Material Selection of Induction Cookware based on Multi Criteria Decision Making Methods (MCDM)

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Resumen

El Ecuador está fomentando nuevos proyectos enfocados en la reducción de consumo de combustibles fósiles. Con este propósito en mente, el gobierno lleva a cabo un plan para reemplazar cocinas dependientes del gas licuado de petróleo (GLP) por cocinas de inducción. Esto contribuirá en la disminución del consumo del GLP, emisiones tóxicas. En contraste, la calidad de vida en el Ecuador y la eficiencia energética en la edificación mejorará. Este documento hay sido elaborado para determinar el material adecuado capaz de interactuar con campos magnéticos.

Los métodos multi-criterio de selección (MCDM) son herramientas analíticas que sirven para juzgar la mejor alternativa de un conjunto de posibilidades. Dependiendo del número de alternativas y el número de criterios de selección, los MCDM aparecen como herramientas de evaluación que permitirán seleccionar al material correcto para el diseño del menaje para cocinas de inducción.

En el desarrollo de este proyecto se empleó las aproximaciones EXPROM2, COPRAS-G, TOPSIS y VIKOR. Los resultados obtenidos de cada método serán valorados y validados. El estudio consiste en recolectar información referente a las propiedades de cada material y su respectiva importancia en el diseño del menaje de cocinas de inducción y establecer una matriz normalizada que relaciona la magnitud de cada propiedad.

Los resultados obtenidos resaltan al acero A677 como la mejor alternativa de un conjunto de 8 opciones con 8 diferentes criterios de selección.

Palabras clave— **cocina de inducción, menaje, campo magnético, multi-criterio**

Abstract

Ecuador has started a national project focus on a new model of energetic management so as to reduce the Ecuadorian dependency on fossil fuels. With this purpose in mind, the government has disposed to replace liquefied petroleum gas (LPG) cookers for induction cookers. This will contribute to decrease the consumption of LPG, emission of toxic fumes and multidimensional poverty index (MPI). In contrast, the Ecuadorian quality of life (EQOL) and the global efficiency of the energetic system will improve. This paper was developed to determine the correct material which can efficiently interact with magnetic fields at low cost.

Multi decision making methods (MCDM) are analytical tools employed to judge the right alternative of a set of possibilities. According to the number of alternatives and criteria of this problem, MCDM appears as an evaluation approach that can ease the selection of materials for induction cookware.

The MCMD methods implemented are AHP, EXPROM2, COPRAS-G, TOPSIS and VIKOR, all of them have been compared to validate the best alternative. The analysis process consists on collecting information about the properties of the material and his weight respect to the others to generate a normalized matrix that relate the dependency among criteria.

The results prove that the steel A677 is the best material, of a set of 8 alternatives with 8 analysis criteria, to be applied as induction cookware.

Index terms— **Induction cookers, cookware, toxic fumes and magnetic fields.**

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1. INTRODUCTION

Material selection has become an important source at engineering processes because of economic, technological, environmental parameters, Inter Alia [1], [2]. It carried out several research processes that give off assessment methods to compare the behavior of elements according to their characteristic properties (density, specific heat, cost) with efficiency indicators [3]. Saaty [4] "The Analytic Hierarchy Process", Hwang y Yoon [5] "Multiple Attribute Decision Making: Methods and Applications", Delhaye, Teghem, Kunsch [6] "Application of the ORESTE method to a nuclear waste management problem", Raju, Kumar, [7] "Multicriterion decision making in irrigation planning", Macharis [8] "PROMETHEE and AHP: The design of operational synergies in multicriteria analysis", have proposed mathematical formulations to relate alternatives and properties in order to select the correct option.

Multi criteria decision making methods (MCDM) appear as an alternative in engineering design due to its adaptability for different applications. To develop this project, the EXPROM2 [9] (extended PROMETHEE II), TOPSIS [5] (technique for order performance by similarity to ideal solution), VIKOR (Vlse Kriterijumska Optimiza- cija Kompromisno Resenje, means Multicriteria Optimization and Compromise Solution) have been used as analytical tools to make the right decision.

Here are some engineering applications where MCDM have been regarded as selection tools. Jahan, Ismail, Sapuan, Mustapha [10] "Material screening and choosing methods -A review", Bitarafan, Hashemkhani Zolfani, Arefi, [11] "Evaluating the construction methods of cold-formed steel structures in reconstructing the areas damaged in natural crises, using the methods AHP and COPRAS-G", Findik, Turan [12] "Materials selection for lighter wagon design with a weighted property index method", Zavadskas, E.K., Çaliskan, Kursuncu, Kurbanoglu y Güven [13] "Material selection for the tool holder working under hard milling conditions using different multi criteria decision making methods", Çaliskan [14] "Selection of boron based tribological hard coatings using multi-criteria decision making methods".

