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- Science Citation Index Expanded (SciSearch®), Clarivate Analytics
- Scopus - Elsevier
- Scientific Electronic Library Online - SciELO, Colombia
- Chemical Abstract
- Índice de Revistas Latinoamericanas en Ciencias Periódica
- Redalyc-Red de Revistas Científicas de América Latina y el Caribe, España y Portugal
- Dialnet
- Sistema Regional de Información en Línea para Revistas Científicas de América Latina, El Caribe, España y Portugal - Latindex
- Ebsco Publishing
- DOAJ - Directory of Open Access Journals
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Editorial

Español

Revisión de los indicadores de citación de la revista Ingeniería e Investigación

Resumen

Recientemente, las distintas bases de datos citacionales han actualizado los resultados de citación y posicionamiento. En esta ocasión, queremos mostrar a los lectores de la revista *Ingeniería e Investigación* cómo han evolucionado nuestros indicadores en tres de ellas.

Datos

Para el presente ejercicio se consultaron los documentos indexados entre 2010 y 2019 y sus respectivas citas en cuatro bases de datos:

1. La Colección de la Revista Ingeniería e Investigación en el Portal de Revistas OJS de la Universidad Nacional de Colombia, de donde se obtuvieron las cantidades reales de documentos publicados;
2. La Base de datos Scopus de Elsevier;
3. La Base de datos SciELO, de consulta pública gratuita;
4. Google Scholar (GS), a través de consultas en el programa Publish or Perish, versión 7.24, desarrollado por Harzing (2007).

La Revista se encuentra indexada en Science Citation Index Expanded de la base de datos Web of Science. Sin embargo, la suscripción institucional a esta base de datos no estaba vigente al momento de reunir los datos y no fue incluida.

La información proveniente de OJS, Scopus y SciELO fue organizada por año de publicación y por el año en que fueron concedidas las citas. Los datos de GS tuvieron que ser depurados de acuerdo con el siguiente procedimiento:

1. Se consultó la colección de la revista año por año a través del ISSN 0120-5609. Los resultados obtenidos consultando el ISSN 2248-8723 presentaron discrepancias significativas con respecto a la colección de la revista, por lo cual se empleó únicamente el ISSN impreso.
2. Se excluyeron todas las apariciones duplicadas de los artículos.
3. Se excluyeron las citas recibidas de fuentes no verificables.
4. Se excluyeron las citas provenientes de tesis, publicadas en su gran mayoría en repositorios institucionales.

English

A Review of the Citation Indicators of the Ingeniería e Investigación Journal

Abstract

Recently, the different citation databases have updated their citation and positioning results. On this occasion, we want to show the readers of the *Ingeniería e Investigación* journal how our indicators have evolved in three of them.

Data

For this exercise, indexed documents between 2010 and 2019 and their corresponding citations were consulted in four databases:

1. The Collection of the *Ingeniería e Investigación* journal on the Portal de Revistas OJS from the Universidad Nacional de Colombia, where the real amount of published documents was obtained;
2. Elsevier's Scopus database;
3. The free, public access SciELO database; and
4. Google Scholar (GS), by consulting the Publish or Perish software, version 7.24, developed by Harzing (2007).

Our journal is indexed on Science Citation Index Expanded from the Web of Science database. However, the institutional subscription to this database was not active when the data were collected; it was therefore not included.

The information from OJS, Scopus, and SciELO was organized by year of publication and by the year in which the citations were conceded. The data from GS had to be filtered according to the following procedure:

1. The journal's collection for each year was consulted by using the ISSN 0120-5609. Results obtained by consulting ISSN 2248-8723 had significant discrepancies with the journal's collection, which is why only the print ISSN was used.
2. All duplicate article appearances were excluded.
3. All citations from unverifiable sources were excluded.
4. All citations from theses, published mostly in institutional reopositories, were excluded.

In Table 1, the amount of published and indexed articles is shown for each year in the different databases. Similarly, Table 2 shows the citations obtained by such documents.

En la Tabla 1 se muestra la cantidad de documentos publicados e indexados por año en las distintas bases de datos. De la misma manera, la Tabla 2 muestra las citas obtenidas por dichos documentos.

Tabla 1. Cantidad de documentos publicados en cada fuente

Año	OJS	Scopus	SciELO	GS
2019	23	23	21	23
2018	37	37	34	37
2017	44	44	42	43
2016	44	44	43	43
2015	62	61	59	58
2014	46	44	44	42
2013	43	38	38	39
2012	49	49	46	47
2011	99	87	90	97
2010	66	66	66	66

Fuente: Autores

Tabla 2. Cantidad de citas totales por año obtenidas por los documentos publicados

Año	Scopus	SciELO	GS
2019	5	52	9
2018	47	93	71
2017	73	81	119
2016	130	124	205
2015	164	90	226
2014	142	61	196
2013	173	51	251
2012	108	48	199
2011	183	30	220
2010	109	32	115

Fuente: Autores

Análisis

Siguiendo las recomendaciones de Hicks, Wouters, Waltman, De Rijcke, Rafols (2015) y DORA (2012), particularmente lo sugerido en cuanto a métricas provenientes de distintas fuentes, presentaremos a continuación los resultados de citas recibidas por los artículos publicados Revista, además de otros indicadores, sin dar preferencia a ninguno en particular. La Figura 1 muestra la evolución de las citas. Se puede observar que, entre 2010 y 2016, GS percibió la mayor cantidad, seguida de Scopus y por último SciELO. Esto cambia a partir de 2017, donde SciELO muestra una tendencia creciente.

En términos generales, las citas de las tres bases de datos no son comparables, ya que los documentos incluidos en cada una son diferentes. No obstante, considerando lo descrito en Martín-Martín, Orduna-Malea, Thelwall y Delgado López-Cózar (2018), existe solapamiento entre las citas percibidas en las distintas fuentes, por lo cual los resultados se pueden interpretar de la siguiente manera:

Table 1. Amount of documents published in each source

Year	OJS	Scopus	SciELO	GS
2019	23	23	21	23
2018	37	37	34	37
2017	44	44	42	43
2016	44	44	43	43
2015	62	61	59	58
2014	46	44	44	42
2013	43	38	38	39
2012	49	49	46	47
2011	99	87	90	97
2010	66	66	66	66

Source: Authors

Table 2. Total amount of citations obtained for each year by published documents

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2013	173	51	251
2012	108	48	199
2011	183	30	220
2010	109	32	115

Source: Authors

Analysis

Following the recommendations from Hicks, Wouters, Waltman, De Rijcke, Rafols (2015), and DORA (2012), particularly regarding metrics from different sources, we will now present the citation results obtained by the articles published in our journal, as well as other indicators, with no preference given to any of them. Figure 1 shows the evolution of the citations. It can be observed that, between 2010 y 2016, GS perceived the greatest amount, followed by Scopus and, finally, SciELO. This changes as of 2017, where SciELO shows a growing tendency.

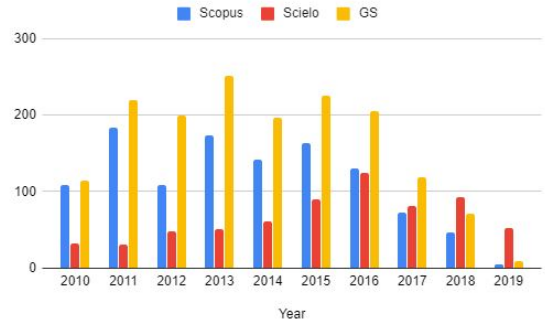

Figure 1. Citations obtained by articles in I&I for each database.
Source: Authors

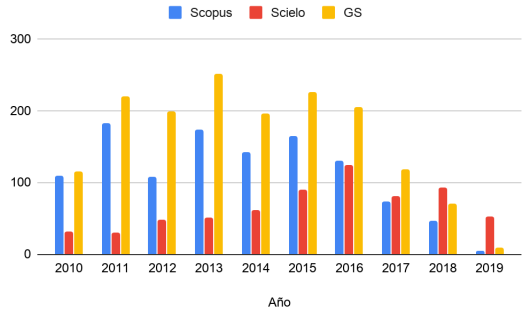

Figura 1. Citas obtenidas por los artículos de I&I en cada base de datos.
Fuente: Autores

En primer lugar, de todas las citas recibidas por revistas científicas en ingeniería, el 63 % se pueden encontrar en GS y Scopus; el 37 % restante puede encontrarse en otras bases de datos o no es legible a través de medios electrónicos. En segundo lugar, SciELO no fue tenido en cuenta por Martín-Martín et al. (2018). Sin embargo, esta base de datos publica los contenidos completos de los artículos indexados en formato PDF, por lo cual todas las citas de SciELO están incluidas en GS. La diferencia en citas percibidas en años recientes entre SciELO y GS puede estar asociada con el momento en que estas son identificadas. Además, la presencia en SciELO permite captarlas más pronto que en Scopus y GS, los cuales ofrecen un número de citas mayor en el largo plazo.

Lo anterior puede ponerse en contraste con el índice de inmediatez (*immediacy index*). En la presente nota, se calcula dicho índice como la razón, expresada como porcentaje, entre las citas obtenidas en el año de publicación de un número de la revista. Los datos se muestran en la Figura 2.

