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Energy Efficiency of Utensils used in Liquefied Gas and Induction Stoves

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DEDICATORIA

Este trabajo lo dedico de manera especial a mis padres, quienes han sido un pilar fuerte sobre todo en las grandes adversidades y que sin ellos ningún proyecto se podría realizarse. Su esfuerzo y sacrificio para ayudarme a culminar una etapa más en mi vida. A toda mi familia quienes siempre están presentes y unidos en todos mis proyectos.

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RESUMEN

En el presente proyecto se estudia la eficiencia energética de distintos tipos de utensilios usados en cocinas a gas licuado y en cocinas de inducción. En el estudio se realiza ensayos en tres diferentes tipos de ollas comúnmente comercializados en el mercado ecuatoriano: ollas de acero inoxidable, ollas de aluminio con base de incrustación de acero inoxidable, y ollas de aluminio con base de metalización de acero. Cada una de las muestras es evaluada considerando un balance de energía y factores que pueden afectar la misma eficiencia de transferencia energética, esto incluye: esfuerzos térmicos y deformaciones de la base (convexidad de la base), por dilatación diferencial de los materiales y gradientes térmicos en el utensilio durante la cocción.
Se ha obtenido resultados de eficiencias energéticas mayores al 80% en cada uno de los ensayos de inducción, mientras en ensayos a cocinas gas licuado se obtiene eficiencias menores al 60% para todos los ensayos. Además, se logra una eficiencia del 82% para las ollas de base de aluminio con metalizado de acero inoxidable, una eficiencia del 85% para las ollas de base de aluminio con incrustación de acero inoxidable, y un 90% para las ollas de acero inoxidable. La convexidad de la base disminuye el valor de la eficiencia energética. Para un desplazamiento de 2.0 mm y 3.27 mm en el punto central de la base, se logra eficiencias del 80% y del 75% respectivamente. El gradiente de temperaturas influye en los recipientes de grandes capacidades. En ensayos en ollas de presión y tamaleras se logra eficiencias menores al 83% en ensayos con recipientes llenos. En los ensayos con ollas de presión se obtiene una eficiencia del 82.8%, mientras que en ensayos con Tamaleras se logra una eficiencia del 79%.

Palabras clave: Cocinas a gas, Cocinas de inducción. Eficiencia energética, Deformación, Gradientes Térmicos.

ABSTRACT

In this project we study the energy efficiency of different types of utensils used in liquefied gas cookers and induction cookers. In the study, tests are carried out on three different types of pots commonly marketed in the Ecuadorian market: stainless steel pots, aluminum with a stainless steel Incrustation and Aluminum coated with steel and stainless steel by metallization. Each of the samples is evaluated considering a balance of energy and factors that can affect the efficiency of energy transfer, these factors are: thermal stresses and deformations of the base (convexity of the base), difference of thermal expansion of the materials and thermal gradients in the utensil during cooking.

Energy efficiencies greater than 80% are obtained in induction tests, while tests in liquefied gas cookers, efficiencies of less than 60% are obtained. In addition, an efficiency of 82% is achieved for Aluminum coated with steel and stainless steel by metallization, 85% for aluminum with a stainless steel Incrustation, and 90% for stainless steel pots. The convexity of the base decreases the value of energy efficiency. For a displacement of 2.0 mm and 3.27 mm at the center point of the base, efficiencies of 80% and 75% are achieved, respectively. The temperature gradient influences big capacity utensils. In tests in pressure cookers and tamaleras efficiencies of less than 83% are achieved with utensils filled with water. In tests with pressure cookers an efficiency of 82.8% is obtained, while in tests with Tamaleras an efficiency of 79% is achieved.

Keywords: Gas cookers, induction cookers. Thermal Efficiencies, Deformation, Thermal Gradient.

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SYMBOLS

E_{gen}	Energy generated in the heating process	KW
E_{cons}	Energy consumed during the process	KW
η	Energy efficiency	%
m_1	Mass of water	Kg
C_1	Specific heat of water	KJ Kg^{-1} K^{-1}
m_2	Mass of the pot	Kg
C_2	Specific heat of the container	KJ Kg^{-1} K^{-1}
m_3	Mass of the lid of the pot	Kg
C_3	Specific heat of lid of the pot	KJ Kg^{-1} K^{-1}
T_f	Final temperature	℃
T_o	Initial temperature	℃
t	Time	s
P	Electric power	KW
V	Voltage	Volts
I	Current	Ampere
V_c	Volume of dry gas consumed	m^3
M_c	Mass of dry gas consumed	Kg
H_s	Heat power value (Commercial Butane Gas)	KW Kg^{-1}
m_e	Equivalent mass of the filled pot	Kg
c_1	Specific heat of water	KJ Kg^{-1} K^{-1}
V_{med}	Measured gas volume	m^3
P_a	Atmospheric pressure	Pa

P_s	Partial pressure of water vapor	Pa
P_w	Partial pressure of water vapor	Pa
T_g	Gas temperature at the point of consumption	℃
Δk	Curvature due to temperature change	m^{-1}
E'_s	Young's modulus of the substrate	N m^{-2}
E'_D	Young's modulus of the coating	N m^{-2}
t_s	Thickness of the substrate	m
t_D	Thickness of the deposit	m
ΔT	Temperature Difference	℃
α_s	Coefficient of thermal expansion of the substrate	$℃^{-1}$
α_D	Coefficient of thermal expansion of the deposit	$℃^{-1}$
$\Delta\alpha$	Differences of the coefficient of expansion of materials	$℃^{-1}$
n	Number of deposition layers	-
h_n	Thickness of the coating for n layers	m
δ_n	Neutral axis position for a compound with n layers	m
c_n	Uniform strain component due to the cooling / heating force	-

INTRODUCTION

The migration to a new energy consumption system requires the comparative analysis of thermal efficiencies to demonstrate the savings that this change represents. Energy efficiency is a reliable comparative measure to compare energy consumption, in other words, it is a measure to achieve energy savings, through low consumption and improving quality (Villacís, et al., 2013).

In past years, electromagnetic induction cookers became popular. Ecuador adopted this form of cooking with a new energy matrix (implemented by the government). The purpose is to generate clean and renewable energy and reduce dependence on fossil fuels. So, Ecuador adopted this type of change to generate savings of millions of dollars a year. But, this unexpected change caused discomfort between people who are used to cook with a traditional cooking system. Especially in rural zones, most of the population uses a traditional systemand it is difficult to inform and switch to a different style of cooking. Due to that, it is necessary to focus on the analysis of the appropriate measurements and appropriate policies to ensure that the implementation causes a low impact on the population improving the efficient use of energy (Villacís, et al., 2015).

Another difficulty is the price of energy consumption in Ecuador. Although in recent years the price of a gas tank does not exceed $ 3, this benefice has a millonary cost for the goverment. Ecuador has spent approximately 1.9 million dollars in gas subsidies and reaching projections of 4 billion dollars of expenditure in the year 2021 (La Hora, 2018). Meanwhile, the electrical cost in Ecuador is around USD 0.01 KWh for residential consumption and USD 0.02. KWh for industrial and commercial sectors (El Comercio, 2017). In evidence of the high cost that Ecuador pays because of the subsidy, the government has decided to improve its electricity supply system in order to reduce the high subsidy cost.

Induction cookers require a variable magnetic field and an electrically conductive material, figure 1. So, it needs an efficient 220 Volt electrical system. The operation of the induction cookers depends on a flat coil of copper and spiral form that generates an electric current. The electric current causes a magnetic flux density of the same frequency of the current. This magnetic field circulates in the utensils whose electric resistance is sufficiently small to allow the circulation of the induced currents, taking advantage of the hysteresis and causing its heating by the dissipation of energy caused by the Joule effect (Franco, 2013).

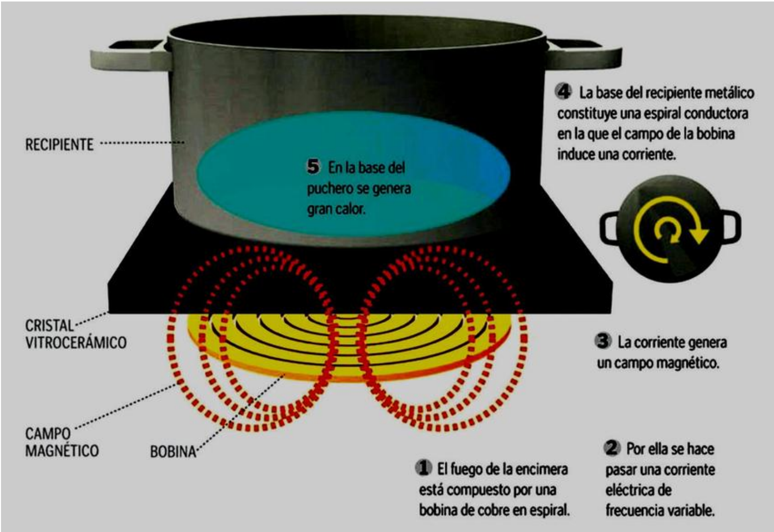


Figure 1. Basic Operation of the Electromagnetic Induction Cookers. (Luna, V. & Vela, E.,2015).

The heat transfer in the gas cookers in contrast to induction cookers presents notable differences. The heating by induction involves only the base of the cooker due to the generation of electromagnetic induction; meanwhile the heating in gas cookers heated by the flame in the lower part and the sides of the pots. This shows that the difference in the location of the heating affects the heat transfer, thus efficiency in both cases (Haruna, et al., 2013). In the case of liquefied gas cookers, a large amount of energy is wasted in the form of heat, thus making them inefficient system, figure 2.

Figure 2. Heating in liquefied gas cookers. (Source: http://www.asifunciona.com).

The maximum efficiency in induction system is necessary to use ferromagnetic utensils, because these types of pots take advantage of the magnetic field (El Comercio, 2014). The appropriate materials for the operation of the induction cookers come into high prices, so there are other types of different pots that are made of two materials such as the body of aluminum and an adapted base of stainless-steel. The aim is to achieve the same efficiency as stainless-steel pots. So, between the options within the Ecuadorian market are aluminum pots with a base with aluminum coated with steel and stainless steel by metallization, aluminum with a stainless steel Incrustation, and stainless-steel pots.

There are many factors that influence the energy efficiency, that includes: the deformation due to different material properties, and thermal gradients present in big and tall pots. The utensils that are formed by two materials in the bases have a different behavior. Different mechanical and thermal properties between the materials (in the base of the pot) causes a different behavior with a temperature change. At the base of the pots a pure bending effect is produced, caused by the temperature ‘increase and the difference of thermal expansions between the two materials. The thermal stresses in the materials cause deformations, which causes the convexity of the base increasing the distance of the base of the container with the glass ceramic. In other words, the composition of materials in the base pot that has a very close relationship in the calculation of thermal efficiencies, figure 3.

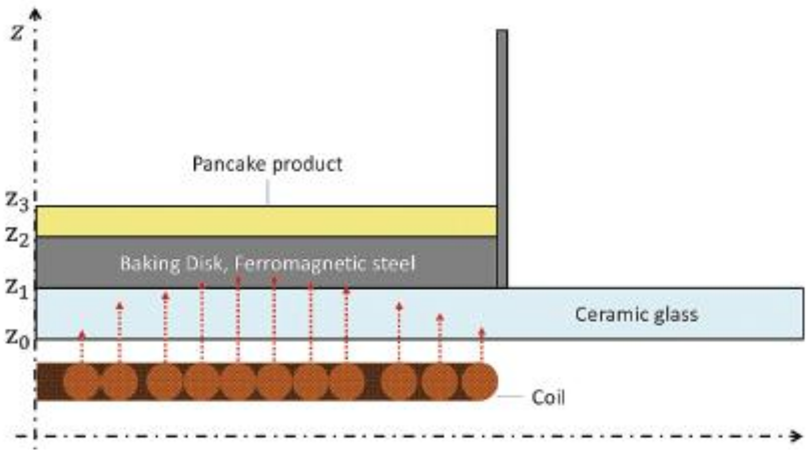


Figure 3. Curvature of the base of the pot due to the change in temperature. (Sanz-Serrano, et al, 2017).