Nowadays, Ecuador is promoting the implementation of a new model of energetic management in order not to depend only on oil production. Its main objective is to restructure production media so as to reduce import products. According to this approach, the government disposed changing traditional gas cooker for induction stoves [15].

The burning of liquefied petroleum gas (LPG) produces high rates of pollution and low energetic efficiency [16], [17]. Therefore, gas cookers are inefficient and dangerous for the environment. On the other hand, induction stoves apply magnetic fields to generate heat in the cooking pot base (made of ferrous material) and increase his temperature [18]. The efficiency of this process is higher than efficiency of burning fossil oils [19].

This project focused on selecting the right magnetic material for cooking pot bases by means of MCDM. It will contribute to Ecuador in the development of the new model of energetic management. With this national purpose, these fundamental questions have been set:

- What is the material which best fits the technological requirements to make cooking pot bases?
- Which are the parameters more valuable to select cooking pot bases?

This paper is organized with an introductory section that explain the development and applications of MCDM. Afterwards, a brief description of the MCDM methods. Finally, the results and conclusions obtained.

2. MULTI CRITERIA DECISION MAKING METHODS

The MCDM methods are applied by business and industrial companies to select the best alternative for an specific application considering qualitative and quantitative design parameters [20]. This article center on the methods VIKOR, TOPSIS, EXPROM2, COPRAS-G and AHP.

2.1. Analytical hierarchy process (AHP)

Every alternative is assigned a value in order to identify its importance in an application. The ranking is composed by three levels: a). general objective, b). criteria for every alternative, c). alternatives to regard [21].

2.2. Comparison among alternatives

The weight of criteria respect to other are set in this section. To quantify its coefficient, it is required the experience and knowledge of the assessing team or technician [22].

Saaty [4] classified the importance parameters as in Table 1.

Table 1: Scale of relative importance

Definition	Intensity of importance
Equal importance	1
Moderate importance	3
Strong importance	5
Very strong importance	7
Extreme importance	9
Intermediate importance	2, 4, 6, 8

Source: [4]

The values 2, 4, 6 and 8 are applied to differentiate slightly differing judgments [4, 14].

The comparison among n criteria are resume in matrix $\boldsymbol{A}\,(\boldsymbol{n}\times\boldsymbol{n})$ the global arrange is expressed in equation 1.

$$A=\begin{pmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{pmatrix},(a_{ij}=1,a_{ji}=\frac{1}{a_{ij}},a_{ij}\neq 0) \quad (1)$$

Afterwards, from matrix A it is determined the relative priority among properties. The eigenvector ω is the weight importance and it corresponds with the largest eigenvector λ:

$$(\boldsymbol{A}-\boldsymbol{\lambda_{max}})\boldsymbol{w}=\boldsymbol{0} \quad (2)$$

The consistency of the results is resumed by the pairwise comparison of alternatives. Matrix A can be ranked as 1 and $\boldsymbol{\lambda_{max}}=\boldsymbol{n}$ [23].

2.3. Consistency assessment

In order to analyze the consistency of the results it is necessary to distinguish the importance of alternatives among them. In equations 3 and 4 is shown the consistency indexes required to validate the results.

$$\boldsymbol{CI}=\frac{\boldsymbol{\lambda_{max}-n}}{\boldsymbol{n-1}} \quad (3)$$

$$\boldsymbol{CR}=\frac{\boldsymbol{CI}}{\boldsymbol{RI}} \quad (4)$$

Where:

n: number of selection criteria.

RI: random index.

CI: consistency index.

CR: consistency relationship.

$\boldsymbol{\lambda_{max}(A)}$: largest eigenvalue.

If CR should be greater than 0.1, otherwise, the importance coefficient (1-9) has to be set again and CR recalculated [13].

1.1. **EXPROM2 method**

This method focuses on ranking each alternative respect to criteria selection. The comparison is made according to [8]:

- Relative importance of each property on the basis of the sort of application
- Information generated from the decision function

The consistency index applied to validate results can be formulated by means of the ideal and anti-ideal solutions [24].

The EXPROM2 is formulated with the equations [7], [25]:

Step 1: Normalize the decision matrix, equation 5

$$\boldsymbol{r_{ij}}=\frac{\boldsymbol{x_{ij}-min(x_{ij})}}{\boldsymbol{max(x_{ij})-min(x_{ij})}},(\boldsymbol{i}=\boldsymbol{1},\boldsymbol{2},\cdots,\boldsymbol{m}|\ \boldsymbol{j}=\boldsymbol{1},\boldsymbol{2},\cdots,\boldsymbol{n}) \quad (5)$$

Where:

$\boldsymbol{x_{ij}}$ is the performance measure of jth criterion respect to ith alternative.

$\boldsymbol{r_{ij}}$ is the normalized value of $\boldsymbol{x_{ij}}$.