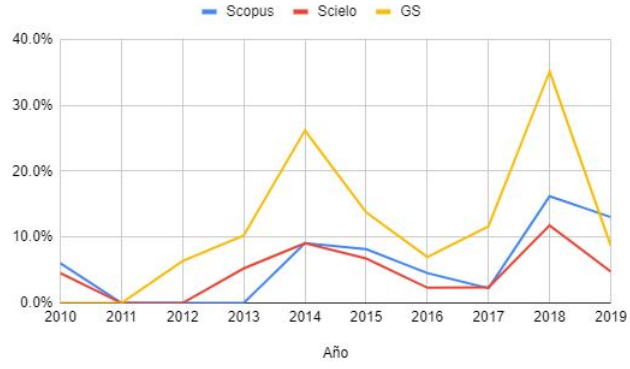

Figura 2. Índice de inmediatez de la Revista I&I para Scopus, SciELO y GS.
Fuente: Autores

Los resultados de la Figura 2 muestran que se perciben citas más rápido a través de GS que Scopus y SciELO. Esto no contradice los resultados previos, ya que en la Figura 1 se muestran las citas obtenidas por un número en varios años, mientras que en la Figura 2 aparecen las obtenidas en el mismo año. La depuración de datos de GS puso en evidencia que una parte significativa de las citas obtenidas

Generally speaking, the citations from the three databases cannot be compared, since the documents included in each one are different. However, considering what was described by Martín-Martín, Orduna-Malea, Thelwall, and Delgado López-Cózar (2018), there is an overlap between the citations perceived by different sources, which is why the results can be interpreted as follows:

First of all, out of all citations received by scientific engineering journals, 63% can be found on GS and Scopus; the remaining 37% can be found on other databases or is not readable by electronic means. Secondly, SciELO was not taken into account by Martín-Martín et al. (2018). However, this database publishes the complete contents of the articles in PDF format, which is why all citations from ScieLO are included in GS. The difference in citations perceived in recent years between SciELO and GS may be related to the moment at which they are identified; presence on SciELO allows to perceive them sooner than on Scopus and GS, which offer a greater amount of citations in the long run.

This can be contrasted with the immediacy index. In the present note, we will calculate such index as the ratio, expressed as a percentage, between the citations obtained in the year of publication of a journal issue. The data are illustrated in Figure 2.

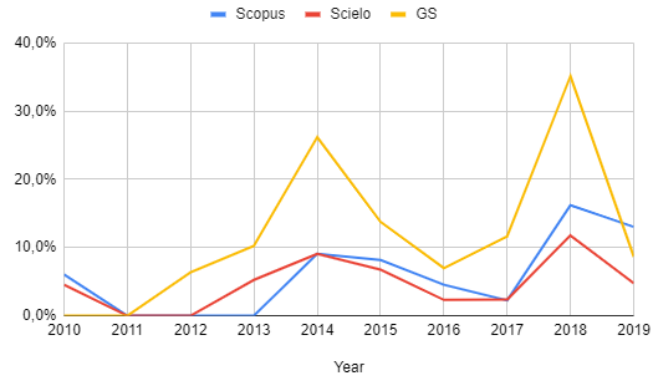

Figure 2. I&I journal immediacy index for Scopus, SciELO, and GS.
Source: Authors

The results from Figure 2 show that citations are perceived more quickly by GS than Scopus and SciELO. This does not contradict previous results, since the citations obtained by an issue throughout several years are shown in Figure 1, while those obtained during the same year are displayed in Figure 2. GS data filtering made it evident that a significant part of the obtained citations come from authentic scientific journals, with a broad publication record and active scientific communitites. Although such journals might not be indexed on Scopus or SciELO, it is possible to claim that the *Ingeniería e Investigación* journal has a wide visibility and an international scope, resulting from its open access policy, as mentioned by Pavas (2017).

The data from Tables 1 and 2 can be combined to calculate the citations-per-document indicator. This is achieved through the ratio of the total citations obtained by the articles

provienen de revistas científicas auténticas, con un historial de publicación amplio y con comunidades científicas activas. Aunque tales revistas no estén indexadas en Scopus o SciELO, es posible afirmar que la Revista *Ingeniería e Investigación* tiene una visibilidad amplia y alcance internacional, derivados de su política de acceso abierto, como se mencionó en Pavas (2017).

Los datos de las Tablas 1 y 2 pueden combinarse para calcular el indicador de citas por documento. Esto se hace por medio de la razón del total de citas obtenidas por los artículos publicados en un año sobre el número de documentos publicados. Los resultados se encuentran en la Figura 3.

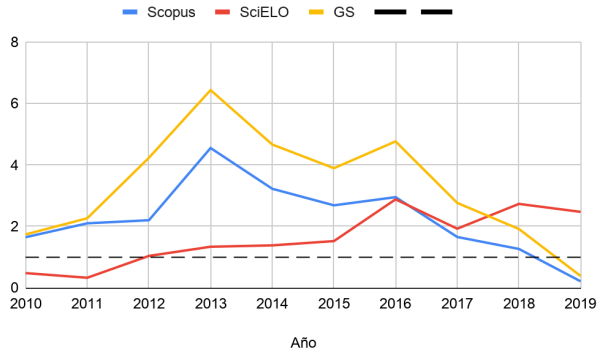

Figura 3. Citas por documento en Scopus, SciELO y GS.
Fuente: Autores

De la Figura 3 es posible confirmar las tendencias previamente observadas. En el largo plazo, GS detecta una mayor cantidad de citas que SciELO y Scopus, que a su vez detecta más citas que SciELO. Sin embargo, SciELO genera más citas en períodos recientes.

En Orduña-Malea, Martín-Martín, Ayllón y Delgado López-Cózar (2016), al igual que en otras fuentes, se mencionan las diversas falencias de Google Scholar como fuente bibliográfica confiable. Hay una gran cantidad de casos en que los documentos identificados como fuentes de citación no son auténticos, no son realmente artículos de revistas científicas o las citas identificadas se asignan por similitud semántica sin haber sido realmente referenciadas. Por otra parte, Sugimoto y Lariviere (2018) destacan las bondades de bases de datos como Scopus, Web of Science y SciELO en cuanto a la calidad de los metadatos generados y una precisión mayor en la identificación de citas –es necesario resaltar que son mejores, pero también tienen defectos. Entre las lecciones aprendidas de este ejercicio de revisión permanente está que la generación y gestión de metadatos al momento de publicar e indexar los artículos publicados mejoran significativamente la visibilidad de los artículos, las citas generadas y la posibilidad de que sean identificados por los lectores. *Ingeniería e Investigación*, con el apoyo de la Dirección Nacional de Bibliotecas de la Universidad Nacional de Colombia, realiza esfuerzos permanentes para difundir y visibilizar sus contenidos, además de generar metadatos que faciliten la localización efectiva de contenidos en todas las bases de datos citacionales.

published during a year, divided by the amount of published documents. The results are shown in Figure 3.

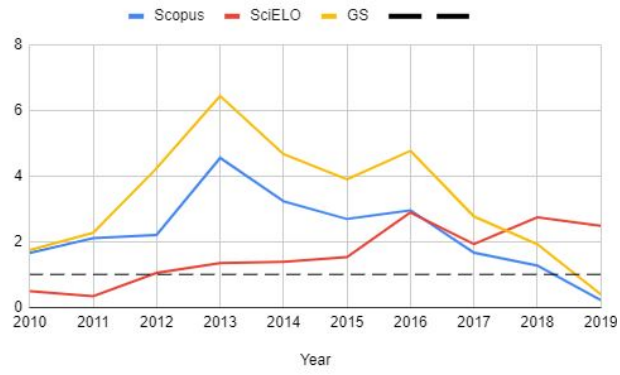

Figure 3. Citations per document on Scopus, SciELO, and GS.
Source: Authors

From Figure 3, it is possible to confirm the previously observed trends. In the long run, GS detects a greater amount of citations than SciELO and Scopus, which, in turn, detects more citations than SciELO. However, SciELO generates more citations in recent periods.

In Orduña-Malea, Martín-Martín, Ayllón, and Delgado López-Cózar (2016), as well as in other sources, Google Scholar's diverse flaws as a reliable bibliographical source are mentioned. There is a large amount of cases in which documents identified as citation sources are not authentic, they are not really articles of scientific journals, or the identified citations are assigned due to semantic similarity without really having been referenced. On the other hand, Sugimoto and Lariviere (2018) highlight the benefits of databases such as Scopus, Web of Science, and SciELO regarding the quality of the generated metadata and a higher accuracy in citation identification –it is necessary to emphasize that they are better, but they still have flaws. Among the lessons learned from this exercise in permanent revision is that the generation and management of metadata at the moment of publication and indexation significantly improve article visibility, generated citations, and the possiblitiy of being identified by the readers. *Ingeniería e Investigación,* with support from the National Library Directorate of the Universidad Nacional de Colombia, makes a permanent effort to distribute and make its contents visible, as well as to generate metadata which enable effective content localization in all citation databases.