Previously, comparative tests have been carried out between induction cookers and liquefied gas cookers. In those experiments, energy efficiency for induction cookers were compared to liquefied gas cookers. In previous research, investigations have determined efficiencies in liquefied gas cookers with efficiencies between 28% to 35.5%, while for induction cookers, around 81.3% approximately. In addition, many publications show that the level of emission of C02 between liquefied gas and inductions stoves are 2`540.086.5 tons CO2/year for gas while for induction cooker CO2 emissions correspond to 23.419.2 tons CO2/year (Martínez, et al, 2017).

The objective of this project is to determine the thermal efficiencies (induction and liquified gas) for each of the samples of utensils with different characteristics, uses and models. In this project will be determine how the thermal efficiencies are affected by the thermal stresses that cause deformation in the base of the utensils. In addition to determining energy efficiencies in large capacity containers and evidence the change in the value of the efficiencies due to temperature gradients. This study is presents experimental results and its correspondent theoretical calculations.

METHODOLOGY

Materials

The project focuses on the study of thermal efficiencies in two cooking systems: liquefied gas and induction heating. For this study, an induction cooker and a standard gas cooker are used for each of the tests, figure 4. The study is carried out in the most commonly cookware used in the Ecuadorian market (Induction stove: Brand Montero, Made in China, Electric Power: 1500 W), (Gas Stove: Brand Haceb, Made in Ecuador, 2 burners). Each of the utensils has been categorized according to their capacity and use. The categories considered are five, including: 1) pots, 2) frying pans, 3) saucepans, 4) pressure cookers, and 4) "tamaleras" (big and tall pots).

Figure 4. Stoves used for energy efficiency tests. Induction Cooker (Left), Gas Cooker (Right).

In each category, three types of cookware were identified considering the materials they are made of, including: 1) thermally sprayed coatings or metallized coatings of steel and stainless steel deposited over the base of an aluminum cookware; 2) stainless steel incrustations applied to aluminum cookware, and 3) cookware of stainless-steel from factory. Additionally, a stainless steel plate, used as a universal accessory, was evaluated. The properties of the materials, which will be used for addressing thermal efficiencies and deformation calculations, of each one of the pots are presented in Table 1. For all tests, the respective lids for each pot are also considered. In the present project two types of lids are used, one of aluminum and another one of glass. The respective properties for the lids are also presented in Table 1.

Table 1. Table of material properties for each of the pots and lids tested.

Materials	**Density** $\left(\frac{Kg}{m^3}\right)$	**Specific heat** (KJ Kg^{-1} K^{-1})	**Thermal conductivity** $(W\,K^{-1}m^{-1})$	**Coefficient of Expansion** $(°C^{-1})$	**Young's modulus** (N m^{-2})
Aluminum	2700	0.89	205	25 E -6	7 E+10
Stainless –steel	7930	0.51	16.3	17.3 E -6	1.93 E+11
Steel	7800	0.45	50.2	12 E - 6	2 E + 11
Glass	2500	0.876	0.85	9 E -6	7 E +10
Water	997	4.18	-	-	-

Cookware of well-known brands in the local market were selected, including INDALRO (Panamericana sur Km 12 1/2 Calle E1C CASA S49-187 Quito, Pichincha), and UMCO (Sincholagua OE1-141 Y Av. Maldonado. Quito – Ecuador) for all groups. Also, some other brands complemented the samples, for example WIKING “Surgical steel pots” which is imported by Insumos Profesionales INSUPROF CIA. LTD (Av. 6 de Diciembre N37 – 224 y G. Serrano). Cookware that was characterized was grouped, as follows:

Group 1- Pots. - this group corresponds to small pots with a maximum capacity of 1.5 to 2 liters. A stainless steel adapter plate is included for testing (common commercialized in Ecuadorian market as universal heating plate”, table 2.

Table 2. Detail of Utensils for the Tests "Group 1 Pots"

Name	**Main Material**	**Base Material**	**Specifications**	**Photos**
Utensil 1	Aluminum	Aluminum coated with steel and stainless steel by metallization	Base diameter: 129.04 mm Thickness Aluminum: 3.38 mm Coating thickness: 0.8 mm Depth: 96.37 mm Maximum Capacity: 2 Liters	 
Utensil 2	Aluminum	Aluminum with a stainless steel Incrustation	Base diameter: 134.60mm Thickness Aluminum: 1.9 mm Incrustation: 0.5 mm Depth: 80.55 mm Maximum Capacity: 1.5 Liters :	 
Utensil 3	Stainless steel	Stainless steel	Base diameter: 144.22 mm Thickness: 1.50 mm Depth: 116.73 mm Maximum Capacity: 2 Liters	 
Utensil 4	Stainless steel	Stainless steel	Diameter: 23.53 mm Thickness: 5.95 mm	

Group 2- Fry Pans. - In the second category of containers are small pans with a maximum capacity of 1 to 1.5 liters, table 3. This category corresponds to the group of fry pans.

Table 3. Detail of Utensils for the Tests "Group 2 Fry Pans"

Name	Main Material	Base Material	Specifications	Photos
Utensil 5	Aluminum	Aluminum with a stainless steel Incrustation	Base diameter: 147.37mm Thickness Aluminum: 1.9 mm Incrustation: 0.5 mm Depth: 43.56 mm Maximum Capacity: 1 Liter	 
Utensil 6	Stainless steel	Stainless steel	Base diameter: 178.81 mm Thickness: 0.74 mm Depth: 67.62 mm Maximum Capacity: 2 Liters	 

Group 3- Sauces Pans. - The third category corresponds to the medium pans, that considers 2 to 3 liters of maximum capacity, table 4.

Table 4. Detail of Utensils for the Tests "Group 4 Sauces Pans"

Name	**Main Material**	**Base Material**	**Specifications**	**Photos**
Utensil 7	Aluminum	Aluminum coated with steel and stainless steel by metallization	Base diameter: 139.30 mm Thickness Aluminum: 3.38 mm Metallization: 0.8 mm Depth: 77.31 mm Maximum Capacity: 2 Liters	 
Utensil 8	Aluminum	Aluminum with a stainless steel Incrustation	Base diameter: 154.16 mm Thickness Aluminum: 1.9 mm Incrustation: 0.5 mm Depth: 81.10 mm Maximum Capacity: 2 Liters	 
Utensil 9	Stainless steel	Stainless steel	Base diameter: 182.17 mm Thickness: 0.78 mm Depth: 102.34 mm Maximum Capacity: 2.5 Liters	 

Group 4- Pressure Pots. - The fourth category corresponds to “pressure pots” whose capacity exceeds the 2 liters, table 5. In the case of the containers of greater capacity, 2 liters of water is used for the “energy efficiency” tests.

Table 5. Detail of Utensils for the Tests "Group 4 Pressure Pots"

Name	**Main Material**	**Base Material**	**Specifications**	**Photos**
Utensil 10	Aluminum	Aluminum coated with steel and stainless steel by metallization	Base diameter: 129.04 mm Thickness Aluminum: 3.38 mm Metallization: 0.8 mm Depth: 154.37 mm Maximum Capacity: 6 Liters	
Utensil 11	Aluminum	Aluminum with a stainless steel Incrustation	Base diameter: 130.55mm Thickness Aluminum: 1.9 mm Incrustation: 0.5 mm Depth: 165.71 mm Maximum Capacity: 6 Liters	
Utensil 12	Stainless steel	Stainless steel	Base diameter: 154.62 mm Thickness: 1.32 mm Depth: 176.66 mm Maximum Capacity: 6 Liters	

Group 5- Tamalera. – This last category of containers corresponds to “Tamaleras” of large capacities, corresponding to 5 to 7 liters of capacity, table 6.

Table 6. Detail of Utensils for the Tests "Group 4 Tamalera"

Name	Main Material	Base Material	Specifications	Photos
Utensil 13	Aluminum	Aluminum with a stainless steel Incrustation	Base diameter: 130.55mm Thickness Aluminum: 1.9 mm Incrustation: 0.5 mm Depth: 141.71 mm Maximum Capacity: 7 Liters	 

Technical Standards

The analysis of the thermal efficiencies for induction and gas cookers is analyzed according to the standards INEN NTE 2851 “Utensilios de Cocina, recipientes de uso doméstico para cocción fabricado en aluminio, hierro y acero” (Instituto Ecuatoriano de Normalización, 2014)

under the ambient conditions specified, and the standard NTC 2832 “Norma para Gasodomésticos para la Cocción de Alimentos” (Norma Técnica Colombiana, 2015).

Each of the standards is based on the analysis of an energy balance in the system, in other words, a balance of energy consumed and generated during the heating process.

INEN STANDARD NTE 2851 (Instituto Ecuatoriano de Normalización)

The standard endorsed by the MEER (Ministry of Electricity and Renewable Energy) and the INER (National Institute of Energy Efficiency and Renewable Energy) describes the test methods for household utensils used on burners, stoves or hot plates even at those that are destined to be used inside a furnace, of the standard applies the part of energy efficiency tests for pots used in induction cookers.

Before each pot is tested, the diameters of the magnetic bottom base that is in contact with the glass ceramic of the induction cooker of the standardized kitchen utensils are taken into consideration, Table 7.

Table 7. Dimensions of standard cookware according to INEN Standard NTE 2851

Cooking utensil	Diameter magnetic Bottom "A" (mm)	Minimum diameter of the pot "B" (mm)	Minimum height "C" (mm)	Minimum bottom thickness (mm)	Maximum bottom level (mm)	Maximum convex bottom (mm)
1	140±10	140 ± 30	70	1.5	0.075	0.3
2	180±10	180 ± 30	90	1.5	0.075	0.3
3	240±10	210 ± 30	110	1.5	0.1	0.3

The standard considers test conditions for the efficiencies with an electric potential difference of 220 ± 11 V, also considering the atmospheric pressure between 68 kPa - 106 kPa and an ambient temperature of 23 ° C ± 10 ° C.

The test is developed in two parts: 1) preheating and 2) heating and measuring, where the volume of water to be tested is considered according to the external diameter of the coil and the standardized utensil used according to the table 7, Table 8.

Table 8. Volume of water for the energy efficiency test

External diameter coil "X" (mm)	Standard cookware utensil chosen for test	Volume of Water (Kg)
X ≤ 140	1	1 ± 1%
140 < X ≤ 180	2	1.5 ± 1%
180 < X	3	2 ± 1%

The preheating part fills the normalized utensil according to table 7 and 8, considering an initial environmental temperature of 15 ° C ± 1 ° C. To realize the test, the pot must be covered with the appropriate lid, while inserting the temperature sensor in a 1 cm hole in the center of the lid.

The heater is turned on to the highest level, reaching a temperature T_2 de 75 °C ± 1°C, to start the measurement stage and remove the container from the hot zone to continue with the heating and measuring part after 60 next seconds.

In the heating and measuring stage, the total mass of the lid and the body of the normalized utensil is measured, adding the amount of water according to table 8. The initial temperature of the test is measured by the sensor located at the top of the lid, the heating zone is turned on to the highest level and the water is heated until reaching a temperature T_4 de 75 °C ± 1°C. At the end of the test the kitchen is switched off and the final temperature T_4 and the energy consumed are recorded.