For non-beneficial criteria the $\boldsymbol{x_{ij}}$ is computed by equation 6:

$$\boldsymbol{x_{ij}}=\frac{\boldsymbol{max(x_{ij})-x_{ij}}}{\boldsymbol{max(x_{ij})-min(x_{ij})}},(\boldsymbol{i}=\boldsymbol{1},\boldsymbol{2},\cdots,\boldsymbol{m}|\ \boldsymbol{j}=\boldsymbol{1},\boldsymbol{2},\cdots,\boldsymbol{n})` \quad (6)$$

Step 2: The difference between alternatives $\boldsymbol{d_j}$ is estimated.

Step 3: Preference function $\boldsymbol{P_j(i,i')}$ is calculated according to the alternatives i and i' respect to jth criterion. The usual criterion has been used in this analysis.

$$\boldsymbol{P_j(i,i')=0,r_{ij}\leq r_{ij}} \quad (7)$$

$$\boldsymbol{P_j(i,i')=1,r_{ij}>r_{ij}} \quad (8)$$

Step 4: The weak preference index $\boldsymbol{WP_j(i,i')}$ is determined based on the criteria weights $\boldsymbol{(w_j)}$

$$\boldsymbol{WP(i,i')}=\left[\sum_{j=1}^{n}\boldsymbol{w_j}\times\boldsymbol{P_j(i,i')}\right]/\sum_{j=1}^{n}\boldsymbol{w_j} \quad (9)$$

Step 5: The strict preference function $SP_j(i,i')$ is performed comparing dm_j (ideal and anti-ideal comparison of jth criteria) with the preference limits L_j (0 for the usual function), see equation 10.

$$SP_j(i,i') = \frac{max(0,d_j - L_j)}{dm_j - L_j} \quad (10)$$

Step 6: Calculation of strict preference index $SP(i,i')$, equation 11.

$$SP_j(i,i') = \frac{\sum_{j=1}^{n} SP_j(i,i')}{\sum_{j=1}^{n} w_j} \quad (11)$$

Step 7: Calculation of the total preference index $TP(i,i')$, equation 12.

$$TP(i,i') = min[1, WP(i,i') + SP(i,i')] \quad (12)$$

Step 8: Comparison of input and output flows by means of equations 13, 14, respectively.

$$\varphi^{+}(i) = \frac{1}{m-1}\sum_{i'=1}^{m} TP(i,i'), (i \neq i'') \quad (13)$$

$$\varphi^{-1}(i) = \frac{1}{m-1}\sum_{i'=1}^{m} TP(i',i), (i \neq i') \quad (14)$$

Where:

$\varphi^{+}(i)$ positive flow of the alternative it h which expresses how much an alternative dominates the others.

$\varphi^{-}(i)$ negative flow of the alternative it h which expresses how much an alternative is dominated by the others.

m: number of alternatives.

Step 9: Calculation of the net outranking flow $\varphi(i)$.

$$\varphi(i) = \varphi^{+}(i) - \varphi \quad (15)$$

Step 10: Rank the alternatives according to $\varphi(i)$. The greatest $\varphi(i)$ corresponds to the best alternative.

2.5. TOPSIS METHOD

This method focus on identifying the right alternative according to the distance between ideal and anti-ideal solutions [10], [26]–[28]and compares results of different sets of weights applied to a previously used set of multiple criteria data. Comparison is also made against SMART and centroid weighting schemes. TOPSIS was not found to be more accurate, but was quite close in accuracy. Using first-order and second-order metrics were found to be quite good, but the infinite order (Tchebycheff norm, L-???.

The TOPSIS approach is structured by the following procedure [29], [30]:

Step 1: Normalize the decision matrix n_{ij} by means of equation 16.

$$n_{ij} = \frac{x\_ij}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}}, (i = 1,2,\cdots,m \mid j = 1,2,\cdots,m) \quad (16)$$

Where:

x_{ij} (ith alternatives and jth criteria)

Step 2: Sync the weight w_j and the normalized matrix n_{ij}, see equation 17.

$$V_{ij} = n_{ij}w_j, (i = 1,2,\cdots,m \mid j = 1,2,\cdots,m) \quad (17)$$

Step 3: Determinate ideal solutions $(V^{+})$and anti-ideal solutions (V^{-}) referring to equations 18, 19.

$$\{V_1^{+}, V_2^{+}, \cdots, V_n^{+}\} = \left\{\left(\min_i V_{ij} \middle| j\varepsilon K\right), \left(\max_i V_{ij} \middle| j\varepsilon K'\right) \middle| i = 1,2,\cdots,m\right\} \quad (18)$$

$$\{V_1^{-}, V_2^{-}, \cdots, V_n^{-}\} = \left\{\left(\min_i V_{ij} \middle| j\varepsilon K\right), \left(\max_i V_{ij} \middle| j\varepsilon K'\right) \middle| i = 1,2,\cdots,m\right\} \quad (19)$$

Where K and K' are the index set of benefit criteria and the index set of cost criteria, respectively.