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Aluminum Waste in Road Pavement Subgrade

Residuos de aluminio en el subsuelo de las carreteras

Ali Firat Cabalar[1], Govar Hayder[2], Mohammed D. Abdulnafaa[3], and Haluk Isik[4]

ABSTRACT

This paper aims to investigate the use of spiral aluminum computer numerical control milling waste (CNC-W) in the construction of road pavement subgrade. The soil (CL) was mixed with CNC-W spirals with ratios of between 0% and 20%, and 5 percent increments by dry weight with different water contents. California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), and consolidation tests were conducted. The experimental results indicated that the inclusion of CNC-W spirals increased the CBR value of clay up to the 15% mixture ratio, then decreased it. Similarly, the UCS value of clay was increased to the same ratio, whilst the UCS was not able to be determined due to the failing of all specimens with a mixture ratio higher than 15%. The permeability and swelling values, as well as the consolidation characteristics of the mixtures, were defined. The swelling percentages decreased from 1,15 cm/sec to 0,81 cm/sec with an increment in the CNC-W spiral content. A reduction was observed in the coefficient of permeability (k) values up to 15% mixture ratio, whilst it remained constant with change in CNC-W spiral content with a 20% mixture ratio. Coefficient of consolidation demonstrated a similar pattern of behavior to the permeability changes.

Keywords: computer numerical control milling waste CNC-W, clay, California Bearing Ratio (CBR), Unconfined Compressive Strength (UCS), consolidation

RESUMEN

Este artículo buscó investigar el uso de desechos espirálicos de aluminio de fresado de control numérico por computador (CNC-W) en la construcción de subrasantes de pavimento de carretera. La tierra (CL) fue mezclada con espirales de CNC-W con proporciones entre 0 % y 20 %, e incrementos del 5 % por peso seco con contenidos diferentes de agua. Se efectuaron las pruebas California Bearing Ratio (CBR), Resistencia a la Compresión Uniaxial (UCS), y de consolidación. Los resultados experimentales indicaron que la inclusión de espirales de CNC-W incrementaba el valor CBR de la arcilla hasta el 15 % de proporción en la mezcla y después lo disminuía. Similarmente, el valor UCS de la arcilla se incrementó con las mismas proporciones, mientras que la USC no se pudo determinar debido a la falla de todos los especímenes con una proporción de mezcla más alta que el 15 %. Se definieron los valores de permeabilidad e hinchazón, así como las características de consolidación de las mezclas. Los porcentajes de hinchazón disminuyeron de 1,15 cm/sec a 0,81 cm/sec, con un incremento en el contenido de espirales de CNC-W. se observe una reducción en los valores del coeficiente de permeabilidad (k) con una proporción de mezcla de hasta el 15 %, mientras que estos permanecieron constantes con el cambio en el contenido de espirales de CNC-W con 20 % de proporción en la mezcla. El coeficiente de consolidación demostró un patrón similar de comportamiento a los cambios de permeabilidad.

Palabras clave: desechos de fresado de control numérico por computador (CNC-W), arcilla, California Bearing Ratio (CBR), resistencia a la compresión uniaxial (UCS), consolidación

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Introduction

Many industrialized countries have massive sources of waste materials such as fly ash, tire rubber, and different types of metal swarf. Instead of being disposed of in landfills, such wastes can have some applications in geotechnical engineering. It is significant to note that soil does not fail in compression alone, but it always fails in shear. Soils are reinforced with waste materials, so that their performance to absorb shear stresses and tensile loads are improved. The use of waste materials for soil reinforcement has been gaining popularity primarily because of its versatility, easy and cost-effective construction. For example, different forms of waste tires have been employed in some applications in civil engineering including insulation beneath roads, slope stability, and lightweight backfill retaining walls (Mitchell and Katti, 1981; Fatani, Bauer and Al-Joulani, 1991; Ahmed and

Lovell, 1992; Edil and Bosscher, 1994; Masad et al. 1996; Shahu, Yudhbir, and Kameswara,1999; Kim and Santamarina, 2008; Tanchaisawat, Bergado, Voottipruex and Shehzad, 2010; Sarkar, Abbas, and Shahu, 2012; Edincliler, Cabalar, Cevik and Cagatay, 2012; Cabalar, Karabash and Mustafa, 2014; Cabalar and Karabash, 2015; Gomes Correira, Winter and Puppala, 2016; Patel and Shahu, 2016; Seddon, Winter and Nettleton, 2018; Cabalar, Zardikawi and Abdulnafaa, 2019). In addition, investigations on plastic waste use as soil reinforcement material have proved its worth in geotechnical applications including road bases, embankments, slope stability, retaining walls by increases in shear strength, and reductions of post peak losses in soils (Maher and Ho 1994; Santoni et al 2001; Zornberg 2002; Consoli, Prietto and Ulbrich, 2007; Muntohar, 2012). Although numerous studies have been performed for use of this material, the combined use of plastic waste and steel slag can provide much more strength to the pavement constructed with certain proportions (Mishra, JhaAjachi, Satrawala and Amin, 2013). Wang (1997, 2006) studied the use of fibers from carpet waste as soil reinforcement, and observed a significant increase in triaxial strength of sandy soils. Murray, Frost and Wang (2000) reported that for every 1% increment in fiber content leads to a 1% increment in optimum moisture content. Miraftab and Lickfold (2008) indicated that carpet waste fibers could be substantially mixed with weak soil until a maximum of 10% to increase internal angle of friction and cohesion. Ghiassian, Poorebrahim, and Gray (2004) stated that randomly placed synthetic strips had an important effect on the strength and constitutive behavior of fine sand.

A Computer Numerical Control (CNC) milling machine, a specific type of computer numerical controlled device, is designed to machine any kind of metal. Spiral aluminum Computer Numerical Control Milling Waste (CNC-W) is a type of swarf, which is known as pieces of metal resulting from CNC milling machining,which is the process of physically machining objects from 3D or 2D digital information. During various steps of aluminum production within this process, a lot of CNC-W scrap is continuously generated due to machining operations (Fratila, 2009; Newman, Nassehi, AsraiandDhokia, 2012; Faludi, Bayley and Bhogal, 2015; Wang et al., 2015). Dumping of this material has become a problem for many countries. The industry in India, for example, generates around 10-20 million tons of CNC-W scrap annually, which is difficult to recycle by conventional methods (Lazzaro and Atzori, 1993; Samuel, 2003; Shinzato and Hypolito, 2005; Sevigne-Itoz, Gasol, Rieradevall and Gabarrell, 2014; Galindo, Padilla, Rodriguez, Hernandez, Andres and Delgado, 2015). After going through the literature, it is worth noting that few researchers reported that addition of CNC-W spirals in concrete mix increased the compressive strength (Shukla, 2013). Although there are several methods of CNC-W disposal, because of the environmental concerns regarding potential contamination (e.g., Hall-Héroult Process; Calder and Stark, 2010), this paper is the first toever examine the impact of CNC-W spiral content on soil behavior. An experimental study (UCS, CBR, consolidation) has been carried out on the mixtures of soil with CNC-W at percentages 0, 5, 10, 15, and 20, by dry weight.

Experimental Work

Materials

The materials used were soil and CNC-W spirals. The soil samples were collected inside the campus at the University of Gaziantep in Turkey. The Atterberg limit tests were performed, and the liquid limit and plastic limits were 49 and 23, respectively. The cohesion (c) and internal friction angle (φ) of the tested samples were measured to be 15 kPa and 22 o, respectively. The clay grains have a specific gravity of 2,65. After the sieve analysis, according to the USCS, the soil sample was classified as CL (low plasticity clay) (see Figure 1).

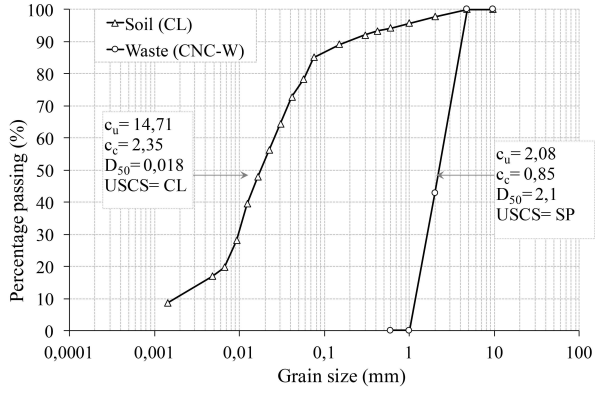

Figure 1. Grain size distributions for the soil and waste grains used during the experimental study.
Source: Authors

The CNC-W was made of aluminum obtained from the industrial area of Gaziantep in Turkey. The density and strength of the aluminum processed for CNC-W spiral scraps were determined to be 2700 kg/m3 and 250 MPa, respectively. The CNC-W spiral scraps with a tensile strength of 24 MPa have about 9% elongation. The abundance of aluminum CNC-W scraps produced in Turkey are available at a low cost. Thus, use of this waste as soil reinforcement instead of recycling in metal industry can reduce energy consumption and make economic sense. The CNC-W scrap grains were classified as SP (poorly graded sand), and its specific gravity was found to be 2,80 (see Figure 1).

Clay grains in the scanning electron micrograph (SEM) picture seem to be consisted of smaller plates (see Figure 2). Figure 2 also indicates a photo of the CNC-W spirals, developing around an axis in a constantly changing series of planes.