The energy efficiency η is determined by the ratio of the energy provided by the induction cooker to the energy consumed to heat the water during the test. The standard is based on an energy balance, which specifies that efficiency is the analysis of the energy or heat that leaves the system with respect to the energy or heat that enters the system. The heat consumed by the system is the heat absorbed by the pot body, lid and water. While the heat entering the system will be the electric power provided by the induction cooker, equation 1.

$$\eta = \frac{E_{cons}}{E_{gen}} \qquad (1)$$

According to the norm equation 1 is the abbreviation of the equations 2 and 3 to obtain the energy efficiency of the system, equation 2 is the representation of the energy consumed to heat the mass of water; meanwhile, equation 3 represents the energy generated by the system to heat the mass of water inside the pot. The two previous equations result in equation 4 that represents equation 1, being in this case the general equation for the calculation of energy efficiency.

$$E_{cons} = (m_1 * C_1 + m_2 * C_2 + m_3 * C_3) * (T_f - T_o) \quad (2)$$

$$E_{gen} = P * t \quad (3)$$

$$\eta = \frac{(m_1 * C_1 + m_2 * C_2 + m_3 * C_3) * (T_f - T_o)}{P * t} \quad (4)$$

NTC STANDARD 2832

Efficiencies in liquefied gas cooking are achieved through the equation of energy efficiencies in gas cookers in the environmental conditions specified by the NTC 2832 standard.

The NTC 2832 standard is a Colombian standard with a test method to determine the efficiencies of domestic cooking devices that use gas fuels. For the efficiency test, the part corresponding to burners discovered is applied, which is based on the nominal calorific consumption of the burner tested. the diameter of the container and the amount of water to be filled inside the pot, Table 9.

Table 9. Volume of water depending on the diameter of the pot and the nominal calorific consumption of the burner

Nominal calorific consumption of the burner (KW)	Diameter inside the pot (mm)	Mass of water (Kg)
1.16 y 1.64	220	3.7
1.65 y 1.98	240	4.8
1.99 y 2.36	260	6.1
2.37 y 4.2	260 Con un ajuste del consumo calorífico del quemador a 2.36 KW ± 2%.	6.1

The initial water temperature T1 is 20 °C± 1 °C and the temperature at the time of burner extinction of 90°C ± 1°C, for the test the initial temperatures and the temperature are measured end of the test on the volume of water. The test in gas burners is carried out after preheating according to table 4 with a 220 mm diameter container with a content of 3.7 kg of water. At the end of the preheating, the pot used for preheating is removed by the recipient to be tested.

As well as the norm for the calculation of energy efficiency in induction cookers this standard is based on an energy balance. The heat that absorbs the body of the pot, the lid and the water, while the heat that enters the system will be the energy that the gas provides, equation 5.

$$\eta = \frac{E_{cons}}{E_{gen}} \tag{5}$$

From equation 5 of the simplified energy balance, two equations 6 and 8 are derived, which are energy consumed and generated by the system. For the case of calculating energy efficiencies, the energy consumed depends on the equivalent mass of the entire system and the temperature difference, equation 7.

In the liquefied gas cooking system commercial butane gas is used as a source for heating, the value of energy efficiency for gas cookers is dependent on the volume of gas consumed in the system, for this experimental test conducted in the laboratory we used a gas volume consumption meter during the tests.

In gas cookers, it is based on the calculation of the volume consumed in order to heat the volume of water used in the experiment, equation 8 and 9.

$$E_{cons} = 4{,}183 * m_e * \left(T_f - T_o\right) \tag{6}$$

$$m_e = c_1 * m_1 + c_2 * m_2 \tag{7}$$

$$E_{gen} = V_c(M_c) * H_s \tag{8}$$

$$V_c = V_{med} * \frac{P_a + P_s - P_w}{1013} * \frac{288.15}{T_g} \tag{9}$$

$$\eta = \frac{4{,}183 * m_e * \left(T_f - T_o\right)}{V_c(M_c) * H_s} \tag{10}$$

For the calculation of the energy efficiency of the gas system, it is carried out under environmental conditions in the city of Cumbayá, at an ambient pressure of 71770 Pascals and an ambient temperature of 22 ℃ (Agencia Espacial Civil Ecuatoriana, 2018). A calorific value of butane gas 11867 Kcal.Kg^{-1}, and a pressure to enter the gas stove of 100000 Pascals (1bar).

Deformation and Efficiency

For the study, an equation that involves the mechanical and thermal properties of the two materials is applied. This equation determines the curvature of the base of the recipients Δk and at the same time the displacement of the base of the container with the induction cooker, equation 11. It applies to containers of two materials such as stainless steel and aluminum pots, figure 5.

$$\Delta k = \frac{1}{\Delta R} = \frac{6E'_D E'_s t_D t_s (t_D + t_s)\Delta T \Delta\alpha}{E'^2_D t^4_D + 4E'_D E'_s t^3_D t_s + 6E'_D E'_s t^2_D t^2_s + 4E'_D E'_s t_D t^3_s + E'^2_s t^4_s} \tag{11}$$

Figure 5. Stainless steel sample plate by incrustation.

In the case of metallized, figure 6 the pots are composed by three materials which have a different behavior to the containers of two materials, due to its thermal and mechanical properties. In this special case we apply general equations of applied curvature for n materials that make up the container, equation 12.

Figure 6. Stainless steel sample by metallization.

$$\Delta k = \frac{3\left(-E_s t^2{}_s (C_n - \alpha_s \Delta T_n) + \sum_{j=1}^{n} E_j t_j (C_n - \alpha_s \Delta T_n)(2h_{j-1} + t_j)\right)}{E_s t^2{}_s (2t_s + 3\delta_n) + \sum_{j=1}^{n}\left(2\left(h^2{}_j + h_j h_{j-1} + h^2{}_{j-1}\right) - 3\delta_n (h_j + h_{j-1})\right)} \qquad (12)$$

Being a general deformation equation for n materials, equation 12 involves the Component of uniform deformation due to the cooling / heating force C_n, and neutral axis position for composite beam with n layers δ_n, equations 13 and 14 (Maldonado, 2014).

$$C_n = \frac{\left(E_s t_s \alpha_s + \sum_{j=1}^{n} E_j t_j \alpha_j\right)\Delta T}{E_s t_s + \sum_{j=1}^{n} E_j t_j} \qquad (13)$$

$$\delta_n = \frac{\sum_{j=1}^{n} E_j t_j (2h_{j-1} + t_j) - \sum_{j=1}^{m} E_j t_j (2h_{j-1} + t_j) - t_s \left(E_s t_s + 2 \sum_{j=1}^{m} E_j t_j\right)}{2\left(E_s t_s + \sum_{j=1}^{n} E_j t_j + \sum_{j=1}^{m} E_j t_j\right)} \quad (14)$$

The deformation of two and three materials corresponds to an experimental part and a theoretical part. For the experimental part, the temperature increases from ambient temperature to 150 °C to obtain an elastic deformation of the material. In the experimental case, a Micro Laser Displacement Sensor is used in order to record the position of the central point of the test material during the heating and cooling period, the laser sends voltage data to the server through a DAQ-3005 that receives the voltage data and sends the position of the sample material, figure 7.

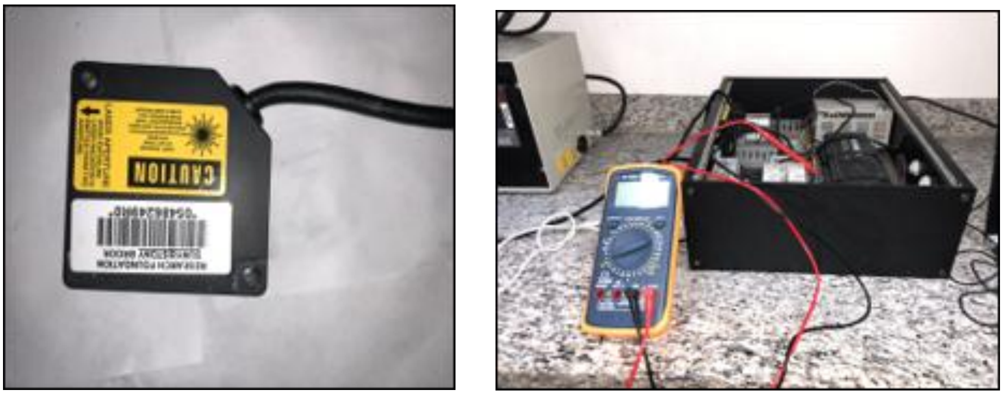


Figure 7. Position laser for deformation tests. Position Laser (Left), DAQ-3005 (Right).

Experimental tests with the position laser. Before the tests an experimental equation for the transformation of the voltage signal to the position in millimeters of the sample is obtained, equation 15. This being a linear equation, where y has units of Voltage while x corresponds to units of distance from the laser to the sample in millimeters.

$$y = 0.511x - 24.23 \tag{15}$$

The laser handles a range of 50 mm ± 10 mm with a resolution of 50 µm, so the laser is within a voltage range of -6.4 Volts to +6.4 Volts. For the determination of the experimental curvature, the displacement of the central point of the sample will be determined, figure 8. Where, according to equations 18 and 19 and figure 8, the experimental curvature is determined. We have the general equation of the curvature, equation 16; and knowing that the length of the center to the first material L is equal to the difference of the radius of the curvature R and the displacement δ, equation 17.

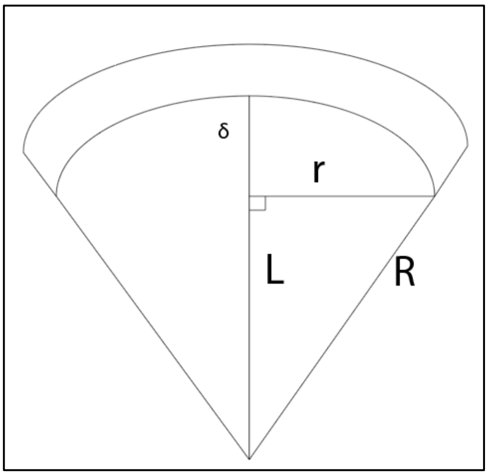


Figure 8. Deformation of the base of the pot in effect of temperature application.

$$R^2 = r^2 + L^2 \tag{16}$$

$$L = R - \delta \tag{17}$$

$$R = \frac{r^2+\delta^2}{2\delta} \tag{18}$$

$$\Delta k = \frac{1}{R} \tag{19}$$

In order to verify the experimental data, a simulation of thermal stresses is developed in the SOLIDWORKS program, for which the table of properties of the materials of the utensils is used, table 1.

A simulation in a steady state where the ambient temperature is considered with a displacement of 0 mm at the center point of the plate. For this type of thermal simulation, a thermal load of T = 25 ℃ is applied.

A thermal simulation in a transient state, considering the initial temperature of 25 ℃. In this simulation, thermal loads of the "Induction Cooker" heater power determined by equation 20 are applied where the power is related to the voltage and amperage of the kitchen; and the natural convection of the plate with the environment.

$$P = V.A \tag{20}$$

Finally, a simulation of static analysis, where thermal simulations in stable and transient state are applied as thermal loads. For the case of the static analysis simulation, a fixed side is considered as a restriction of the whole system. For the case of the static analysis simulation, a fixed side is considered as a restriction of the whole system. In all the simulations a meshing of 5.39166 mm in size was applied for each element and with a tolerance of 0.269583 mm, figure 9.

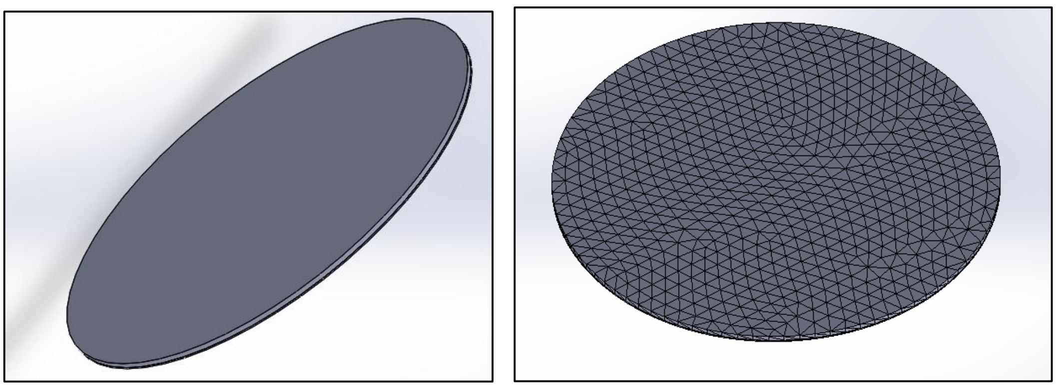


Figure 9. CAD model and meshing the plate of two and three materials. CAD model two/tre materials (Left), mesh of the CAD model in SOLIDWORKS (right).