Step 4: The distance between the ideal and anti-ideal solution is quantified by equations 20, 21.

$$S_i^{+} = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^{+}\right)^2}, (i = 1,2,\cdots,n \mid j = 1,2,\cdots,n) \quad (20)$$

$$S_i^{-} = \sqrt{\sum_{j=1}^{n}\left(V_{ij} - V_j^{-}\right)^2}, (i = 1,2,\cdots,n \mid j = 1,2,\cdots,n) \quad (21)$$

Step 5: The relative closeness C_i is computed by equation 22:

$$C_i = \frac{S_i^{-}}{S_i^{+} + S_i^{-}}, (i = 1,2,\cdots,n \mid 0 \leq C_i \leq 1) \quad (22)$$

The highest C_i coefficients correspond to the best alternatives.

2.6. VIKOR method

The VIKOR method considers the closeness to the ideal solution in order to rank the alternatives [3, 31].

Step 1: Select the maximum magnitude of $(x_{ij})_{max}$ and minimum magnitude of $(x_{ij})_{min}$ of each criterion.

Step 2: E_i and F_i are computed by equations 23, 24.

$$E_i = \sum_{j=1}^{n} w_j \frac{(x_{ij})_{max} - x_{ij}}{(x_{ij})_{max} - (x_{ij})_{min}} \quad (23)$$

$$F_i = max^n \left\{ w_j \frac{(x_{ij})_{max} - x_{ij}}{(x_{ij})_{max} - (x_{ij})_{min}} \right\}, (j = 1, 2, \cdots, n) \quad (24)$$

Step 3: P_i are calculated by equation 25

$$P_i = \nu \frac{E_i - E_{i-min}}{E_{i-max} - E_{i-min}} + (1 - \nu) \frac{F_i - F_{i-min}}{F_{i-max} - F_{i-min}} \quad (23)$$

E_{i-max} is the maximum value of E_i.

E_{i-min} is the minimum value of E_i.

F_{i-max} is the maximum value of F_i.

F_{i-min} is the minimum value of F_i.

ν the weight of the strategy of ``majority criteria".

ν is usually 0.5, but it could be in the range of 0 to 1.

Step 4: Rank the results according to P_i, E_i y F_i , y in different cells.

The minimum value of P is set as the committed solution for a weight criterion, if condition 1 and 2 are compiled:

Condition 1. - "Acceptable advantage" $P(x'') - P(x') \geq (1/(m-1))$ where x' and x" are the best alternatives.

Condition 2. - "Acceptable stability in decision making". The alternative x' must be the best in the ranking of E_i and/or F_i. The committed solution is made by: "voting by majority rule" (if is $\upsilon < 0,5$ required) or "by consensus" (if $\upsilon \approx 0,5$) or ``with veto" (if $\upsilon > 0,5$)

If one of the conditions is not fulfil, one of the following alternatives can be adopted:

- Alternatives x' and x" if condition 2 in not satisfied.
- Alternatives x', x", …, x^k condition is not satisfied: x^k is determined by the relation $P(x^k) - P(x') < (1/(m-1))$, where the alternative position is "in closeness".

2.7. COPRAS-G method

COPRAS-G [11] is a MCDM method that apply gray numbers to evaluate several alternatives of an engineering application. The gray numbers are a section of the gray theory to confront insufficient or incomplete information. The uncertainty level can be expressed by three numbers: white, gray and black [32].

Let the number $\otimes X = |\underline{x}, \overline{x}| = \{x | \underline{x} \leq x \leq \overline{x}\}$ and $x \in R$, where $\otimes X$ has two real numbers $\underline{x}$ (lower limit of $\otimes X$) y $\overline{x}$) y (the upper limit of $\otimes X$) [33].

- *White number*: if $\overline{x} = \underline{x}$, , complete information
- *Gray number*: if $\otimes X = |\underline{x}, \overline{x}|$, incomplete or uncertain information
- *Black number*: if $\underline{x} \to -\infty$ and $\overline{x} \to +\infty$, no significant information.

El formato del texto debe respetar las siguientes características:

$$\otimes X = \begin{pmatrix} [\otimes x_{11}] & [\otimes x_{12}] & \cdots & [\otimes x_{1m}] \\ [\otimes x_{21}] & [\otimes x_{22}] & \cdots & [\otimes x_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\otimes x_{n1}] & [\otimes x_{n2}] & \cdots & [\otimes x_{nm}] \end{pmatrix} ; j = 1, \cdots, n, i = 1, \cdots, m \quad (26)$$

$$= \begin{pmatrix} [\overline{x}_{11}, \underline{x}_{11}] & [\overline{x}_{12}, \underline{x}_{12}] & \cdots & [\overline{x}_{1m}, \underline{x}_{1m}] \\ [\overline{x}_{21}, \underline{x}_{21}] & [\overline{x}_{22}, \underline{x}_{22}] & \cdots & [\overline{x}_{2m}, \underline{x}_{2m}] \\ \vdots & \vdots & \ddots & \vdots \\ [\overline{x}_{n1}, \underline{x}_{n1}] & [\overline{x}_{n2}, \underline{x}_{n2}] & \cdots & [\overline{x}_{nm}, \underline{x}_{nm}] \end{pmatrix}$$

Where, $\otimes x_{ij}$ is portrait by the lower limit $\underline{x}_{ij}$ and the upper limit $\overline{x}_{ij}$.

