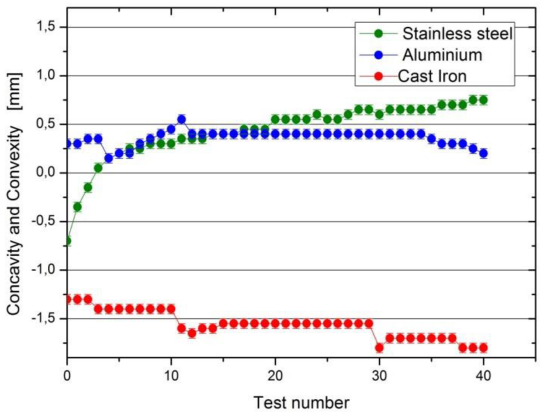

Fig. 3 Results of concavity and convexity after thermal impact

Table 2. Energy efficiency before and after structural stability of the pots bottom under thermal impact conditions test.

Body pot material	Energy efficiency before test [%}	Energy efficiency after test [%}
Stainless steel	86.62	83.98
Enameled iron	91.35	85.05
Aluminium	82.10	83.57

3.3. Concavity/convexity evolution

Fig. 3 shows concavity/convexity evolution of three pots. It can be concluded that stainless steel pot went from concave to convex, while aluminium pot went from convex to concave, and finally the enameled iron pot increased its concavity during the tests. An increase in convexity could cause a problem when cooking, because the contact area between the pot bottom and the induction zone could be smaller and it could present a destabilization during cooking process. Convexity and concavity also could cause an unequal heating and unsteadiness of pots bottom. It can produce a decrease on the energy efficiency as shown in Fig. 2-b).

3.4. Energy efficiency after thermal impact conditions test

Table 2 shows how energy efficiency of stainless steel pot decreased in a 3,28% after 40 thermal impact tests, while enameled iron pot decreased in a 6.9 % and finally energy efficiency for aluminum pot increased in a 1.70 %. These measurements are related to concavity/convexity measurements obtained in stainless steel pots of Fig. 2-b). The stainless steel increased its convexity, as a result energy efficiency decreased, the enameled iron increased its concavity, which made energy efficiency decrease and aluminum went from concave to convex, as a consequence energy efficiency increased.

4. Conclusions and discussions

This work determines enameled cast iron material as the most efficient material for producing pots between the three tested materials because the energy efficiency during tests was higher than the stainless steel one and especially comparing it with aluminium pot, in the same induction cooker.

The pot made of aluminium increased its energy efficiency after structural stability of the pot bottom under thermal impact conditions test, since it went from convex to concave, these results belong with the ones obtained from several stainless steel pots energy efficiency with different initial measurements of concavity/convexity test, where an increasing tendency of energy efficiency can be seen, going from convex to concave until it got to 0.9 mm. Finally, it is expected that, even with an intensive use, cookware will allow to have an efficiency higher than 80%, which complies with the Ecuadorian standard.

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References

[1] Barragán L., Navarro D., Acero J., Urriza I., & Burdío J. (2008). *IEEE Transactions on Industrial Electronics 55 (1), 11-20.*

[2] Bertoldi P. (2008). Editorial. *Energy Efficiency*, *1*(1), 1–3.

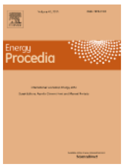
[3] Houšová J., Topinka P., (1985). *Journal of Food Engineering 4(3). 169-188*

[4] Martínez J., Orozco M., Vaca D., Carrión D., Montero. A, (2014). *Revista Energía, 135-144.*

[5] Milne G., & Boardman, B. (2000). *Energy Policy, 28 (6-7), 411–424.*

[6] Orozco M., Villacis S., Riofrío A., Martínez J., Carrión D., Vaca D., (2014), *COLIM 76-84.*

[7] Riofrío A., Carrión D., Vaca D., Orozco M., Martínez J., (2014) *COLIM 232-241.*



Biography

Stefany Villacís was born in Quito, Ecuador in 1990. She is studying Mechatronics Engineering at Universidad Tecnológica Equinoccial. She is working in the Energy Efficiency and Renewable Energies National Institute of Ecuador as a research assistant. (e-mail: stefany.villacis@iner.gob.ec)