Thermal Gradient

Thermal efficiency tests are only carried out on containers whose capacity exceeds the volume limit required for the detailed test in the standard, table 8. Due to the large capacity of these types of containers, the calculation of the efficiencies it tends to change, for this type of tests the same energy efficiency standards will be used for induction cookers, but for the present case different amounts of water will be used, table 10.

Table 10. Volume of Water for the Thermal Gradient Test.

Maximum Capacity	Name	Volume of Water for the test
6 Liters	Pressure Pan (By Incrustation)	5 Liters
7 Liters	Tamalera (By Incrustation)	6 Liters

For thermal gradient tests, the same procedure of Standard NTE 2851 will be used.

For each of the tests temperature sensors. These types of sensors are K-type thermocouples for temperature recording. For this test, an Arduino programming are used, the electronic schematic for the determination of the Temperature, Time, Amperage and Voltage data in each one of the tests is presented in the annex part A. the part of annexes B presents the programming in Arduino.

RESULTS

Energy Efficiency

For each one of the utensils 5 energy efficiency tests have been conducted. In this section, the results of the energy efficiencies of each of the pots tested within the laboratory are shown. The comparison graphs of each of the efficiencies obtained in each of the pots are presented, as well as the temperature change curves with time.

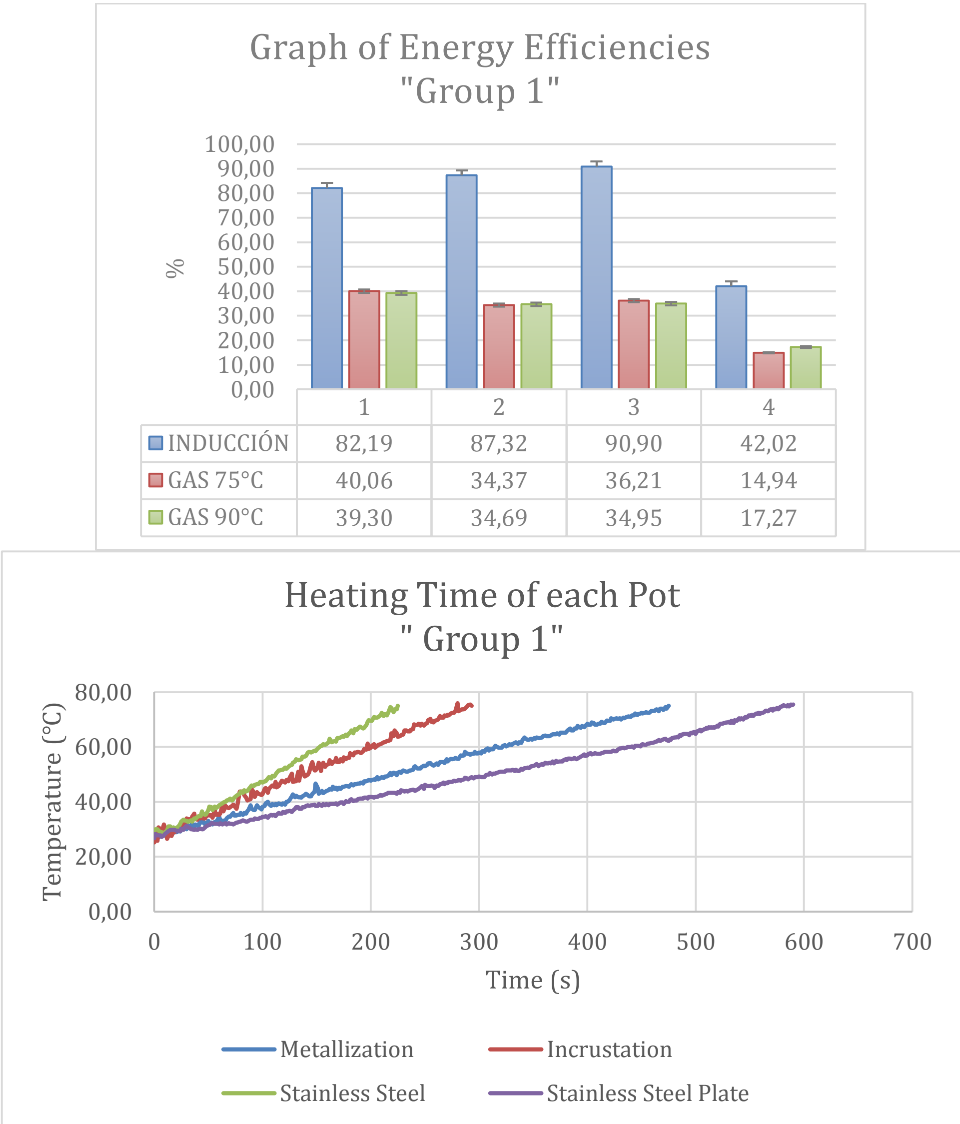


Figure 10. Energy efficiency results of the first group of pots.

In the results obtained from the first pots the efficiency values shown in table 2 can be observed, noting that in all group 1 of the utensils the efficiency exceeds 80% considered in the norm. So also, within the first group in the efficiency tests, a much lower efficiency result is noted in the stainless plate with a 42.02% efficiency. Between metallization, incrustation and stainless containers, the result of the efficiency is lower for metallization with 82.19%. However, it continues to comply with the INEN standard for the applicable tools for induction cookers.

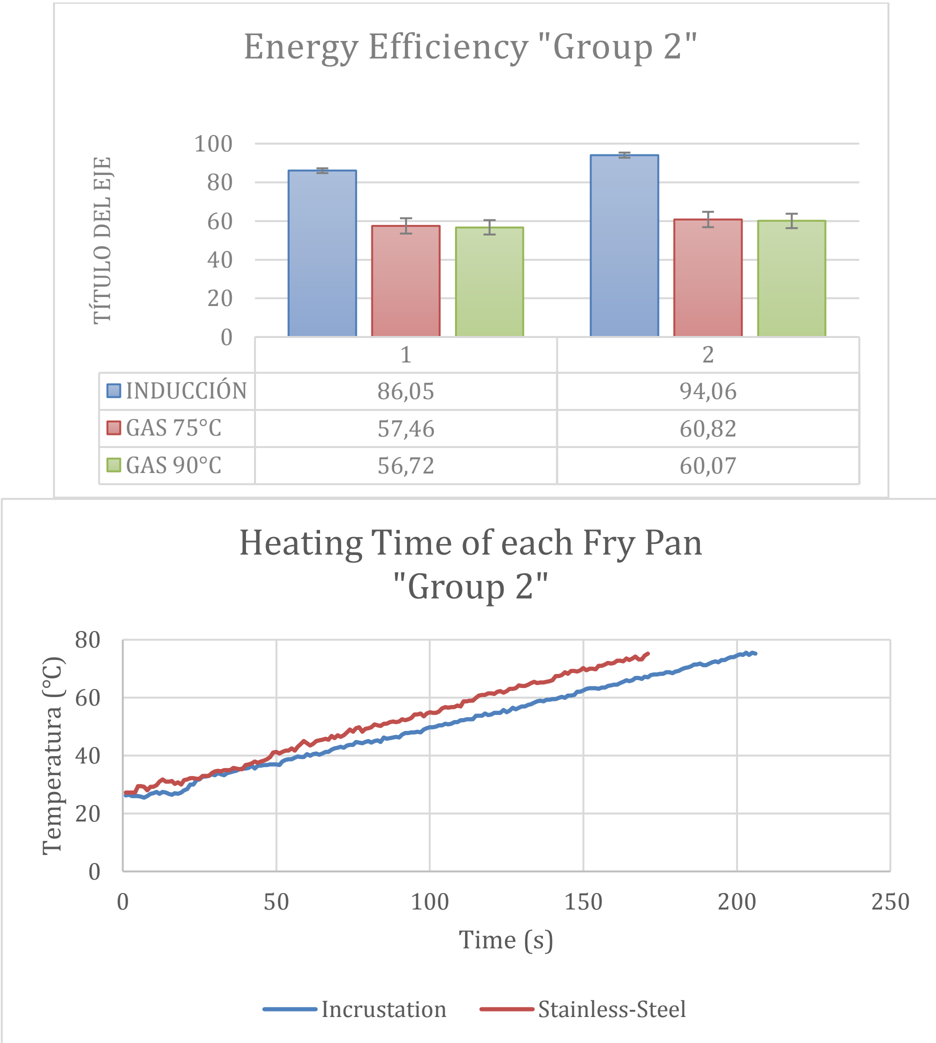
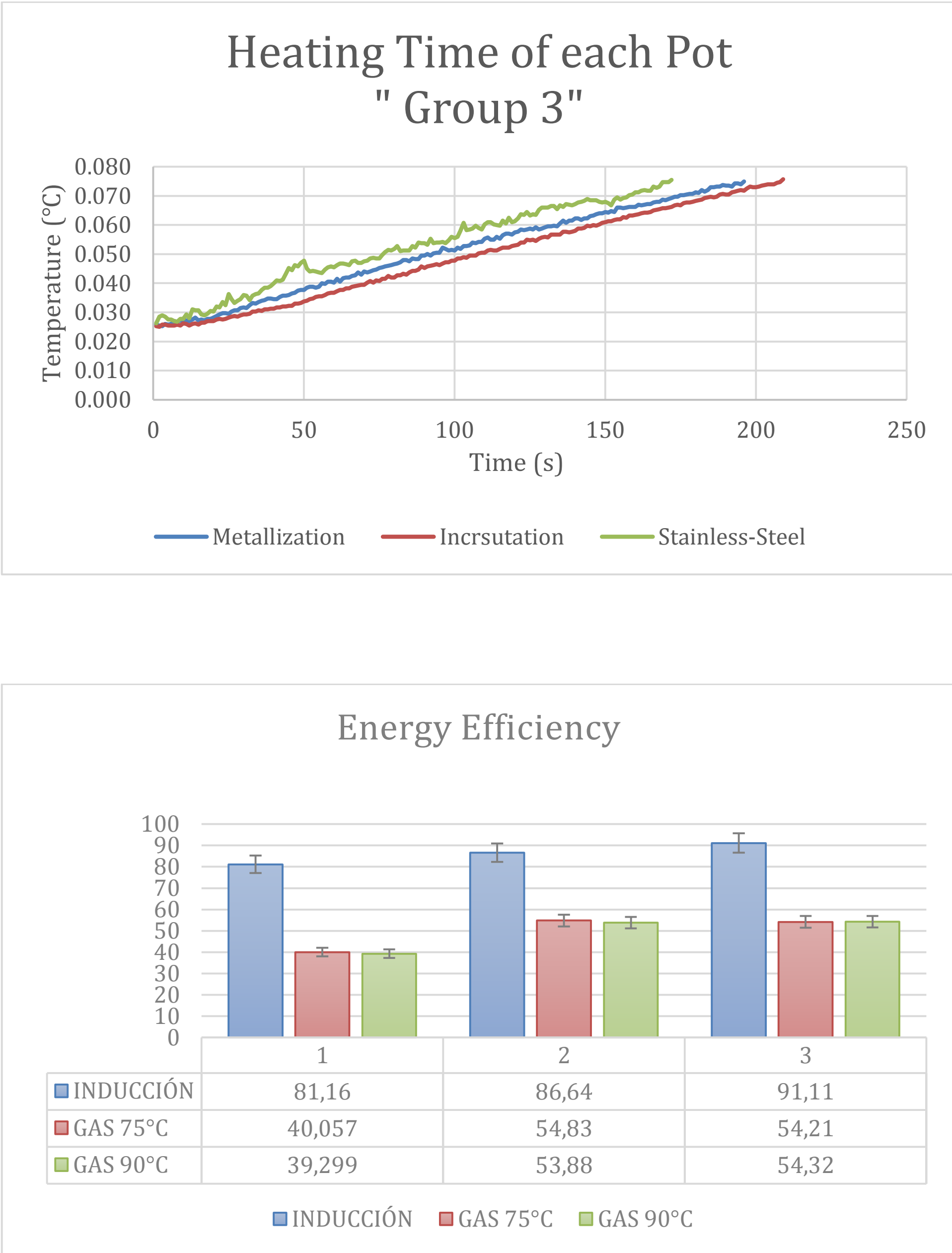