Step 2: Normalize the decision matrix, $\otimes X$ through the equation 27 for the lower limit $\underline{x}_{ij}$ and equation 28 for the upper limit $\overline{x}_{ij}$.

$$\otimes \overline{X} = [\underline{x}_{ij}]_{m \times n} = \frac{2\underline{x}_{ij}}{\sum_{j=1}^{n} \underline{x}_{ij} + \sum_{j=1}^{n} \overline{x}_{ij}} \quad (27)$$

$$\otimes \overline{X} = [\overline{x}_{ij}]_{m \times n} = \frac{2\overline{x}_{ij}}{\sum_{j=1}^{n} \underline{x}_{ij} + \sum_{j=1}^{n} \overline{x}_{ij}} \quad (28)$$

Step 3: Determine the weight of each criterion.

Step 4: Determine the normalized decision matrix by means of equations 29, 30.

$$\otimes \overline{\overline{X}} = [\underline{x}_{ij}]_{m \times n} = \underline{x}_{ij} \times w_j \quad (i = 1, 2, \ldots, m; j = 1, 2 \ldots n) \quad (29)$$

$$\otimes \overline{\overline{X}} = [\overline{\overline{x}}_{ij}]_{m \times n} = \overline{x}_{ij} \times w_j \quad (30)$$

Step 5: The weighted mean normalized sums are computed for the beneficial attributes P_i based on equation 31 and non-beneficial attributes R_i according to equation 32.

$$P_i = \frac{1}{2}\sum_{j=1}^{n}\left(\overline{\overline{x}}_{ij} + \underline{\underline{x}}_{ij}\right) \quad (31)$$

(31)

$$R_i = \frac{1}{2}\sum_{j=k+1}^{n}\left(\overline{\overline{x}}_{ij} + \underline{\underline{x}}_{ij}\right) \quad (32)$$

Step 6: Determine the minimum value R_i

$$R_{min} = min\, R_i \quad (33)$$

Step 6: Determine the relative priority of the alternatives. It can be calculated with equation Q_i 34, the highest value of Q_i represents the best alternative and it is called Q_{max}

$$Q_i = P_i + \frac{\sum_{i=1}^{m} R_i}{R_i \sum_{i=1}^{n}\frac{1}{R_i}} \quad (34)$$

Step 7: Calculate the quantitative utility U_i for every alternative through the equation 35 The ranking is set by the magnitude of Q_i.

$$U_i = \left[\frac{Q_i}{Q_{max}}\right] \times 100\% \quad (35)$$

2.8. Induction stove

The government of Ecuador has proposed the changing of gas cookers for induction stoves. Some advantages are [34]

- Reduce power consumption and the use of fossil fuels.
- Increase efficiency during the heating process.
- Noiseless and non-contaminant systems.

This technology is new for Ecuador, therefore, there are not enough resources to support the materials that can be used to produce the right pot for induction cookers. This project focus on determine the adequate material for induction pot bases.

2.8.1. Working principle

The induction heating is based on the static magnetic field principle. An electric current is induced over a coil to produce a magnetic field that change of polarity. Its develops the effect of ``Eddy currents" that stay in the conductive metal (pot base) and generate the heat [34], [35]. In Figure 1 is described the heating process of pot bases for the induction effect.

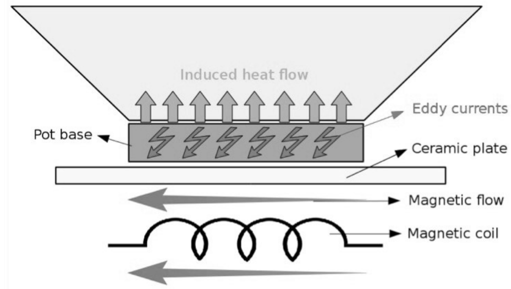

Figure 1: Working principle of induction effect over magnetic pot bases.

2.8.2. Material requirements for induction pot bases

The pot must be flat and made of ferromagnetic materials that allow the formation of Eddy currents.

3. RESULTS

The results reached with the methods EXPROM2, VIKOR, TOPSIS, COPRAS-G are compared in order to determine their convergence and sensibility.

3.1. Criteria weighting

The weight of each alternative was assigned according to the AHP approach. The identification for materials and properties are en Table 2 and Table 3 respectively. The comparison among properties of every alternative is in Table 4. An schematic resume of the AHP process is illustrated in Figure 2.