Testing equipment and the preparation of specimens

The CBR testing machine employed in the laboratory had a proving ring with 28 kN capacity, and a dial gauge with 0,01 mm sensitivity. The CBR tests were performed in soaked condition according to ASTM D1883 (2016), in order to

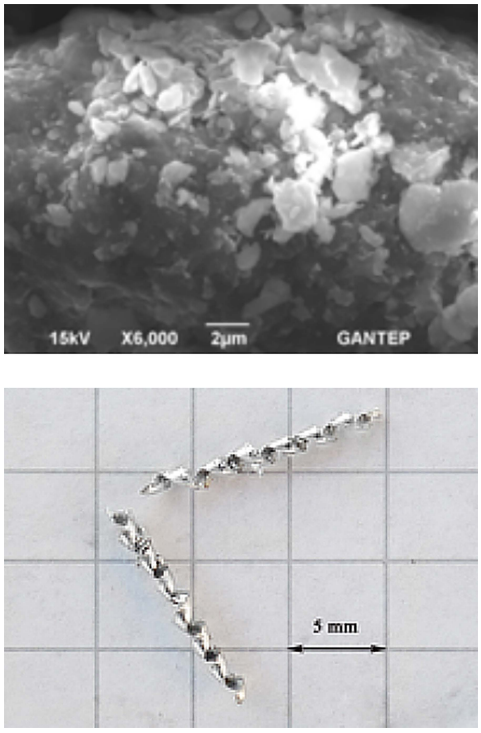

Figure 2. SEM picture of the soil (top), and photo of the aluminum CNC-W spiral (bottom).
Source: Authors

evaluate the strength of the material and CNC-W mixtures prepared at optimum water contents (ASTM D1557, 2012). Only the soil specimens were evaluated with regard to their performance, and soil with CNC-W at the mixture proportions of 5%, 10%, 15%, and 20% by dry weight of the specimens. The weight of water, CNC-W spirals, and soil were calculated, and they were mixed uniformly. Each of these mixtures were compacted in a CBR mold in 5 layers following the instructions for modified compaction (2700 kN-m/m^3). Bottom and top surfaces of the specimens in the mold, whose diameter and height measurements were 152 mm and 178 mm respectively, were covered by paper filters in order to prevent the fines to leak out of them during the procedure. The CBR tests were carried out after a 96-hour soaking period. The piston penetrating at a rate of 1,25 mm per minute into the compacted subbase material was observed, and stresses were recorded at penetration levels of 2,54 mm, 5,08 mm, 7,62 mm, 10,16 mm, and 12,70 mm (ASTM D1883, 2016).

The samples with the same mixture ratios were studied by employing the UCS tests. Sample preparation techniques for both the CBR and UCS tests were the same. The samples were prepared by compacting them into split 43,2mm x 98,5 mm mouls (diameter x height). A hammer with a uniform pattern was employed in order to compact the samples with a certain energy, equivalent to the energy applied during the modified compaction test. After compaction, they were removed from the mold, flattened, and fixed onto the UCS pedestal (ASTM D2166, 2016).

The consolidation characteristics of these composite specimens were determined with help from laboratory consolidation tests (ASTM D2435, 2011). The oven dried soil and CNC-W samples were mixed by dry weight. The appropriate volume of soil and CNC-W were measured, and blended physically in a dry condition, up to the point where samples were noted to be uniform. They were placed in very thin layers by spooning gently into the mold. After filling the mold completely, the cap on top of the it was placed, and then the cell was periodically filled with water until the specimen was completely saturated and submerged under water. The outside ring was kept full with water for the entire period of the test. The oedometer machine used was 7,5 in diameter and 2 cm in height, which was equipped with a transducer. In the standard testing method used in this study, the submerged cell that is confined in the steel ring is subjected to a vertical loading while drainage is allowed through either the top and bottom faces. This load that is applied on the cell is increased twice its amount every day in order to measure the consolidation characteristics of the specimen.

Results and Discussion

The amount of water versus the dry unit weight of the soil only and the soil with different CNC-W inclusions were studied by traditional compaction tests, which were carried out by following the procedures defined in ASTM D1557 (2012). A comparison between the specimens prepared by conventional testing procedures is illustrated in Figure 3. The maximum dry unit weight of the specimens was observed to increase with increasing CNC-W inclusions because of relatively higher specific gravity of the CNC-W spirals. However, the optimum water content values were observed to decrease with increasing CNC-W inclusion. Certain similarities were observed between the results obtained here and the results on discrete fiber and micro grid stabilized soils (Shukla, Sivakugan, and Das, 2009). For example, Leshchinsky, Evans, and Vesper (2016) suggested using micro grids for earthworks where shallow ground improvement is required (e.g., retaining wall, surficial slope stabilization, or erosion protection).

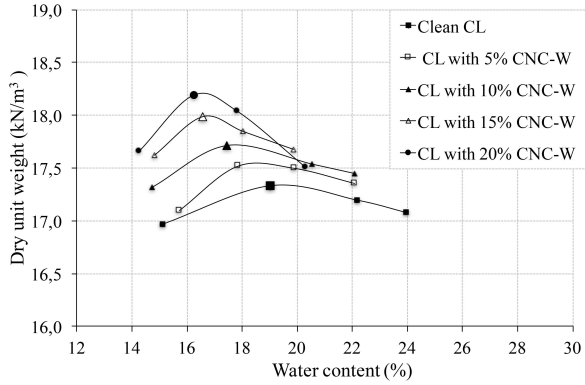

Figure 3. Compaction curves of the specimens at different mix ratios.
Source: Authors

After determining the optimum water contents for each mixture, CBR values of soil alone, and of soil with CNC-W at different ratios were determined. Figure 4 indicates the change in CBR performance of the samples tested with CNC-W content at optimum water content (w_{opt}). The CNC-W inclusions increased the CBR performance of the mixture of soil and CNC-W up to 15%, and then a decrease was observed. The reason behind it is that either soil or CNC-W scraps govern the overall behavior of the sample. For example, 10% CNC-W inclusion to soil resulted in an approximately 2% increment in the maximum CBR performance of the mixture, whilst 20% CNC-W inclusion to soil decreased its performance by approximately 1%. The increment in the maximum CBR performance can be attributed to the increment in the maximum dry unit weights and thereby resulting increase in strength of the soil-CNC-W matrix. Similar results were obtained by employing natural and geosynthetic fiber reinforcements in soil. Actually, construction of geotechnical structures on soft soils is very much risky, given the possibility of settlement, low shear strength, and high compressibility. Fiber reinforcement in soil is accepted as an appropriate improvement technique due to its low cost and local availability (Consoli, Prietto, and Ulbrich, 1998; Rafalko, Brandon, Filz, and Mitchell, 2007; Sivakumar and Vasudevan, 2008; Pradhan, Kar, and Naik, 2012; Singh and Bagra, 2013). The strength of the compacted soil-CNC-W samples is due primarily to the mobilization of material frictional strength. Showing a similar behavior, described by Cabalar and Mustafa (2015), samples with higher quantity of the CNC-W reached the maximum dry unit weight and CBR performance with a relatively small variation in water content. However, samples with relatively less amount of CNC-W reached the maximum CBR with a relatively larger variation. This, in turn, is due primarily to the high-water intake capacity of CL type soils in the samples. When CNC-W scraps are introduced into the soil, they improve its strength. The mechanism behind this behavior is believed to be the ability of these scraps to interact with each of the soil grains through frictional force and inter-locking. Actually, the function of interlocking is to transfer the stress from soil to CNC-W scraps by mobilizing their tensile strength. This may be because of the fact that the volume filled by the CNC-W scraps is greater, leading to more interaction. Thus, influence of scraps will be predominant. CNC-W scraps eventually behave like a frictional resistance element in the soil matrix. The CBR performance of soil samples with CNC-W scraps was observed to be higher than clean soil samples. Therefore, the significant increase in the CBR performance of soil because of CNC-W scraps will substantially reduce the thickness of subgrade layer.

It has long been understood that CBR performance of a subgrade material can determine the thickness of the pavement. The design thickness and capping details for this study are shown in Figure 5. It can be seen that, for a subgrade that has a CBR performance over 15%, the thickness will be 150 mm. If the CBR performance is within a range of 2,5% and 15%, the subgrade can be designed with (i) a 150-mm thickness with a capping of a varying thickness value,

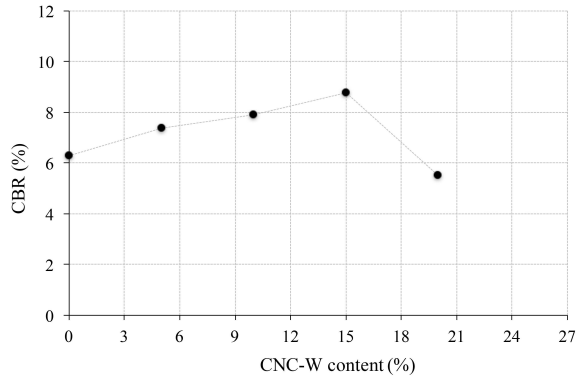

Figure 4. Variation in CBR values at wopt with CNC-W content.
Source: Authors

or (ii) a capping-free and a thicker subbase (HD 26/06, 2006). Table 1 lists some soil-CNC-W mixtures while also showing the capping and sub-base design thickness for each one of them.