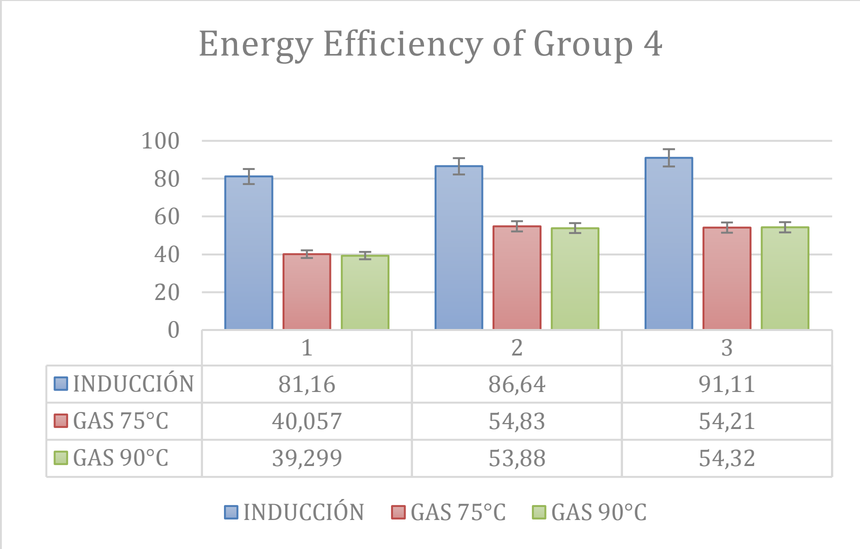
Figure 11. Energy efficiency results of the second group of pots.

In the second group, the results of the pans are presented, figure 11. In the graphs, the difference in the value of the energy efficiency of the fry pans can still be noticed. In the energy efficiency tests in gas cookers, a very low value is shown compared to the tests in induction cookers.



	1	2	3
INDUCCIÓN	81,16	86,64	91,11
GAS 75°C	40,057	54,83	54,21
GAS 90°C	39,299	53,88	54,32

Figure 12. Energy efficiency results of the third group of pots.



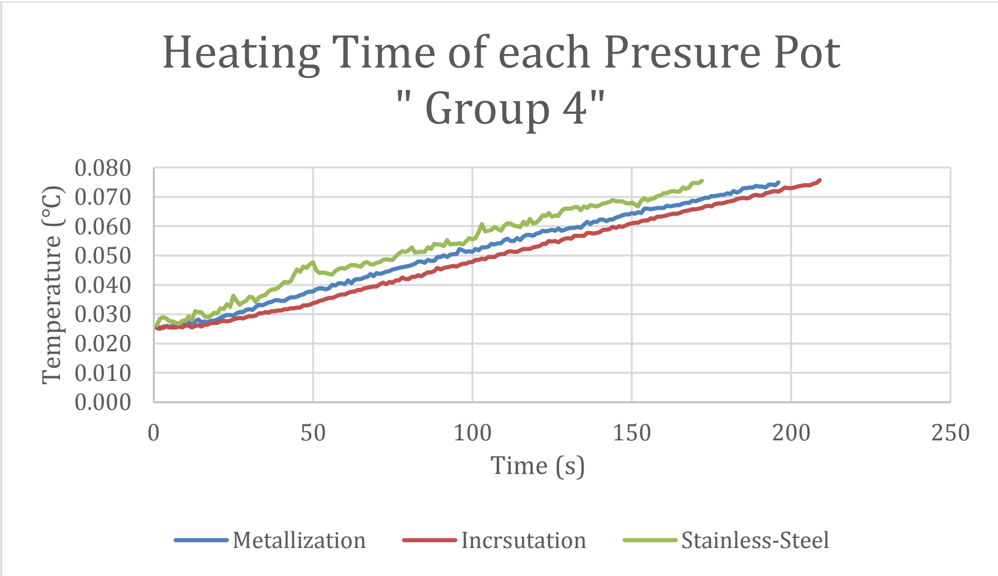
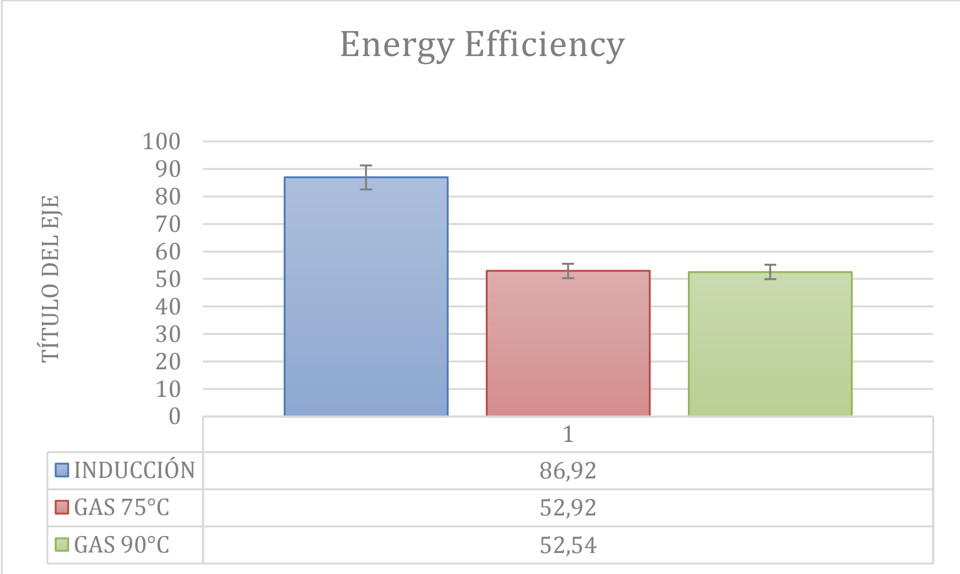


Figure 13. Energy efficiency results of the fourth group of pots.



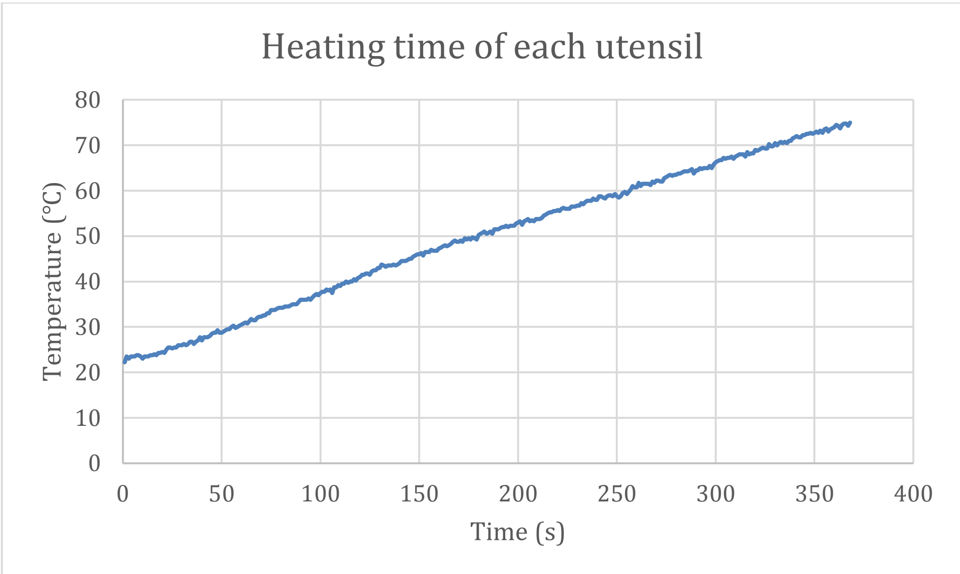


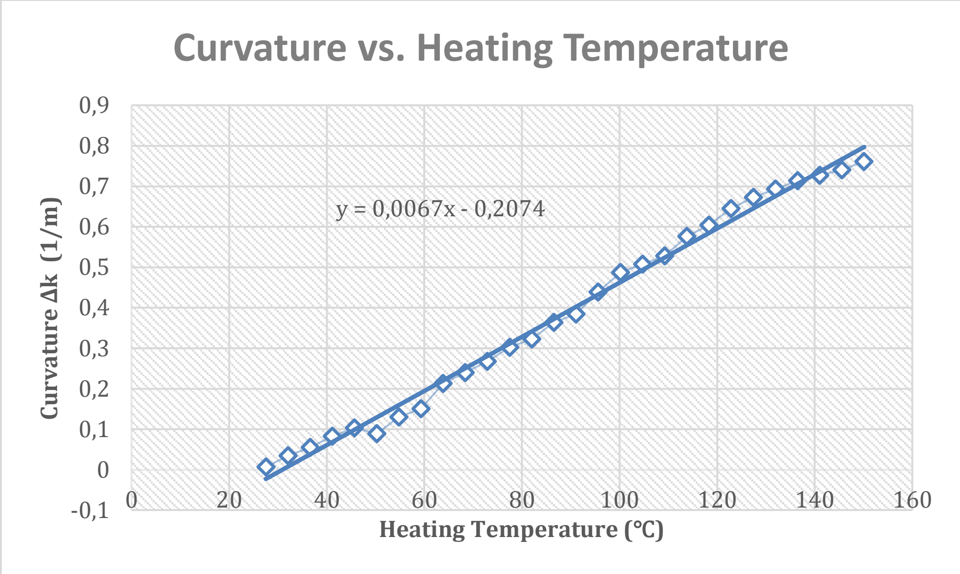
Figure 14. Energy efficiency results of the fifth group of pots.

In all the groups that obtain a possession of results, being the efficiency greater for the kitchens of induction, reason why the energy is not used thus also the metallic one arrives to satisfy with the efficiency that shows the Ecuadorian Standard.

Deformation and Efficiency

In these tests, it starts at ambient temperatures and ends at 150 ℃. In this type of test, it will be verified that the deformations only occur in utensils which are formed by two and *n*-materials. Therefore, a test has been carried out on the stainless-steel plate in order to verify that there is no deformation in a single material.

In the present the curvature for each of the materials is calculated, these will be experimentally and theoretically with equations 11, 12 and 18. In addition, the results of the simulations of the static analysis in transitory state for the two plates are presented, figure 15. In the experimental results due to the use of temperature sensors, the displacement-temperature curve of the central point can be obtained, and also the displacement and time curves of each of the tests are presented.