Table 2: Material identification

Material	Identification
Permalloy 80 (80% Ni, 4% Mo, 16% Fe)	a
ASTM A677 Steel M-47 Nonoriented Electrical Steel	b
Mumetal (77% Ni, 4% Mo, 14% Fe, 5% Cu)	c
AISI 430	d
AISI 410	e
Cast iron	f
Cobalto	g
Niquel	h

Table 3: Property identification

Property	Identification
Permeability	μ
Electric conductivity $\times 10^{-7} (S/m)$	G
Thermal conductivity (W/mK)	λ
Specific heat $(KJ/Kg \cdot K)$	C_p

Density	(g/cm^3)
Thermal diffusivity .10−6, m2/s)	α
Cost	USD/Kg
Yield (Mpa)	Y

Table 4: Properties of each alternative.Material

	μ	G	λ	Cp	ρ	α	USD/ Kg	*Y*
a	190000	1,710	32,5	0,500	8,24	7,90	37,500	321,0
b	11550	2,700	65,0	0,460	7,75	18,20	0,975	300,0
c	127500	1,695	33,5	0,495	8,74	7,65	38,000	715,0
d	850	1,600	24,9	0,460	7,8	6,95	1,500	513,5
e	850	1,700	24,7	0,460	7,8	6,90	2,000	1180,0
f	425	9,000	26,6	0,505	7,18	7,40	0,125	385,0
g	155	1,600	84,6	0,440	8,8	21,85	30,000	225,0
h	670	1,125	79,0	0,455	8,89	19,85	18,000	52,0

Source: [36]

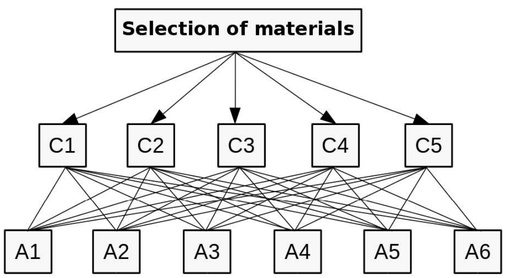

Figure 2: AHP hierarchy process.

The alternatives and relevant properties for this study are in Table 4. In Table 5, the decision matrix generated is shown. The coefficients were assigned based on the heating principle on induction cookers. The most valuable parameters are the permeability (), cost and electric conductivity.

Table 5: Comparison among criteria

AHP	μ	G	λ	Cp	ρ	α	Cost	Y
μ_r	1,00	5,00	7,00	7,00	5,00	3,00	0,33	3,00
G	0,20	1,00	3,00	3,00	1,00	0,33	0,14	0,33
λ	0,14	0,33	1,00	1,00	0,33	0,20	0,11	0,20
c_p	0,14	0,33	1,00	1,00	0,33	0,20	0,11	0,20
ρ	0,20	1,00	3,00	3,00	1,00	0,33	0,14	0,33
α	0,33	3,00	5,00	5,00	3,00	1,00	0,20	1,00
Cost	3,00	7,00	9,00	9,00	7,00	5,00	1,00	5,00
Y	0,33	3,00	5,00	5,00	3,00	1,00	0,20	1,00

In order to get the weight for every property, equation 1 has been applied. In Table 6 the weight coefficient of every criterion was determined. On one hand, the most representative values are cost 38.96%, permeability (μ_r) 22.17% and thermal diffusivity (α) 11.46%. On the other hand, less than 30% of the overall weight is distributed in G, c_p, λ, Y. The results are consistent due to the value of the consistency index (CI = 0.0489) and the consistency ratio (CR = 0.0347) which are lower than the limit 0.1.

Table 6. AHP weighting

	W_j
μ	0,221670
G	0,054324
λ	0,025436
cp	0,025436
ρ	0,054324
α	0,114580
Cost	0,389640
Y	0,114580

3.2. EXPROM2

The normalized matrix were computed by means of equations 5 and 6, its values are in Table 7.

Table 7: Normalized matrix

Material	μ	G	λ	C_p
a	1,0000	0,0743	0,1302	0,9231
b	0,0600	0,2000	0,6728	0,3077
c	0,6708	0,0724	0,1469	0,8462
d	0,0037	0,0603	0,0033	0,3077
e	0,0037	0,0730	0,0000	0,3077
f	0,0014	1,0000	0,0317	1,0000
g	0,0000	0,0603	1,0000	0,0000
h	0,0027	0,0000	0,9065	0,2308

Table 7: Normalized matrix (continuation)

Material	ρ	α	Cost	Y
a	0,3824	0,0669	0,0000	0,2364
b	0,6706	0,7559	0,9773	0,2179
c	0,0882	0,0502	0,0000	0,5826
d	0,6412	0,0033	0,9632	0,4055
e	0,6412	0,0000	0,9498	1,0000
f	1,0000	0,0334	1,0000	0,2926
g	0,0529	1,0000	0,2007	0,1529
h	0,0000	0,8696	0,5217	0,0000

In Table 8 the rank of best alternatives was computed on the basis of equations 7, 8, 9. The material that support all the requirements for magnetic heating is the steel ASTM A677. Other good alternatives could be cast iron and steel AISI 410 but their low permeability will reduce considerably the efficiency of the induction cooker.

