Corrosion analysis in different materials for induction cookware

J. Martínez, S. P. Villacís, M. A. Orozco, D. E. Vaca,
Instituto Nacional de Eficiencia Energética y Energías Renovables – INER.
Av. 6 de diciembre N33-32 e Ignacio Bossano
Edificio Torre Bossano, 2do. Piso Quito, Ecuador
e-mail: javier.martinez@iner.gob.ec, javiermtnezg@gmail.com

***Abstract*— the efficient use of energy is a priority when a technology migration plan is being held. 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 shown. To accomplish this study several test have been performed in three kinds of pots made of different materials: stainless steel, enameled cast iron and aluminium. The purpose of this test is to see how different materials for cookware would be affected into a salt spray chamber. These tests try to reach conditions similar to cooking with salt. The results of this study try to emphasize the selection in terms of corrosion of the best material to produce the cookware suitable for induction cookers. The standard test methods ASTM B895 − 05 have allowed to evaluate the corrosion property. The wrong choice of the material can lead to an inadequate life cycle assessment of the pot. After completing this research, it has been found that the enameled cast iron and the stainless steel present a higher corrosion resistance**

Keywords-component; corrosion, cookware, induction cookware, pots, induction pots, ASTM B895 – 05

***Resumen*— El uso eficiente de la energía es una prioridad cuando se lleva a cabo un plan de migración tecnológica. Varios factores deben ser tenidos en cuenta con el fin de lograr este objetivo. En este trabajo la migración del menaje de cocina que puede ser usado como recipientes en cocina de gas licuado de petróleo, deben ser adaptados para cocinas de inducción eléctricas. Para llevar a cabo este estudio varios ensayos se han realizado en tres tipos de ollas de diferentes materiales: acero inoxidable, hierro enlozado y aluminio fundido. El propósito de este estudio es ver el desempeño de los diferentes materiales para utensilios de cocina y como se ven afectados cuando se sumergen en una cámara de niebla salina. Los resultados de este trabajo enfatizan la selección del mejor material para producir el menaje de cocina adecuado para cocinas de inducción en términos de resistencia a la corrosión. Esta prueba trata de llegar a condiciones similares a cocinar con sal, o el uso de determinadas bases con el menaje. La norma y métodos de prueba ASTM B895 − 05 nos ha permitido evaluar la resistencia a la corrosión. La mala elección de un material puede llevar a una evaluación del ciclo de vida inadecuado de la olla. Después de completar esta investigación, se ha encontrado que el hierro fundido esmaltado o enlozado y el acero inoxidable presentan una mayor resistencia a la corrosión.**

Palabras claves; corrosión, menaje de cocina de inducción, ollas para cocinas de inducción, ASTM B895 – 05

I. INTRODUCTION

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 households [1], [2], [3], [4].

Induction cooker has a few advantages when compared with traditional cooker. There are two major advantages of the induction cooker, namely, energy saving and safety enhancement, Also the induction cooker has provided different types of built safety functions to reduce potential fire hazard in contrast with electrical and LPG based cookers [5], [6].

Currently in Ecuador is running the migration from liquefied petroleum gas (LPG) based cookers to electric induction cookers plan for changing the productive 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 from 2 to 3 million of induction cookware sets between 2014 and 2016. They would be compound of three pots with bottom diameters of 140, 160 and 180 mm respectively and a frying pan with bottom diameters of 180 mm. Within this policy is really important to choose the material in terms of corrosion resistance.

This program is world pioneer campaign called "efficient cooking plan", and they have been working in several adaptation of the electrical grid and industry [7], [8].

The main global challenges for the twenty-first century are energy, water and air, which mean to have sufficient energy to ensure a reasonable standard of living, clean water to drink and clean air to breathe. Within this context, the ability to manage corrosion is an important aspect of using materials effectively and efficiently in order to meet these challenges. Currently, materials reliability is becoming more important, otherwise when reliability is not assured, safety is compromised, and failure occurs [9]

Perhaps the most striking feature of corrosion is the immense variety of conditions under which it occurs and the large number of forms in which it appears. Numerous handbooks of corrosion data have been compiled that list the corrosion effects of specific material/environment combinations; still, the data cover only a small fraction of the possible situations and only for specific values of the study involved [10], [11], [12], [13].To prevent corrosion, to interpret corrosion phenomena, or to predict the outcome of a corrosion situation for conditions other than those for which an exact description can be found, the engineer must be able to apply the knowledge of corrosion fundamentals [14], [15], [16].

Laboratory corrosion tests are used to predict corrosion behavior when service history is lacking and time or budget constraints prohibit simulated service (field) testing. They can also be used as screening tests prior to simulated service testing. Laboratory tests are particularly useful for quality control, materials selection, materials and environmental comparisons, and the study of corrosion mechanisms.

Standard Test Methods for Evaluating the Corrosion Resistance of metals parts/specimens by immersion in a sodium chloride solution, this standard are used to measure the corrosion of several home instruments [17], [18], [19]. ASTM B895 − 05 test methods cover a procedure for evaluating the ability of sintered PM stainless steel and aluminum parts/specimens to resist corrosion when immersed in a sodium chloride (NaCl) solution.