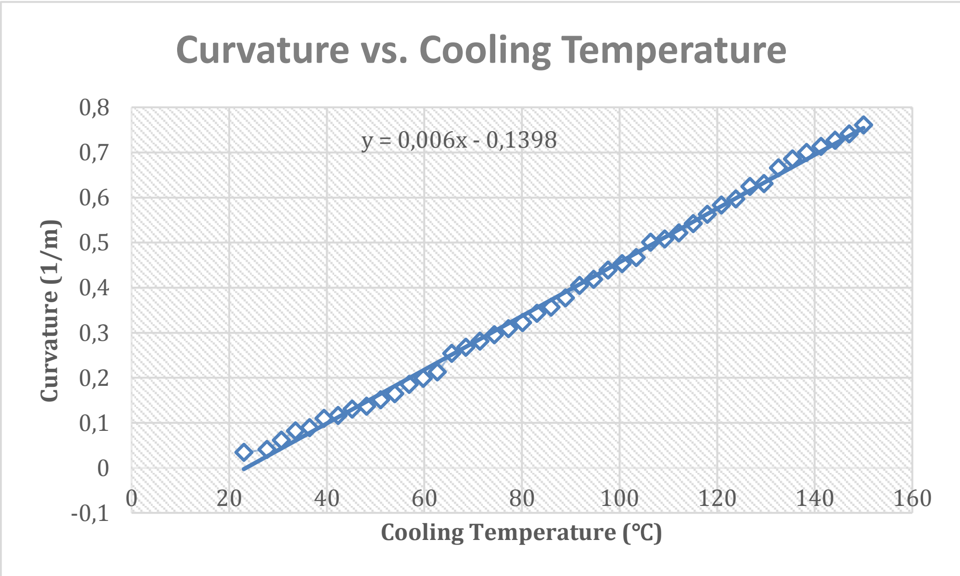


Figure 15. Experimental deformation test on the stainless-steel plate.

In the experimental case there is a maximum displacement of the central point of 2,17 mm at the temperature of 150 °C, from figures 16 and 17 there is a tendency line that models the experimental data obtained. These equations have the slope of the curve is that which is compared with the theoretical data for samples of two materials.

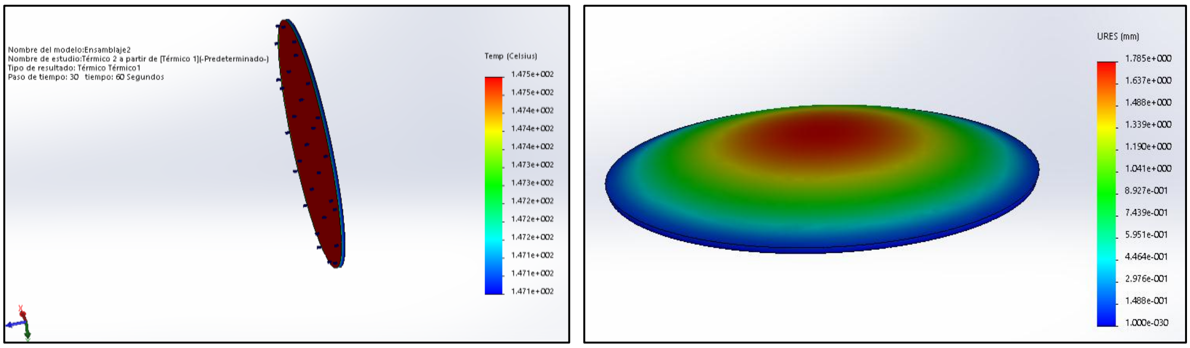


Figure 16. Experimental deformation test on the stainless-steel plate.

From the experimental and theoretical results for the plate of two materials. These results have a close relationship in their final results, both theoretical and experimental. It shows the results of the experimental and theoretical deformation values, as well as the slopes of the experimental and theoretical curve by means of equation 11, table 11.

Table 11. Experimental and theoretical results of deformation tests.

Variables	Results
Theoretical Displacement	1.785 mm
Experimental Displacement	2.14 mm
Slope of the experimental curve	0.6 m/°C
Slope of the Theoretical curve	0.47 m/°C

For the tests of the deformation in the three materials, figure 6. We have the same conditions of the simulations and the curves shown above for the two materials. It has simulations in steady state, transient and static analysis.

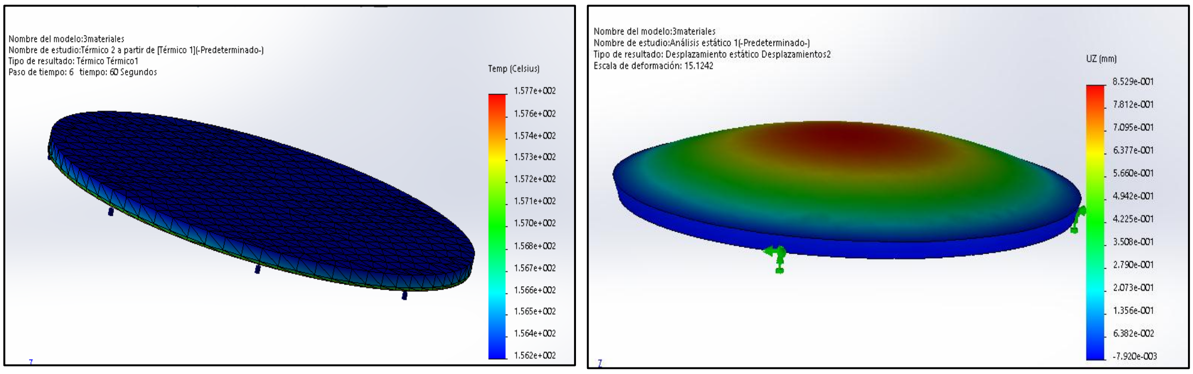


Figure 17. Experimental deformation test on the stainless-steel plate.

For this pot we also have the experimental and theoretical results of the curvature and the displacement of the central point of the plate, table 12.

Table 12. Experimental and theoretical results of deformation tests.

Variables	Results
Theoretical Displacement	0.852 mm
Experimental Displacement	0.567 mm
Experimental radius of curvature of the base of the experimental pot	2.39 m
Theoretical radius of curvature of the base of the experimental pot	3.66 m

The analysis involves the study of the relationship between the deformation of the base of the pot with the energetic efficiencies of the pots that are composed of two materials. In this study, tests are conducted on the sample that shows the greatest deformation, that is, on the recipient with a stainless base by incrustation. For this test, the base of the container is mechanically deformed until it has a maximum displacement at the center point of the base. Each of the 5 energy efficiency tests is carried out at different displacement values, table 13.

Table 13. Experimental and theoretical results of deformation tests.

Displacement	Energy efficiency value
0 mm	87.32 ± 1,82 %
1.27 mm	80.97 ± 1,01 %
2.00 mm	78.02 ± 2,05 %
3.268 mm	75.89 ± 1,42 %

Table 24 shows the influence of the base of the containers in the calculation of energy efficiency, as the distance between the base of the container and the glass ceramic increases, the efficiency tends to decrease gradually. In all test the center point of the utensil base moves away causing the decrease of the efficiency value as the distance of the base increases. The efficiency decreases because there is a distance between the base of the utensils and the magnetic field generated by the coils of the induction cooker. Due to the different mechanical and thermal properties of the base materials, it provokes a change of shape (concavity) in the base of the container, moving the base of the container causing the decrease in the value of the efficiency as the distance of the base.

Thermal Gradient

For this part, tests are carried out on containers of large capacities with the volume detailed in table 10. The results of energy efficiencies in large volumes are obtained. It is evident that the value of efficiency changes its value for these types of containers, the standard considers only the diameter of the kitchen, but not the volume of the containers that exceed 2 liters of capacity.

Figure 18. Experimental test on Pressure Pots and Tamalera with more than 2 litres. Pressure Pot (Rigth), Tamlarea (Left).

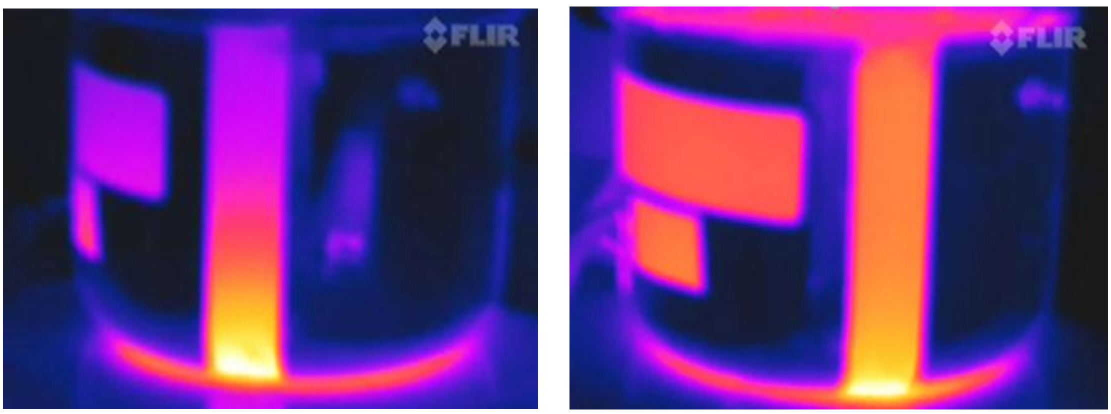


Figure 19. Experimental test on Pressurewith thermal gradients. Test with 2 literts (Left), Test with full water volume (Right).

The efficiency of the pressure cooker drops to 82.88 ± 1.70%, while the efficiency of the Tamalera decreases to an efficiency of 79 ± 2.68%, showing that the volume of water for larger containers must also be considered to 2 liters in larger capacity containers.

In containers of large volumes, the value of energy efficiency is dependent on the presence of thermal gradients. The standard does not consider performing efficiency tests on large containers (pressure cookers and tamaleras). In testes with these types of utensils and small volumes (2 liters) there is the presence of thermal gradients that modify the thermal efficiency. Because to obtain the value of energy efficiency (equation 4) consider the whole system with a homogeneous temperature. In the case of the tests with 2 liters, the container is not completely filled, causing a temperature difference along the container and modifying the value of the efficiency. In tests with full utensils a homogeneous temperature is achieved for the whole system (pot - water), so that there are no thermal gradients and the correct efficiency value is obtained for large utensils.

CONCLUSIONS

The induction cookers make the best use of energy since all the results showed efficiencies that exceed 80%, while in gas stove tests there are efficiencies values of 40%, which shows the advantage of induction cookers over gas cookers.

There is a difference between the results of the three main pots that were tested, the first with metallization, incrustation of steel and stainless steel. In all three cases, there are different energy efficiencies. Pots with metallization have an energy efficiency of 81%, the pots that have steel incrustation have an energy efficiency of 88% and the stainless-steel pots have a much higher efficiency of 90.50%. This shows the influence of the materials in obtaining the thermal efficiencies of the containers.

There is a notable difference in the energy efficiencies between the induction and gas stoves, during the tests under the same environmental conditions for the two cases (similar heating rate and handling -the same initial and final reference temperatures). Despite maintaining similar test conditions, very different results are obtained for each of the tests.

Induction cookers handle a shorter heating time than gas cookers, with a heating time of half being obtained in induction cooker tests. A heating time is obtained in induction cookers of approximately 285 seconds, while in gas cookers a time of 480 seconds is obtained.

The efficiency of the containers has a strong relationship between the concavity of the base of the containers because as the distance between the glass ceramic and the base of the container increases the efficiency decreases. The efficiency values are obtained for a displacement of 0 mm, 1.27 mm, 2.0 mm and 3.27 mm in the center point of the base, and efficiencies of 87%, 80%, 78% and 75% for each displacement are achieved.

The temperature gradient influences in large capacity utensils. In pressure cookers and tamale drills ‘tests efficiencies of less than 83% are achieved. In the tests with pressure cookers an efficiency of 82.8% is obtained, while in tests with Tamaleras an efficiency of 79% is achieved.

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APPENDIX A: ENERGY EFFICIENCY TESTS OF EACH UTENSILS.

Figure 20. Energy efficiency test pot 1. Induction (left), Gas (Right).

Figure 21. Energy efficiency test pot 2. Induction (left), Gas (Right).

Figure 22. Energy efficiency test pot 3. Induction (left), Gas (Right).