Table 8: Rank obtained by EXPROM2

Material				Rank
a	0,4589	0,6946	-0,2327	6
b	0,5745	0,1942	0,3802	1
c	0,3546	0,7043	-0,3496	7
d	0,4229	0,2877	0,1352	4
e	0,5463	0,2669	0,2795	3
f	0,5982	0,25	0,3483	2
g	0,2595	0,6434	-0,3839	8
h	0,3272	0,5041	-0,1769	5

3.3. TOPSIS

The normalized matrix for TOPSIS is gotten by equation 16 and Table 4 resume the data of this matrix. Afterwards, this is linked with the weights (W_j) and beneficial and non-beneficial solutions based on equations 18 and 19. Finally, the alternative rank is expressed in the coefficient, equation 22.

The overall results are illustrated in Table 9. The steel ASTM A677 corresponds to the best alternative as it was with EXPROM2. The value reached was 54.84%. The second best is the steel AISI 410. Materials with the highest permeability are not regarded as the best alternatives because of his high cost.

Table 9: Rank obtained by TOPSIS

Material	S_i^+	S_i^-	S_{ij}	Rank
a	0,2411	0,1888	0,4307	5
b	0,1846	0,2299	0,5484	1
c	0,2432	0,1376	0,3490	7
d	0,1949	0,2265	0,5287	4
e	0,1890	0,2354	0,5461	2
f	0,2016	0,2303	0,5428	3
g	0,2683	0,0770	0,1959	8
h	0,2284	0,1328	0,3516	6

3.4. VIKOR

The coefficient (E_i) which relates weights and criteria is computed with equations 23 and 24. After that, it can be determined the parameter P_i to rank each alternative, equation 25. The steel ASTM A677 has been reached as the best alternative for the purpose of magnetic field heating. Again, the second best alternative agree with steel AISI 410.

Table 10: Rank obtained by VIKOR

Material	E_i	F_i	P_i	Rank
a	0,6457	0,3896	0,8993	7
b	0,3895	0,2084	0,0000	1
c	0,6983	0,3896	0,9813	8
d	0,4832	0,2209	0,1805	3
e	0,4215	0,2209	0,0843	2
f	0,4921	0,2214	0,1957	4
g	0,7103	0,3115	0,7843	6
h	0,6132	0,2211	0,3837	5

3.5. COPRAS-G

The gray numbers applied in COPRAS-G are resumed in Table 11. Equations 27 and 28 allow to normalize the gray numbers, Table 12. Later, the normalized matrix and the weight are compared by means of equations 29 and 30. To sum up, the best alternatives were Permalloy, Numetal and steel ASTM A677. In table 13 the alternatives were ranked.

Table 11: Gray numbers

Material	μ		G		λ	
a	80000	300000	1,61	1,81	30	35
b	6800	16300	2,50	2,90	60	70
c	35000	220000	1,67	1,72	32	35
d	600	1100	1,55	1,65	24,85	24,95
e	700	1000	1,65	1,75	24,5	24,9
f	100	750	8,00	10,00	11,3	41,9
g	60	250	1,50	1,70	69,2	100
h	100	1240	1,00	1,25	67	91

Table 11: Gray numbers (continuation)

Material	cp		ρ		α	
a	0,49	0,51	8,23	8,25	7,3	8,5
b	0,45	0,47	7,7	7,8	16	20,4
c	0,49	0,5	8,73	8,75	7,3	8
d	0,455	0,465	7,75	7,85	6,85	7,05
e	0,455	0,465	7,75	7,85	6,7	7,1
f	0,5	0,51	7,14	7,24	3,2	11,6
g	0,42	0,46	8,79	8,81	18	25,7
h	0,45	0,46	8,83	8,95	17	22,8

Table 11: Gray numbers (continuation)

Material	Cost		Y	
a	30	45	304	338
b	0,85	1,1	269	331
c	31	44	530	900
d	1	2	496	531
e	1,7	2,3	1155	1225
f	0,12	0,13	276	494
g	25	35	221	231
h	17	19	45	59

Table 12: Normalized matrix made of gray numbers.

Material	μ		G		λ	
a	0,0534	0,2003	0,0041	0,0047	0,0021	0,0024
b	0,0045	0,0109	0,0064	0,0075	0,0041	0,0048
c	0,0234	0,1469	0,0043	0,0044	0,0022	0,0024
d	0,0004	0,0007	0,0040	0,0042	0,0017	0,0017
e	0,0005	0,0007	0,0042	0,0045	0,0017	0,0017
f	0,0001	0,0005	0,0206	0,0257	0,0008	0,0029
g	0,0000	0,0002	0,0039	0,0044	0,0047	0,0069
h	0,0001	0,0008	0,0026	0,0032	0,0046	0,0062

Table 12: Normalized matrix made of gray numbers (continuation).