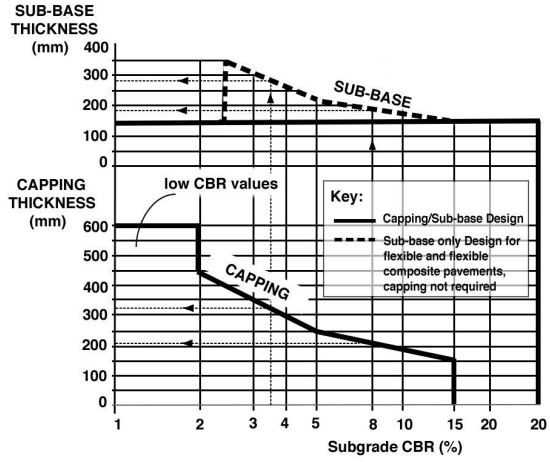

Figure 5. Capping and sub-base thickness design.
Source: HD 26/06 (2006)

The samples of soil-CNC-W mixtures were evaluated for possible swelling. The swelling potential of the sample was calculated using their expansion ratio, which is the increase in height compared to the beginning of the experiment. Samples prepared with different contents and different swelling potentials can be seen in Figure 6. It was observed that the inclusion of CNC-W in the samples was efficient in managing the swelling. The pressure that develops during swelling can be in any direction and in turn mobilize the frictional forces between the soil particles and the CNC-W, thus counteracting the swelling pressure. The presence of CNC-W inclusions reinforced the soil, and consequently decreased swelling. Eventually, the swelling ratio was seen to have decreased from 1,15% for the soil to only 0,8% for the soil with 20% CNC-W. A certain decrease in swelling percentage was also described by Vyas, Phougat, Sharma, and Ratnam (2011), and by Megeed (2012), who employed polymeric and natural fibers, respectively.

Table 1. Testing results

Specimen	CBR (%)	γ_{drymax} (kN/m^3)	w_{opt} (%)	SP (%)	UCS (kPa)	Pavement design alternatives		
						1		2
						Subbase (mm)	Capping (mm)	Subbase (mm)
CL	6,3	17,2	19,5	1,15	373	150	230	205
CL+5% CNC-W	7,4	17,5	18,7	1,06	389	150	210	190
CL+10% CNC-W	7,9	17,7	17,9	0,99	405	150	202	181
CL+15% CNC-W	8,8	18,1	17,0	0,87	470	150	195	178
CL+20% CNC-W	5,5	18,1	16,3	0,81	-	150	241	217

CBR: California bearing ratio; γ_{drymax}: Maximum dry density; w_{opt}: Optimum water content; SP: Swelling percentage; UCS: Unconfined compressive strength.

Source: Authors

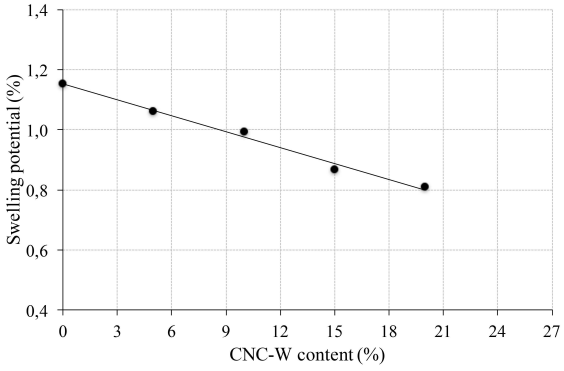

Figure 6. Variation of swelling potential vs. CNC-W content for the specimens tested at w_{opt}.
Source: Authors

The results of the UCS show that there is a significant correlation between the stress-strain behavior of the soil samples and the amount of CNC-W in the mixtures (Figures 7 and 8). All of the samples in the study were prepared at their optimum water content (Figure 9). The samples were prepared with an increasing CNC-W scrap ratio up of to 20% in the mixture until no further test was able to be performed. The addition of the scrap materials resulted in a decrease in the peak compressive strength of the samples (Table 1). Similar findings were also reported by Chauhan, Mittal, and Mohanty (2008) for investigation of problematic soils tested with the addition of natural fibers and waste materials.

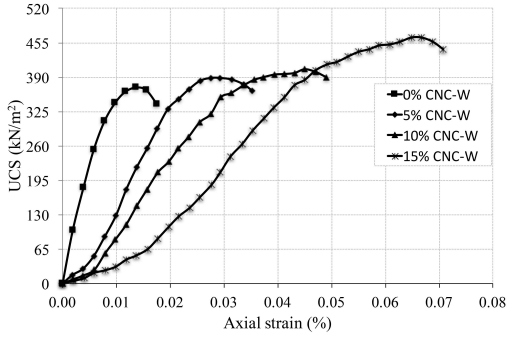

Figure 7. Variation of UCS vs. strain for the specimens with CNC-W tested at w_{opt}.
Source: Authors

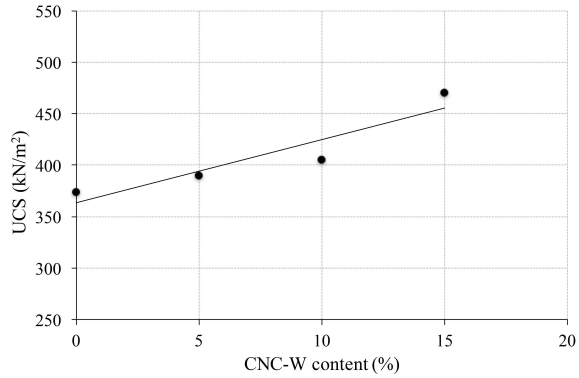

Figure 8. Effect of CNC-W content on UCS of the specimens tested at w_{opt}.
Source: Authors

Figure 9. A picture of two tested CL with 20% CNC-W specimens.
Source: Authors

The strength gain rate with CNC-W content was defined in terms of the strength increment index (SII) parameter as described by the expression below (Eq. 1):

$$SII = \frac{UCS_{CLwithCNC-W} - UCS_{CL}}{UCS_{CLwithCNC-W}} \cdot 100 \qquad (1)$$

A plot of the SII with CNC-W content was drawn in Figure 10, which shows that the SII increases as CNC-W content grows. Figure 10 illustrates the relative degree of strength gain due to CNC-W inclusion.

As the water pressure increases for the samples of clay (CL) and CNC-W, the change in void ratio is recorded, and its results are given in Figure 11. The figure shows that, due to the initial condition of the samples, the starting void ratios are collected within a wider range (Δe = 0,1225). After having evaluated these oedometer test results, and given the previous research of the literature, the authors concluded that the CNC-W samples used in this study could make the soil less compressible due to its ability to hinder the flow. The characteristics illustrated in Figure 11 suggest that the clean soil grains change much more freely than those tested with CNC-W, possibly as a consequence of

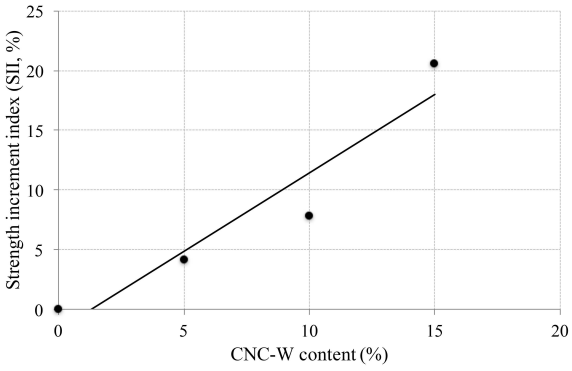

Figure 10. Effect of CNC-W content on the SII values of the specimens tested at w_{opt}.
Source: Authors

grains packing closer to each other during sample formation, which leads to a reduction in the voids. Then, the CNC-W spirals were thought to act as reinforcement between soil grains, and thereby result in substantial decrease in hydraulic conductivity (k) (Figure 12). Further, addition of CNC-W scraps helps in cutting of strain failure, increasing its stiffness and strength in comparison to non-CNC-W added soil. There are still many experiments to be made to be able to have more confidence in the effects of CNC-W to the soil. There are some researchers who have made contributions on this topic, including Thevanayagam (1998), Monkul and Ozden (2007), Cabalar (2010), Cabalar and Hasan (2013), and Cabalar and Mustafa (2015). In light of the readily available papers, during one dimensional consolidation, the effect of the addition of CNC-W scraps on the soil varies. One way to explain the effect of CNC-W is by using an inter-granular void ratio approach, which is hereby referredas the void ratio of the CNC-W scrap spirals with respect to the whole mixture (e_{CNC-W}).

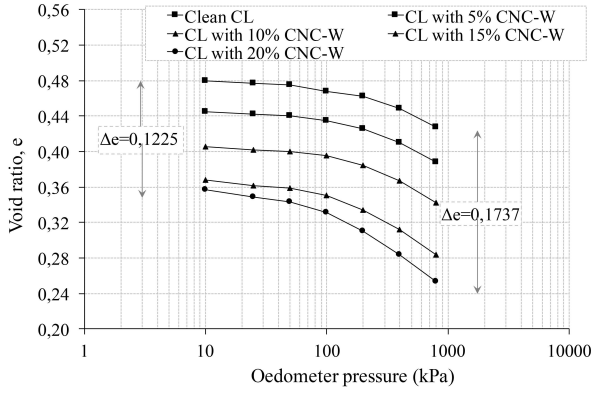

Figure 11. Variation of void ratio (e) with oedometer pressure for CL with CNC-W.
Source: Authors

The voids of the CNC-W mixtures are due to the spiral nature of CNC-W materials (which is e_{CNC-W}) and also to the voids in the soil grains. It is understood that the direct spiral to spiral connections of the CNC-W scrap matrix start when the void ratio of the CNC-W scraps spiral to that of CNC-W alone in a mixture (i.e., $e_{CNC-W} = e_{\max}$).