Figure 23. Energy efficiency test pot 4. Induction (left), Gas (Right).

Figure 24. Energy efficiency test fry pan 1. Induction (left), Gas (Right).

Figure 25. Energy efficiency test fry pan 2. Induction (left), Gas (Right).

Figure 26. Energy efficiency test saucepan 1. Induction (left), Gas (Right).

Figure 27. Energy efficiency test saucepan 2. Induction (left), Gas (Right).

Figure 28. Energy efficiency test saucepan 3. Induction (left), Gas (Right).

Figure 29. Energy efficiency test pressure cooker 1. Induction (left), Gas (Right).

Figure 30. Energy efficiency test pressure cooker 2. Induction (left), Gas (Right).

Figure 31. Energy efficiency test Tamalera 1. Induction (left), Gas (Right).

APPENDIX B: THERMAL DEFORMATION TESTS OF EACH UTENSILS.

Figure 32. Deformation test. Aluminum with a stainless steel Incrustation plate.

Figure 33. Deformation test. Aluminum with a stainless steel Incrustation pot.

Figure 34. Deformation test. Aluminum coated with steel and stainless steel by metallization.

Figure 35. Deformation test. Stainless steel.

APPENDIX C: ARDUINO CODE AND TEMPERATURE SENSORS.

```
#include <LiquidCrystal.h>
#include <SD.h>
#include <max6675.h>


LiquidCrystal lcd(21,   20,   19, 18, 17, 16);

int ktcSO    = 11;          // chip select primer MAX6675 //SO
int ktcCS1   = 23;           // CS
int ktcCLK   = 3;         //SCK siempre poner desde 2 hasta el 13 en PWM


//int ktcSO    = 11;         // chip select tercer MAX6675
int ktcCS2   = 25;
//int ktcCLK   = 3;


//int ktcSO    = 11;            // chip select tercer MAX6675
int ktcCS3   = 27;
//int ktcCLK   = 3;



//int ktcSO    = 11;            // chip select cuarto MAX6675
int ktcCS4   = 29;
//int ktcCLK   = 3;


//int ktcSO    = 11;           // chip select quinto MAX6675
int ktcCS5   = 31;
//int ktcCLK   = 3;

//int ktcSO    = 11;           // chip select sexto MAX6675
int ktcCS6   = 33;
//int ktcCLK   = 3;
```

```
//int ktcSO    = 11;          // chip select septimo MAX6675
int ktcCS7   = 35;
//int ktcCLK   = 3;


//int ktcSO    = 11;          // chip select octavo MAX6675
int ktcCS8   = 37;
//int ktcCLK   = 3;

// SD CARD PINES ARDUINO MEGA

//CS PIN 53
// SCK PIN 52
// MOSI PIN 51
// MISO PIN 50

MAX6675 ktc1(ktcCLK, ktcCS1, ktcSO);
MAX6675 ktc2(ktcCLK, ktcCS2, ktcSO);
MAX6675 ktc3(ktcCLK, ktcCS3, ktcSO);
MAX6675 ktc4(ktcCLK, ktcCS4, ktcSO);
MAX6675 ktc5(ktcCLK, ktcCS5, ktcSO);
MAX6675 ktc6(ktcCLK, ktcCS6, ktcSO);
MAX6675 ktc7(ktcCLK, ktcCS7, ktcSO);
MAX6675 ktc8(ktcCLK, ktcCS8, ktcSO);

File myFile;
void setup()
{
  Serial.begin(9600);
  lcd.begin(5,2);
  lcd.begin(2,2);
  lcd.print("Gradiente");
  lcd.setCursor(3,1);
  lcd.print("Termicos");
  delay(3000);
  lcd.clear();
  Serial.print("Iniciando SD ...");
  if (!SD.begin(53)) {
    Serial.println("No se pudo inicializar");
    lcd.print("ERROR AL INICIAR");
    return;
  }
  Serial.println("inicializacion exitosa");
  lcd.print("INICIO EXITOSO");
  delay(3000);
  lcd.clear();
}

void loop()
{
```

```
myFile = SD.open("datalog.txt", FILE_WRITE);//abrimos  el archivo

if (myFile) {
    Serial.print("Escribiendo SD: ");
    //int sensor1 = analogRead(0);
    //int sensor2 = analogRead(1);
    //int sensor3 = analogRead(2);
    myFile.print("Tiempo(ms)=");
    myFile.print(millis()/1000);
    myFile.print(", sensor1=");
    myFile.print(ktc1.readCelsius());
    myFile.print(", sensor2=");
    myFile.print(ktc2.readCelsius());
    myFile.print(", sensor3=");
    myFile.println(ktc3.readCelsius());
     myFile.print(", sensor4=");
    myFile.println(ktc4.readCelsius());
     myFile.print(", sensor5=");
    myFile.println(ktc5.readCelsius());
     myFile.print(", sensor6=");
    myFile.println(ktc6.readCelsius());
     myFile.print(", sensor7=");
    myFile.println(ktc7.readCelsius());
     myFile.print(", sensor8=");
    myFile.println(ktc8.readCelsius());




    myFile.close(); //cerramos el archivo

    Serial.print("Tiempo(ms)=");
    Serial.print(millis()/1000);
    Serial.print(", Temp1=");
    Serial.print(ktc1.readCelsius());
    lcd.print("Temp1=");
    lcd.print(ktc1.readCelsius());
    delay(3000);
    lcd.clear();
    Serial.print(", Temp2=");
    Serial.print(ktc2.readCelsius());
    lcd.print("Temp2=");
    lcd.print(ktc2.readCelsius());
    delay(3000);
    lcd.clear();
    Serial.print(", Temp3=");
    Serial.println(ktc3.readCelsius());
    lcd.print("Temp3=");
    lcd.print(ktc3.readCelsius());
```

```
        delay(3000);
        lcd.clear();
        Serial.print(", Temp4=");
        Serial.println(ktc4.readCelsius());
        lcd.print("Temp4=");
        lcd.print(ktc4.readCelsius());
        delay(3000);
        lcd.clear();
        Serial.print(", Temp5=");
        Serial.println(ktc5.readCelsius());
        lcd.print("Temp5=");
        lcd.print(ktc5.readCelsius());
        delay(3000);
        lcd.clear();
        Serial.print(", Temp6=");
        Serial.println(ktc6.readCelsius());
        lcd.print("Temp6=");
        lcd.print(ktc6.readCelsius());
        delay(3000);
        lcd.clear();
        Serial.print(", Temp7=");
        Serial.println(ktc7.readCelsius());
        lcd.print("Temp7=");
        lcd.print(ktc7.readCelsius());
        delay(3000);
        lcd.clear();
        Serial.print(", Temp8=");
        Serial.println(ktc8.readCelsius());
        lcd.print("Temp8=");
        lcd.print(ktc8.readCelsius());
        delay(3000);
        lcd.clear();
        delay(1000);
  } else {
    Serial.println("Error al abrir el archivo");
  }
  delay(500);
}
```

APPENDIX D: NORMA INEN RTE 2851.

Instituto Ecuatoriano de Normalización

Quito – Ecuador

NORMA
TÉCNICA
ECUATORIANA

NTE INEN 2851

UTENSILIOS DE COCINA. RECIPIENTES DOMÉSTICOS USADOS SOBRE HORNILLAS, COCINAS O PLACAS DE CALENTAMIENTO. REQUISITOS Y MÉTODOS DE ENSAYO

COOKWARE. DOMESTIC COOKWARE FOR USE ON TOP OF A STOVE, COOKER OR HOB. REQUIREMENTS AND TEST METHODS

ANEXO A
(Normativo)

ENSAYO DE EFICIENCIA ENERGÉTICA PARA LOS RECIPIENTES USADOS EN COCINAS DE INDUCCIÓN

A.1 Equipo de ensayo

A.1.1 Cocina de inducción de por lo menos tres zonas cuyos diámetros correspondan a los diámetros de base de fondo magnético del juego de utensilios de cocina normalizados.

A.1.2 Dos juegos de recipientes de cocina normalizados conforme se muestra en la tabla A.1.

TABLA A.1 Dimensiones de los utensilios de cocina normalizados

Utensilio de cocina	Diámetro fondo magnético "A" (mm)	Diámetro mínimo de la boca "B" (mm)	Altura mínimo "C" (mm)	Espesor fondo mínimo (mm)	Llanura máxima del fondo (mm)	Fondo convexo(1) máximo (mm)
1	140 ±10	140 + 30	70	1,5	0,075	0,3
2	180 ±10	180 + 30	90	1,5	0,075	0,3
3	210 ±10	210 + 30	110	1,5	0,1	0,3
(1) Fondo convexo quiere decir la distancia máxima entre 2 puntos del fondo (por ejemplo el punto central puede ser más alto que los puntos de los bordes).						

Los utensilios de cocina normalizados tienen que ser de:

A.1.2.1 Base sanduche cuyo material de cápsula debe ser acero AISI 430, de espesor 0,5 mm y el material de alta conductividad térmica debe ser de aluminio, de espesor 0,5 mm.

A.1.2.2 Cuerpo del utensilio de cocina de acero de grado alimenticio AISI 304 o AISI 202, de espesor mínimo de 0,5 mm.

En el caso de los utensilios de cocina sean de mayor diámetro efectivo que los utensilios de cocina normalizados, se debe tener una zona de ensayo de mayor o igual tamaño que del utensilio de cocina de ensayo.

A.1.3 Equipo para medir la diferencia de potencial eléctrica con una exactitud de ±5 %.

A.1.4 Contador de consumo de energía con una exactitud de 0,5 % y una lectura cada segundo.

A.1.5 Sonda de temperatura tipo PT100, PT1000 o K, J, L.

A.1.6 Balanza digital con una exactitud de 1 gramo.

A.2 Condiciones de ensayo

Durante el ensayo, la cocina de inducción a ensayar debe estar a una diferencia de potencial eléctrico de 220 V ± 11 V, adicionalmente se deben cumplir las siguientes condiciones de ensayo:

a) Presión atmosférica: 68 kPa ~ 106 kPa;

b) Temperatura ambiente: 23 °C ± 10 °C, y sin la influencia de otras fuentes de calor en el lugar de ensayo.

A.3 Método de ensayo para la eficiencia energética

A.3.1 El ensayo se llevará a cabo bajo las condiciones especificadas.

El recipiente tiene que ser elegido según el diámetro externo de la bobina (ver tabla A.1).
El ensayo para cada zona se desarrolla en dos partes: una primera parte de precalentamiento y una segunda parte de calentamiento y medición.

El ensayo debe seguir los siguientes pasos previos:

1. Medir el diámetro del fondo magnético del utensilio de cocina a ensayar.

2. Seleccionar el recipiente normalizado de igual diámetro de fondo magnético.

3. En caso de que no exista un recipiente normalizado de similar diámetro-geometría, utilizar procedimiento 2.

4. Realizar el método de ensayo de eficiencia energética para el utensilio de cocina normalizado.

5. Calcular el resultado de eficiencia energética obtenido con un recipiente normalizado.

6. Repetir los pasos 4 y 5 con un utensilio de cocina a ensayar.

A.3.2 Procedimiento 1

a) Precalentamiento

Llenar el utensilio de cocina normalizado con la cantidad de agua (Ver tabla A.2 para el volumen de agua). La temperatura inicial del agua debe ser de 15 °C ± 1 °C. Cubrir el recipiente con la tapa. Insertar el sensor en el centro de la tapa a través del agujero hasta 1 cm del fondo del recipiente.

Confirmar que la temperatura t_1 es de 15 °C ± 1 °C. Prender la zona con el nivel más alto (se puede utilizar el potenciador, en caso de existir). Calentar el agua hasta la temperatura t_2 de 75 °C ± 1 °C.