Material	cp		ρ		α	
a	0,0033	0,0034	0,0069	0,0069	0,0086	0,0101
b	0,0030	0,0032	0,0064	0,0065	0,0189	0,0242
c	0,0033	0,0034	0,0073	0,0073	0,0086	0,0095
d	0,0031	0,0031	0,0065	0,0065	0,0081	0,0083
e	0,0031	0,0031	0,0065	0,0065	0,0079	0,0084
f	0,0034	0,0034	0,0059	0,0060	0,0038	0,0137
g	0,0028	0,0031	0,0073	0,0073	0,0213	0,0304
h	0,0030	0,0031	0,0074	0,0075	0,0201	0,0270

Table 12: Normalized matrix made of gray numbers (continuation)

Material	Cost		Y	
a	0,0916	0,1374	0,0094	0,0105
b	0,0026	0,0034	0,0083	0,0102
c	0,0947	0,1344	0,0164	0,0279
d	0,0031	0,0061	0,0153	0,0164
e	0,0052	0,0070	0,0357	0,0379
f	0,0004	0,0004	0,0085	0,0153
g	0,0763	0,1069	0,0068	0,0071
h	0,0519	0,0580	0,0014	0,0018

Table 13: Rank obtained by COPRAS-G

Material	P_i	R_i	Q_i	U_i	Rank
1	0,1517	0,1258	0,1670	100,0000	1
2	0,0461	0,0164	0,1629	97,5613	3
3	0,1219	0,1261	0,1371	82,1242	5
4	0,0295	0,0152	0,1554	93,0592	4
5	0,0504	0,0170	0,1630	97,6329	2
6	0,0262	0,0295	0,0910	54,4985	6
7	0,0417	0,1031	0,0603	36,1167	8
8	0,0341	0,0653	0,0634	37,9799	7

3.6. SPEARMAN'S CORRELATION COEFFICIENT

In Table 14 is shown the Spearman's correlation coefficients. These represent the mutual correspondence among MCDM methods. The magnitude of this parameter exceeds 0,9 for the relation of VIKOR, TOPSIS and EXPROM2. Nonetheless, the correlation between COPRAS-G-VIKOR, COPRAS-G-TOPSIS, COPRAS-G-EXPROM2 are 0,262, 0,595 and 0,5, respectively [37].

Table 14: Spearman's correlation indexes

	EXPROM2	VIKOR	TOPSIS	COPRAS
EXPROM2	-	0,929	0,952	0,500
VIKOR		-	0,857	0,262
TOPSIS			-	0,595
COPRAS				-

3.7. DISCUSSION

In Table 15 is resumed the overall rank of each MCDM method. The best alternative in almost all the methods is the steel ASTM A677, because of its low cost, high permeability, low density, etc. A comparison among these results is shown in Figure 3. Whereas in COPRAS-G the best alternative was the mumetal.

Table 15: Rank vs alternative.

METHOD	RANKING							
EXPROM II	6	1	7	3	2	4	8	5
VIKOR	7	1	8	3	2	4	6	5
TOPSIS	5	1	7	4	2	3	8	6
COPRAS	1	3	5	4	2	6	8	7

The trend in the results has changed only in COPRAS-G method due to the wide range of variability in the magnitude of every criterion. In other words, if the permeability of mumetal is 190000, in the steel ASTM A677 the permeability is 11550. Therefore, this method cannot manage to treat with wide differences in a same criterion.

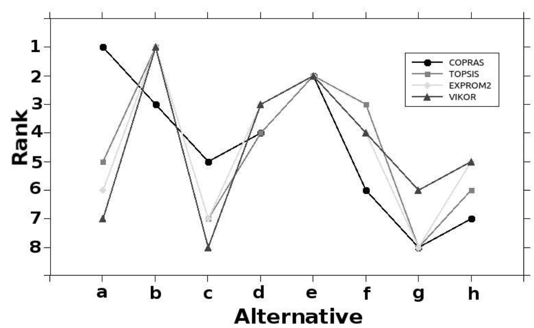

Figure 3: Rank vs Alternative.

4. CONCLUSIONS

The multi criteria decision making methods are an important tool to recognize and identify the best alternative in a bunch of several of them. These methods can adapt to different sort of environments and conditions that would affect the final result and that is why these approaches are applied in different areas of science, engineering and management. In this case, we take advantage of MCDM methods in order to contribute to the Ecuadorian government in the new model of energetic management.

According to the results, steel ASTM A677 would be the best material to start producing pots for induction stoves. This steel is adequate for serial production because of it has a low cost and density and a high permeability in order to induce Eddy currents and produce heat.

The method validation was correlated by Spearman's coefficients. Most of the methods are equivalent among them unless COPRAS-G due to the magnitude of the properties.

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