Granular compression index, which is symbolized by c_{c-s}, is a definition that helps study the compression behavior of these mixtures (Monkul and Ozden, 2007). The term gives a relationship between the effective stress and void ratio, as can be seen in Eq. 2:

$$c_{c-s} = \frac{\Delta e_s}{\Delta \log \sigma'} \tag{2}$$

The change in these two compression indices (c_c and c_{c-s}) in CNC-W mixed soils is displayed in Figure 13. CNC-W inclusion caused an increase in both parameters within the same experiment. The increase in global compression index values was observed to occur in smaller proportions. Actually, with increasing clay content, the CNC-W spirals become further separated, to the point where there is almost no interaction between the spirals. At such stage, it is thought that compressive behavior is mainly due to clay particles. The difference between the two compression index parameters becomes larger as more CNC-W materials are added to the mixture.

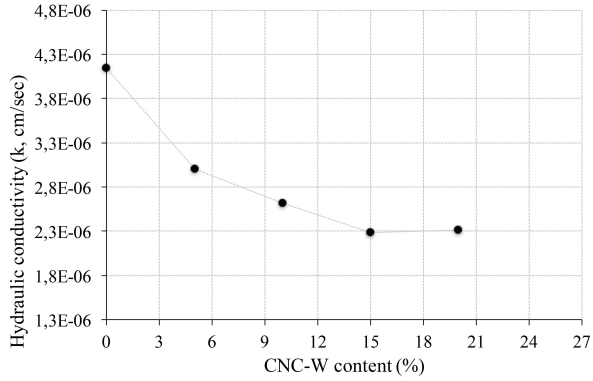

Figure 12. Effect of CNC-W content on the hydraulic conductivity (k) values of the specimens.
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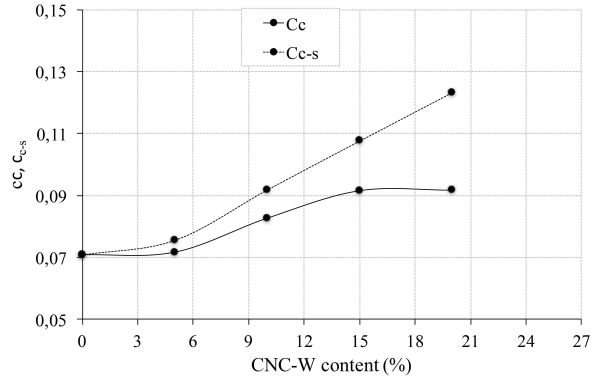

Figure 13. Variation of compression parameters for specimens with various CNC-W content.
Source: Authors

Conclusions

A novel investigation was presented in this paper that examines the behavior of soils, which were mixed with CNC-W scraps. An extensive series of laboratory tests were carried out on the mixtures of CL type soil reinforced with CNC-W spirals. The tests included a series of consolidation, UCS, and CBR tests. Influence of the CNC-W spirals on soil behavior was studied by adding CNC-W spirals in concentrations of 0%, 5%, 10%, 15%, and 20% by dry weight. Four new aspects of behavior can be concluded from the results of this study:

1. The increase in CNC-W content causes the maximum dry unit weight of the mixtures to increase, from 17,25 kN/m^3 to 18,25kN/m^3 by 20% CNC-W addition, whilst causing the optimum water content to decrease, from 19% to 16%.
2. The addition of CNC-W increased the CBR value of the samples up to 15%, which could lead to large reductions in thickness of highway pavement design.
3. The peak compressive strength of the samples reduced as the quantity of CNC-W content increased up to 15%, whilst no test was able to be performed with a 20% mixture ratio.
4. CNC-W scraps in the samples cause a lower compressibility (Δe_o = 0,1225 with 20% CNC-W addition), and a substantial decrease in hydraulic conductivity, from 4,3E-0 6cm/sec to 2,3E-06 cm/sec, because of their ability to reduce voids.

These conclusions suggest that specimen formation. in the way it is used here, could be considered as an alternative soil reinforcement technique for construction of road pavement subgrade.

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Rapid Drawdown in Homogeneous Earth Dam Considering Transient Flow and Suction

Reducción rápida en presas de tierra homogéneas considerando flujo transitorio y succión

Grover Romer Llanque Ayala[1], Francisco Chagas da Silva Filho[2], Rosiel Ferreira Leme[3], Maria do Carmo Reis Cavalcanti[4], and Claudio Fernando Mahler[5]

ABSTRACT

The present work intends to demonstrate the advantages of considering transient flow regime in the stability analysis of the upstream slope for the rapid drawdown situation of a homogeneous earth dam. Upstream slope stability evaluations were carried out, considering pore pressure and suction from transient flow analysis while simulating rapid drawdown of the reservoir. The evaluations comprised different geometries of the upstream slope (from 1V:1.1H to 1V:2.5H) and heights varying from 10 m to 50 m, as well as several low permeability materials (SM, SM-SC, SC, ML, ML-CL, CL, MH and CH). In addition, equations relating the safety factor to such slopes or dam height were adjusted to the analysis data, in order to define the minimum slope for a certain dam height or the maximum height for a given upstream slope. The results have shown that, considering the transient flow condition, including suction, within the slope stability analysis of the rapid drawdown situation, increases the safety factor in relation to the simplified analysis that is usually adopted. This also results in much steeper slopes (for a safety factor of 1,1) than the ones recommended by the U.S. Bureau of Reclamation (USBR), suggesting the importance of performing transient flow analysis for rapid drawdown situations and considering its results instability analysis.

Keywords: rapid drawdown, unsaturated soils, suction, slope stability, homogenous earth dam

RESUMEN

El presente trabajo pretende demostrar las ventajas de considerar el régimen de flujo transitorio en el análisis de estabilidad de talud aguas arriba para la situación de reducción rápida de una presa de tierra homogénea. Se llevaron a cabo análisis de estabilidad de taludes aguas arriba, considerando la presión de poro / succión para análisis de flujo transitorio que simula la reducción rápida del embalse. Los análisis comprendieron diferentes geometrías del talud aguas arriba (de 1V: 1.1H a 1V: 2.5H), alturas que varían de 10 m a 50 m, así como varios materiales de baja permeabilidad (SM, SM-SC, SC, ML, ML-CL, CL, MH y CH). Además, las ecuaciones que relacionan el factor de seguridad con dichos taludes o la altura de la presa se ajustaron a los datos de análisis, para definir el talud mínimo para una determinada altura de la presa o la altura máxima para un determinado talud aguas arriba. Los resultados han demostrado que: teniendo en cuenta la condición de flujo transitorio, incluida la succión, en el análisis de estabilidad de taludes de la situación de reducción rápida, aumenta el factor de seguridad en relación con el análisis simplificado que generalmente se adopta. Esto también ha resultado en taludes mucho más pronunciados, para un factor de seguridad de 1,1, que los recomendados por la Oficina de Reclamación de los E.E.U.U. (USBR), sugiriendo la importancia de realizar análisis de flujo transitorio para las situaciones de reducción rápida y considerando sus resultados en el análisis de estabilidad.

Palabras clave: reducción rápida, suelos no saturados, succión, estabilidad de talud, presa de tierra homogénea

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Introduction

The stability of a slope depends on its geometry, soil properties and the forces to which it is subjected internally and externally (Berilgen, 2007). In the case where the slope is subject to partial or total submersion, the internal and external forces (pore water pressure and external water load) that affect the stability of the slope can change significantly.

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The rapid drawdown of the reservoir represents a critical situation for the upstream slope of an earth dam because lowering the water levels has in two negative effects: it reduces the stabilizing water pressure on the upstream slope while reversing the flow in the upstream slope material to dissipate the initial pore pressures, which takes significantly longer. Although this situation is mainly associated with massive dams, collapses due to this phenomenon are also common in natural slopes or embankments built along rivers and channels, due to the rising of water level caused by floods. When the flood water level is maintained long enough to saturate the material of the soil on the river margins, if the descent to the Normal water level (NW) is too quick, the delay in the dissipation of pore pressure on the slope generates an excess of pores pressures without their stabilizing counterpart, which may induce a failure in the slope, (Alonso and Pinyol, 2016).

The condition known as "instantaneous or rapid drawdown" is often a priority in the definition of the upstream slopes of an earth dam because it is the most unfavorable condition for slope stability (Cruz, 1996).

However, a more realistic or less conservative evaluation of the stability for the reservoir drawdown condition would take into account the aspects of unsaturated soil behavior, such as the influence of the variation of hydraulic conductivity on the dissipation of pore pressures and suction, which has direct influence on increasing resistance and, therefore, stability.

Dam stability in rapid drawdown conditions

Figure 1 below illustrates the typical section of a homogeneous dam on which the geometric analyses developed in this work were based.

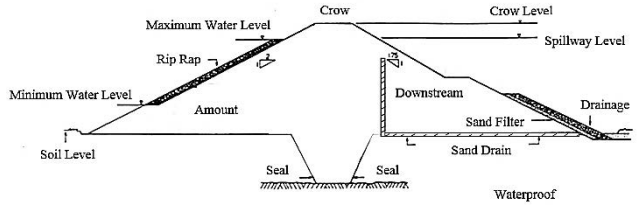

Figure 1. Typical profile of a homogeneous dam.
Source: adapted, Stephens, 2011.

The stability evaluation of the upstream slope of earth dams during rapid drawdown of the reservoir is necessary not only for existing dams but also in the phases of inventories, feasibility studies, and basic and executive design of future homogeneous earth dams.