Quitar el recipiente caliente de la zona. El precalentamiento se termina. La segunda parte de calentamiento y medición debe empezar dentro de los siguientes 60 segundos.

b) Calentamiento y medición

Medir la masa total de la tapa y el cuerpo del segundo utensilio de cocina normalizado (m_2). Llenar el segundo recipiente con la cantidad de agua (según la tabla A.2). La temperatura inicial del agua debe ser de 15 °C ± 1 °C. Cubrir el recipiente con la tapa. Insertar el sensor en el centro de la tapa a través del agujero hasta 1 cm del fondo del utensilio de cocina). Confirmar que la temperatura t_3 es de 15 °C ± 1 °C. Prender la zona con el nivel nominal más alto (si está provisto de potenciador, no se usa el potenciador). Calentar el agua hasta la temperatura t_4 de 75 °C ± 1 °C. Apagar la zona y registrar la temperatura t_4 y la energía consumida.

$$\eta = \frac{(c_1 \times m_1 + c_2 \times m_2 + c_3 \times m_3) \times \Delta t \times 100\%}{(3,6 \times 10^3 \times E)} \qquad \text{(A.1)}$$

donde:

η = eficiencia energética (%) redondeada a una décima

c_1 = capacidad calorífica del agua, 4,18 kJ/kg·K

m_1 = masa de agua (kg)

c_2 = capacidad calorífica del cuerpo del utensilio de cocina y la tapa, 0,5 kJ/kg·K, para el acero inoxidable; 0,89 kJ/kg·K, para el aluminio

m_2 = masa total del cuerpo del utensilio de cocina (kg)

c_3 = capacidad calorífica de la tapa de vidrio, 0,876 kJ/kg·K

m_3 = masa de la tapa (kg)

E = consumo de energía (kW·h)

Δt = incremento de temperatura ($\Delta t = t_4 - t_3$), unidad de K

A.3.2 El ensayo anterior tiene que ser realizado para cada zona de inducción que compone la cocina.

Repetir el paso b) con el recipiente de muestra a ensayar, en la misma zona de inducción, calcular la eficiencia η_2, comparar las eficiencias η_1 y η_2, y comparar con los términos de aceptación.

A.3.3 Procedimiento 2

a) Seleccionar los utensilios de cocina normalizados de diámetro inmediato superior e inferior al utensilio de cocina a ensayar.

b) Seleccionar la zona de inducción del utensilio de cocina normalizado más grande, para realizar todos los ensayos.

c) Precalentar con el utensilio de cocina normalizado más grande.

d) Realizar el procedimiento de ensayo para los dos utensilios de cocina normalizados y el utensilio de cocina de muestra.

e) Calcular la eficiencia corregida para un utensilio de cocina normalizado correspondiente al diámetro del utensilio de cocina a evaluar, conforme la siguiente fórmula:

$$n_{2c} = \eta_3 \frac{d_2 - d_1}{d_3 - d_1} + \eta_1 \frac{d_3 - d_2}{d_3 - d_1} \qquad \text{(A.2)}$$

donde:

d_1 = diámetro del utensilio de cocina normalizado de menor diámetro

d_2 = diámetro del utensilio de cocina de muestra a ensayar

d_3 = diámetro del utensilio de cocina normalizado de mayor diámetro

η_1 = eficiencia del utensilio de cocina normalizado de menor diámetro

n_2 = eficiencia del utensilio de cocina de muestra a ensayar

η_3 = eficiencia del utensilio de cocina normalizado de mayor diámetro

n_{1c} = eficiencia corregida mediante ponderación de las eficiencias de los utensilios de cocina normalizados η_1 y η_3.

TABLA A.2 Cantidad de agua a añadir para el ensayo de eficiencia energética

Diámetro externo bobina "X" (mm)	Utensilio de cocina normalizado elegido	Cantidad de agua (kg)
X ≤ 140	1	1 ± 1%
140 < X ≤ 180	2	1,5 ± 1%
180 < x	3	2 ± 1%

APPENDIX E: NORMA NTC 2832.

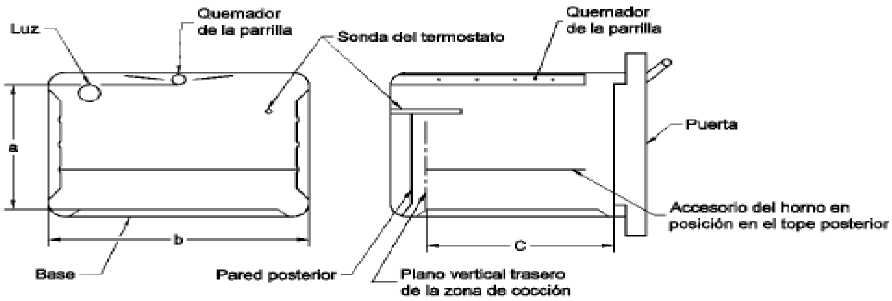

Figura I.3. Volumen útil del horno

I.3.1. Altura útil del horno: altura calculada desde la parte inferior del horno hasta la parte superior de la abertura de la puerta, que se puede reducir de tamaño debido a las proyecciones (base, quemador o entramado de la parrilla, etc.). Cuando la puerta no es rectangular, se toma la altura promedio.

Nota. Se considera que una puerta es rectangular si tiene cuatro esquinas redondeadas. Estas dimensiones nc tienen en cuenta las proyecciones locales: bombillas, tornillos, luz para el panel de visión del horno, etc.

I.3.2. Área útil del plano del horno: se define utilizando las dimensiones útiles medidas de forma que representen la superficie real disponible para cocinar (véase la Figura I.3). Es el producto de la distancia entre los soportes de repisa (o el ancho de la abertura de la puerta, lo que sea menor) y la distancia entre la superficie interna de la puerta y:

- la pared posterior, o
- el plano vertical posterior de la zona de cocción tal como pasa por el extremo más lejano del accesorio más largo del horno sostenido en su lugar por un dispositivo de fijación; el cálculo se basa en el que sea menor de estos valores.

Estas dimensiones no toman en cuenta las proyecciones locales: sondas, tornillos, luz del panel de visión del horno, etc.

I.4. DOCUMENTO DE REFERENCIA

EUROPEAN COMMITTEE FOR STANDARDIZATION. Domestic Cooking Appliances Burning Gas. Part 2-1: Rational Use of Energy. General. Brussels, 1998. 10 p. (BS - EN 30-2-1)

I.5. MÉTODOS DE ENSAYO

I.5.1 GENERALIDADES

I.5.1.1 Alimentación del quemador

Según la categoría del artefacto, cada quemador se alimenta individualmente con uno de los gases de referencia indicados en el presente reglamento, o un gas de los realmente distribuidos, respetando las condiciones del numeral 7.1.1.2 de la NTC 2832-1.

El quemador se ajusta según el numeral 7.1.3.1.3 de la NTC 2832-1, a su consumo calorífico nominal, o al consumo calorífico regulado con ± 2 %, siguiendo las indicaciones de la Tabla 1.

Se señala la posición correspondiente de los dispositivos de reglaje o el valor correspondiente de la presión en el quemador. Se enfría, entonces, el quemador antes de proceder al ensayo según el numeral I.5.2.1 ó I.5.2.2.

I.5.1.2 Condiciones de ensayo

Los ensayos se realizan en las condiciones de instalación especificadas en el numeral 7.1.3.2 de la NTC 2832-1.

I.5.1.3 Recipientes de ensayo

Se utilizan los recipientes de aluminio con fondo mate, paredes pulidas, y sin asas, que responden a las características definidas en el numeral C1 o al numeral 7.1.4.1 para los quemadores de pescado de la NTC 2832-1.

Los recipientes estarán provistos de su tapa.

I.5.2 EFICIENCIAS

I.5.2.1 Quemadores descubiertos

En función del consumo calorífico nominal del quemador ensayado, el diámetro del recipiente a utilizar, y la cantidad de agua con la que debe llenarse, se indican en la Tabla I.5.2.1.

Para los quemadores de pescado, la masa de agua se indica en la Tabla I.5.2.1 en función del consumo calorífico nominal del quemador.

Tabla I.5.2.1. Diámetro del recipiente y masa de agua en función del consumo calorífico nominal del quemador

Consumo calorífico nominal del quemador en kW	Diámetro interior del recipiente en mm	Masa de agua m_{e1} a introducir en kg
Entre 1,16 y 1,64	220	3,7
Entre 1,65 y 1,98	240[1)]	4,8
Entre 1,99 y 2,36	260[1)]	6,1
Entre 2,37 y 4,2	260[1)] Con un ajuste del consumo calorífico del quemador a 2,36 kW ± 2 % utilizando el método indicado en el numeral 7.3.1.2. 1. 1.a) de la NTC 2832-1.	6,1

1) Si el diámetro indicado (260 mm respecto a 240 mm) es superior al diámetro máximo indicado en las instrucciones de uso, el ensayo se realizará con el recipiente de diámetro inmediatamente inferior (240 mm respecto a 220 mm) conteniendo la cantidad de agua correspondiente (4,8 kg respecto a 3,7 kg). En este caso, el consumo calorífico nominal del quemador se ajustará a 1,98 kW respecto al 1,64 kW, con ± 2 % utilizando el procedimiento descrito en el numeral 7.3.1.2.1.1.a) de la norma NTC 2832-1.

La temperatura inicial del agua t_1 debe ser de (20 ± 1) °C y la temperatura en el momento de la extinción del quemador de (90 ± 1) °C.

Se mide la temperatura máxima t_2 observada después de la extinción del quemador [temperatura final, expresada en grados Celsius (°C)].

El elemento sensible se coloca en el centro del volumen de agua, y la temperatura se mide con ayuda de una sonda cuya incertidumbre de medida sea inferior a 0,1 °C.

Se realiza un calentamiento previo del quemador en las siguientes condiciones:

- El quemador funciona durante 10 min a su consumo calorífico nominal, o al consumo ajustado, según la Tabla I.5.2.1, en la posición de reglaje definida y marcada según el numeral I.5.1.1;
- Cualquiera que sea el consumo calorífico nominal del quemador, este se cubre con un recipiente de 220 min de diámetro conteniendo 3,7 kg de agua.

Al finalizar este precalentamiento, se retira el recipiente de 220 mm e inmediatamente después se coloca el recipiente correspondiente para el ensayo de rendimiento. La medida del consumo de gas comienza entonces y se termina después de la extinción del quemador, permaneciendo el recipiente en su lugar.

El rendimiento se calcula por la fórmula:

$$\eta = 4{,}186 \ x\ 10^{-3}\, m_e \ \frac{t_2 - t_1}{V_c(oM_c)H_s} \cdot 100$$

Donde:

η rendimiento, expresado en tanto por ciento (%);

m_e masa equivalente del recipiente lleno, conforme a las indicaciones dadas en la Tabla I.5.2.1;

La masa m_e se obtiene como sigue:

$$m_e = m_{e1} + 0{,}213\, m_{e2}$$

Donde:

m_{e1} masa del agua introducida en el recipiente;
m_{e2} masa del aluminio correspondiente al recipiente considerado, con su tapa (la masa m_{e2} a tener en cuenta, será la masa medida);

Todas las masas se expresan en kilogramos (kg);

V_c volumen de gas seco consumido, en metros cúbicos (m^3), determinado a partir del volumen medido, mediante la siguiente fórmula:

$$V_c = V_{mas} \cdot \frac{P_a + P - P_w}{1013{,}25} \cdot \frac{288{,}15}{273{,}15 + t_g}$$

Donde:

V_{mas} volumen de gas medido, en metros cúbicos (m^3)
P_a presión atmosférica, en milibar (mbar);
P presión de alimentación de gas en el punto de medición del consumo, en milibar (mbar);
P_w presión parcial del vapor de agua, en milibar (mbar).
t_g temperatura del gas en el punto de medida del consumo, en grados Celsius (°C);
M_c masa de gas seco consumido, en kilogramos (kg);
H_s poder calorífico superior del gas.