The ability of metals to resist corrosion when immersed in sodium chloride solution is important to their end use. Causes of unacceptable corrosion may be incorrect alloy, contamination of the parts by iron or some other corrosion-promoting material or improper sintering of the parts (for example, undesirable carbide and nitride formations caused by poor lubricant burn off or improper sintering atmosphere).

The purpose of this test is to see how different materials for cookware would be affected into a salt spray chamber. This test tries to reach conditions similar to cooking with salt. The wrong choice of the material can lead to an inadequate life cycle assessment of the pot.

Fig. 1. a) Image of the salt spray chamber for material corrosion test. b) Image of two pots suspended in the salt spray chamber.

II. MATERIALS AND METHODS

A. Pots material corrosion resistance in a salt spray chamber

The following test was conducted using the observational method applied to three kind of induction pots, each one is made from different materials. In TABLE I is observed the specifications of the three tested pots.

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	20.00	20.00	0.5	1.8
2	Enameled iron	Enameled iron	20.00	20.00	0.7	0.7
3	Aluminium	Aluminium and AISI 430 Stainless steel	20.50	20.50	2.0	2.5

Fig. 2. a) y b) Images of stainless steel cookware before and after corrosion resistance in a salt spray chamber test, c) y d) Images of cast iron pot before and after corrosion resistance in a salt spray chamber test, e) y f) Images of aluminum body pot before and after corrosion resistance in a salt spray chamber test.

The first one is made of AISI 304 stainless steel in its body and AISI 430 stainless steel in its bottom. This pot has been processed through a sheet of material having the composition given by the designation of AISI 304 stainless steel. Then it was embedded and welded to the base by a sheet of cast iron alloy and other made of AISI 430 stainless steel in its bottom,

The second one was made by cast iron. Then, when cooled it had been applied a vitrification treatment to achieve good properties against the environment.

The last one made of aluminum in its body and stainless steel in its bottom.

This pot is processed from recycled cast aluminum from different sources, which has not controlled its composition after casting. From the aluminum plates they have been laminated to get a plate which has been embedded. Finally with the base of aluminium pot still hot it had been welded an AISI 430 stainless steel sheet.

ASTM B895 – 05 Standard Test Methods for Evaluating the Corrosion Resistance of metals parts/specimens by immersion in a sodium chloride solution had been used. The pots are immersed in the solution. Then they are examined periodically and the time to the first appearance of staining or rust is used to indicate the end point.

In order to perform this test the following tools and reagents were required:

- A salt spray chamber.
- A rope clamp.
- Salt.
- Water.

The procedure was the following:

- 2 liters of water mixed with 104,6 g of salt were added into the salt spray chamber, as can be seen in Fig. 1 a):
- The pots were placed in a suspended position inside the salt spray chamber, as can be seen in Fig. 1 b):
- The salt spray chamber was covered with a lid and it was kept the temperature of 30 °C with heather.
- This temperature was maintained during 24 hours.
- Some pictures of pots were taken at half, 1, 2, 4, 8, 12 and 24 hours of the test.
- Finally pots were taken out and immediately to verify if they presented corrosion or bubbles.

Once that data was obtained from mentioned tests, their respective analysis was made after they were expressed with graphics and tables based on the standard test methods ASTM B895 − 05 Standard Test Methods for Performance of Range Tops.

III. RESULTS

Fig. 2 shows pictures of body stainless steel AISI 304 and bottom stainless steel AISI 430 pot, enameled cast iron pot and body aluminium and bottom stainless steel AISI 430 pot before and after corrosion resistance test in a salt spray chamber. After 8 h of test aluminium body pots had shown a different color and the first appearance of stain or rust.

After have finished the test, the corrosion percentage of cookware was analyzed by ASTM B895 − 05 Standard Test Methods, the results are showed in TABLE II. In these results you compare the area of stain or rust after 24 hours with the total area of the surface of the cookware.

After analyzing the obtained results it was possible to determine that it is not good when pots present a minimum percentage of stain or rust. The aluminium pot showed a little of oxidation, due to the wrong material choice not suitable for food. While enameled iron and stainless steel pots did not present any oxidation at all.

TABLE II. RESULTADOS OBTENIDOS AL REALIZAR EL ENSAYO DE CORROSIÓN DEL MATERIAL EN CÁMARA DE NIEBLA SALINA.

N`	*Body material*	*Bottom material*	*Corrosion percentage [%]*
1	AISI 304	AISI 430	< 1
2	Enameled cast iron	Enameled cast iron	< 1
3	Aluminium	AISI 430	> 25

These analyzed results according to standard ASTM to evaluate corrosion resistance, show that stainless Steel and enameled cast iron pots presented lower corrosion percentage, while aluminium pot presented a higher corrosion inside; at the end the pot that showed the highest corrosion percentage inside and outside was the made of aluminium.

IV. CONCLUSIONS

Once that the obtained results were analyzed, it was possible to establish that pots that showed the lowest oxidation percentage were the ones made from stainless steel and cast iron, aluminium pots showed oxidation because of a wrong material choice, due to manufactures use aluminium recycling material instead of using an aluminium alloy suitable for food.

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