When the slope is partially or totally submerged, the internal and external forces (water pore pressure and external water load) are equalized with medium saturation, varying with NW changes. However, this equalization occurs in a longer or shorter period of time according to the permeability of the porous medium. For slopes comprised of high permeability soils, these NW variations are reflected almost instantaneously in pore pressures and do not represent a risk of slope instability.

In the case of soils with low permeability, pore pressure changes are not likely to dissipate in the same proportion as the variations in the external water level and, in this way, totally or partially undrained behavior of the slope soil can occur.

Figure 2 illustrates flow behavior in a slope of low permeability with the lowering of the NW of the reservoir, where the existence of pore pressure in the upstream embankment, without the stabilizing counterpart of the reservoir, can be observed.

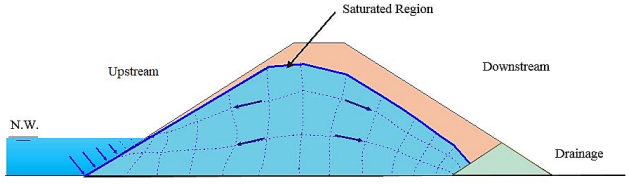

Figure 2. Flow behavior in U/S dam slope of low permeability with rapid drawdown N.W.
Source: Authors

The rapid lowering of U/S water level stability can lead to failure, according to different case studies of natural and artificial slopes. Many authors have dealt with the evaluation of slope stability during rapid drawdowns (Morgenstern, 1963; Lane and Griffiths, 2000; Berilgen, 2007; Alonso and Pinyol, 2009, 2016; Fattah, M. Y., Omran, H. A., and Hassan, M. A., 2015, 2017, Fattah, M. Y., Al-Labban, S. N. Y., and Salman, F. A., 2014) making use of classical stability analysis, slope stability limit approach or numerical solutions.

Pre-dimensioning of the upstream slopes of dams, according to the U.S. Bureau of Reclamation (2002), does not take into account the level of stresses acting on the mass due to the height of the dam, which may result in oversized projects for small dams and undersized design for higher dams. One of the aspects discussed in this work is the influence of the magnitude of the dam on the stability of the upstream slope in rapid drawdown conditions, considering the transient flow and the suction that is generated inside the body of the dam.

In this work, the transient flow behavior in the dam, associated with the water level lowering of the reservoir, is simulated by the finite element method, coupled with several slope stability evaluations of the upstream slope through limit equilibrium methods for different stages of water level in the reservoir.

Pre-dimensioning of slopes of an earth dam

Pre-dimensioning of slopes depends largely on the type of dam (homogeneous or heterogeneous) and the nature of the materials used in its construction. Table 1 presents the recommendations of the U.S. Bureau of Reclamation (2002) for slopes of homogeneous dams, considering or not the possibility of rapid drawdown, for different types of soils.

Table 1. Recommended slopes for small homogenous earth dams with stable foundation

Case	Type	Object	Subject to rapid drawdown[1]	Soil Type[2]	Upstream	Down stream
A	Homogeneous or modified homogeneous	Retention or storage	No	GW, GP, SW, SP	No waterproof	
				GC, GM, SC, SM	2,5:1	2:1
				CL, ML	3:1	2,5:1
				CH, MH	3,5: 1	2,5:1
B	Modified homogeneous	Storage	Yes	GW, GP, SW, SP	No waterproof	
				GC, GM, SC, SM	3:1	2:1
				CL, ML	3,5:1	2,5:1
				CH, MH	4:1	2,5:1

[1] Speed of water level lowering of 15 cm or more per day, after a prolonged situation with high reservoir level.

[2] Soils OL and OH are not recommended for zones in large homogeneous earth dams.

Source: adapted, Bureau of Reclamation, 2002.

Safety factors in slope stability studies

Considering all the aspects presented above, the Brazilian standard of slope stability (NBR 11.682, 2009) proposes safety factors according to the associated risk conditions.

However, U.S. Corps of Engineers (2003) recommended, specifically for dam structures, the safety factor values presented in Table 2 that range from 1.0 to 1.2 for upstream slopes subjected to the rapid lowering condition.

Table 2. Safety factors according to U.S. CORPS OF ENGINEERS

Situation	Safety factor
End of Construction	1,3
Long-term permanent flow	1,5
Rapid drawdown	1,0 a 1,2

Source: U.S. Corps of Engineers, 2003.

The safety factor associated with rapid drawdown may be the smallest figure among all the requirements regarded as critical to the stability of an earth dam, because it reflects the consequences of rupture in this kind of situation, once the mass of water stored in the lowered reservoir is reduced and the possible collapse of the dam causes less damage than in a full storage situation.

Methodology used in the analysis

Description of the studied hypothetical dam

The work consisted in simulating the transient flow induced by the lowering of the reservoir and performing stability analysis of the upstream slope at several stages of the transient analysis for different heights of a dam (from 10 m to 50 m), different inclinations of the upstream slope (1V: 1.1 H to 1V:2.5 H) as well as different materials in the dam embankment (SM, SM-SC, SC, ML, ML-CL, CL, MH and CH) according to the Unified Soil Classification System (USCS).

The typical section studied is shown in Figure 3, consisting of a dam with 5.0 m wide crest, 1.0 m thick rip-rap, Brazilian section (homogeneous compacted embankment with vertical filter associated to an horizontal downstream drainage mat) resting on a permeable foundation layer 3.0 m thick, in which a cut-off was implanted down to the bedrock.

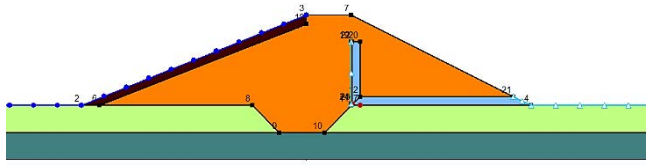

Figure 3. Typical section homogeneous dam: H=10 m, upstream slope 1V:2.5 H.
Source: Authors

Analysis of flow in transient conditions during the lowering of the water level

The bidimensional transient simulations were performed on the SEEP/W platform, considering that the lowering of the NW occurs at a limit speed of 15 cm/day as indicated by the USBR (2002), which is necessary to consider the rapid drawdown in slope stability assessments of an homogeneous dam.

In the SEEP/W platform, two functions were employed: the soil characteristic curve (volumetric water content x suction) and the permeability variation curve (hydraulic conductivity x suction). In the case of SC soil, those curves came from laboratory tests, while characteristic curve for volumetric moisture, evaluated by Fredlund and Xing (1994), was adopted for the other soil types.

In the present work, the hydraulic conductivity function was developed in an unsaturated context, where voids filled by air increased the tortuosity of the flow passage, thus reducing permeability in relation to saturated conditions. The permeability curves were defined by providing to the software the saturated permeability values, obtained from conventional tests, and the volumetric water content.

In order to adequately simulate the transient phenomenon and its impacts on the suction in the upstream slope, the transient flow analyses considered daily time intervals, being the total period of analysis proportional to the height of the dam, that is:

- Up to 30m = 180 days / time intervals;
- 35m = 240 days / time intervals;
- 40m = 260 days / time intervals;
- 45m = 290 days / time intervals;
- 50m = 330 days / time intervals;

Table 3. Results of 1500 trials carried out by U.S. Bureau of Reclamation

Soil properties							
USCS Soil type	Compactation			Permeability	Strength parameters		
	maximum unit weight γ_g (KN/m^3)	optimum moisture content h (%)	wet unit weight γ_w (KN/m^3)	(m/day)	C′ (kPa)	C′ sat(kPa)	$\phi^{(\circ)}$
GW	>19,0	<13,3	>21,53	2,33E+07 ± 1,12E+07	(x)	(x)	>38,3
GP	>17,6	<12,4	>19,78	5,53E+07 ± 2,94E+07	(x)	(x)	>36,5
GM	>18,2	<14,5	>20,84	>2,59E-04	(x)	(x)	>33,8
GC	>18,4	<14,7	>21,10	>2,59E-04	(x)	(x)	>31,0
SW	19,0 ± 0,8	13,3 ± 2,5	21,53 ± 0,82	*	40 ± 4,0	(x)	38,6 ± 1,2
SP	17,6 ± 0,3	12,4 ± 1,0	22,03 ± 0,30	>1,30E-02	23 ± 6,0	(x)	36,5 ± 1,2
SM	18,2 ± 0,2	14,5 ± 0,4	20,80 ± 0,20	6,48E-03 ± 4,15E-03	52 ± 6,0	20 ± 7,0	33,8 ± 1,2
SM-SC	19,0 ± 0,2	12,8 ± 0,5	21,40 ± 0,20	6,91E-04 ± 5,18E-04	51 ± 2,0	14 ± 6,0	33,4 ± 4,0
SC	18,4 ± 0,2	14,7 ± 0,4	21,10 ± 0,20	2,9E-04 ± 1,73E-04	76 ± 2,0	11 ± 6,0	31,0 ± 4,0
ML	16,5 ± 0,2	19,2 ± 0,7	19,70 ± 0,20	5,10E-04 ± 1,73E-05	68 ± 1,0	09 ± (x)	31,8 ± 2,3
ML-CL	17,4 ± 0,3	16,8 ± 0,7	20,30 ± 0,30	1,12E-04 ± 6,05E-05	64 ± 2,0	22 ± (x)	31,8 ± 3,4
CL	17,3 ± 0,2	17,3 ± 0,3	20,30 ± 0,20	6,91E-05 ± 2,59E-05	88 ± 1,0	13 ± 2,0	28,4 ± 2,3
MH	13,1 ± 0,6	36,3 ± 3,2	17,90 ± 0,62	1,38E-04 ± 8,64E-05	36,3 ± 3,2	20 ± 9,0	25,2 ± 2,9
CH	15,0 ± 0,3	25,5 ± 1,2	18,80 ± 0,30	4,32E-05 ± 4,32E-05	25,5 ± 1,2	11 ± 6,0	19,3 ± 5,1

The resistance parameter ϕ_b, considered was the average value of $\phi'/2$ as suggested by Kranh (2004).

Source: U.S. Bureau of Reclamation, 2002.

Analysis of stability during the lowering of the water level

Stability analyses of upstream slopes were performed on the SLOPE/W platform with the Morgenstern-Price method (1965), which is based on the limit equilibrium of rupture surfaces comprising both equilibrium of moments and forces. It also considers efforts between the slices.

The pore pressures considered in the stability analyses were obtained from the results of transient reservoir water level lowering analyzes performed every 30 days, until the complete depletion of the reservoir.

Geotechnical parameters used in the analysis

The analyses contemplated only the materials of reduced permeability, for which the rapid lowering of the NW represents a risk of destabilization. These materials are highlighted in blue in Table 3 of USBR (2002) whose recommended parameters were used in the performed analyses.

For the analyzes with suction, in addition to the drained parameters, saturated specific gravity, and Mohr Coulomb rupture criterion, a resistance parameter (ϕ_b) was used, as suggested by Kranh (2004), to consider the suction effect on the material shear strength.

For SC soil, the parameters were determined in laboratory tests with materials from an experimental dam with similar geometric characteristics to the model proposed in Figure 3, located in the Lavoura Seca Experimental Farm, in the municipality of Quixadá, belonging to the Federal University of Ceará. For the other soil types, the parameters presented by the U.S. Bureau of Reclamation (2002) were used.

Physical Characterization of the soil (SC)

Table 4 presents the summary of the geotechnical properties obtained in laboratory tests for SC soil of the experimental dam:

Table 4. Geotechnical Properties of Soil SC

Granulometry	Gravel	Sand	Silt	Clay
	3%	59%	10%	28%
Atterberg Limits (%)	LL	PL	PI	
	26	17	9	
Specific Gravity	2,62			
Soil Classification	USCS		HRB	
	SC		A-2-4	
Proctor Normal	W optimum (%)		γ_d (g/cm^3)	
	14,7		1,84	
Resistance Parameters	c'(kPa)		$\phi(\circ)$	$\phi b(\circ)$
	11,7		26,6	12,0

Source: Authors

Hydraulic properties of SC soil

The saturated hydraulic conductivity was obtained in laboratory tests performed in deformed samples, according to the NBR 14545/2000 standard for variable load tests, resulted in a permeability coefficient (k) of 2,6 x 10^{-7} m/s for the studied sample.

Soil characteristic curve

The filter paper method, according to ASTM Standard D5298-03 (2003), is generally accepted to be an inexpensive, technically simple, and reasonably accurate method that could be used to measure soil suction to a great extent. The method, however, is dependent of the accuracy of the calibration curve that relates filter paper water content to soil suction. Additionally, applying contact stress to the filter papers significantly influences this curve.

This is the basic approach, suggested by the American Society for Testing and Materials (ASTM) standard D5298-03 for the measurement of either matric suction using the contact filter paper technique or total suction using the non-contact filter paper technique. This standard employs a single calibration curve that has been used to infer both total and matric suction measurements, and it recommends the filter papers to be initially oven-dried (for 16 h or overnight) and then allowed to cool to room temperature in a desiccator. Its calibration curve is a combination of both wetting and drying curves. However, because of the marked hysteresis on its wetting and drying, the calibration curve for initially dry filter paper is different from that of the initially wet one.

Some publications present calibration for the wetting path, with the paper initially air dry (Chandler and Gutiérrez, 1986; Chandler et al., 1992; Ridley, 1993; and Marinho, 1994). Marinho and Oliveira (2006) shows that the calibration for the particular type of paper is unique in relation to the type of suction (i.e., total or matric).

Figure 4 shows the characteristic curve for SC soil, where the determination of soil suction was performed through the filter paper technique consisting of placing a soil sample in contact with a known calibration filter paper in a hermetically sealed environment until the system was balanced, while carefully handling the tools used in the test.

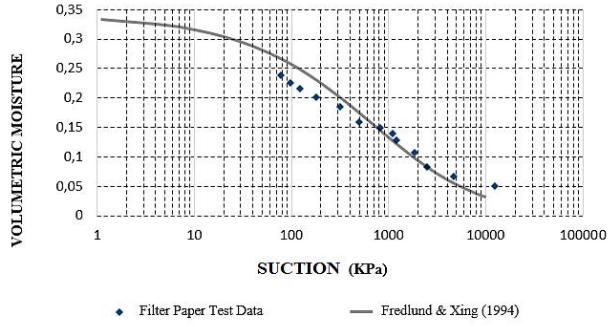

Figure 4. Relation matric suction and moisture (core) for SC soil
Source: Authors

Results of stability analysis in transient regime

The results of the stability analyses, carried out considering the transient behavior of the flow during the lowering of the reservoir and the effect of the suction on the stability of the upstream slope of a homogeneous dam, are presented in the graphs of Figure 5, relating the minimum safety factor with the inclination of the upstream slope for different dam heights, and in Figure 6, relating the minimum safety factor with the dam heights for different upstream slope inclination.

As expected, the influence of the permeability coefficient was observed in the results; in general, more permeable soils result in higher values of the minimum safety factor, keeping the due influence of the shear strength of the materials.

A linear relationship between the minimum safety factor for the rapid drawdown situation and the inclination of the upstream slope was found for practically all soil types according to the dam height, as well as an exponential relationship between the safety factor and the height of the dam for a given inclination of the upstream slope.

Except for 10 m dams, all results present excellent correlation for the adjusted equations to the minimum safety factor points obtained.

Using such equations and considering a safety factor of 1,1 a minimum slope and maximum height of the dam were determined for all types of material studied, which are presented in Tables 5 and 6, respectively.

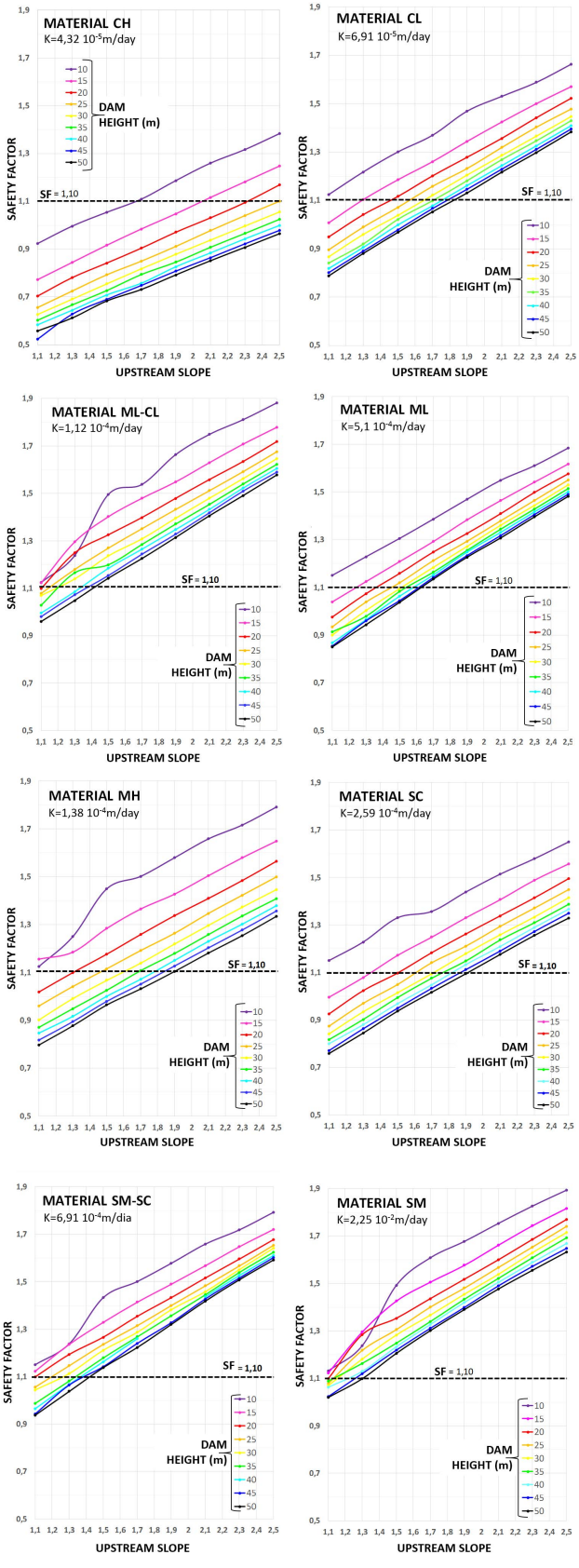

Figure 5. Safety Factor x Upstream Slope.
Source: Authors

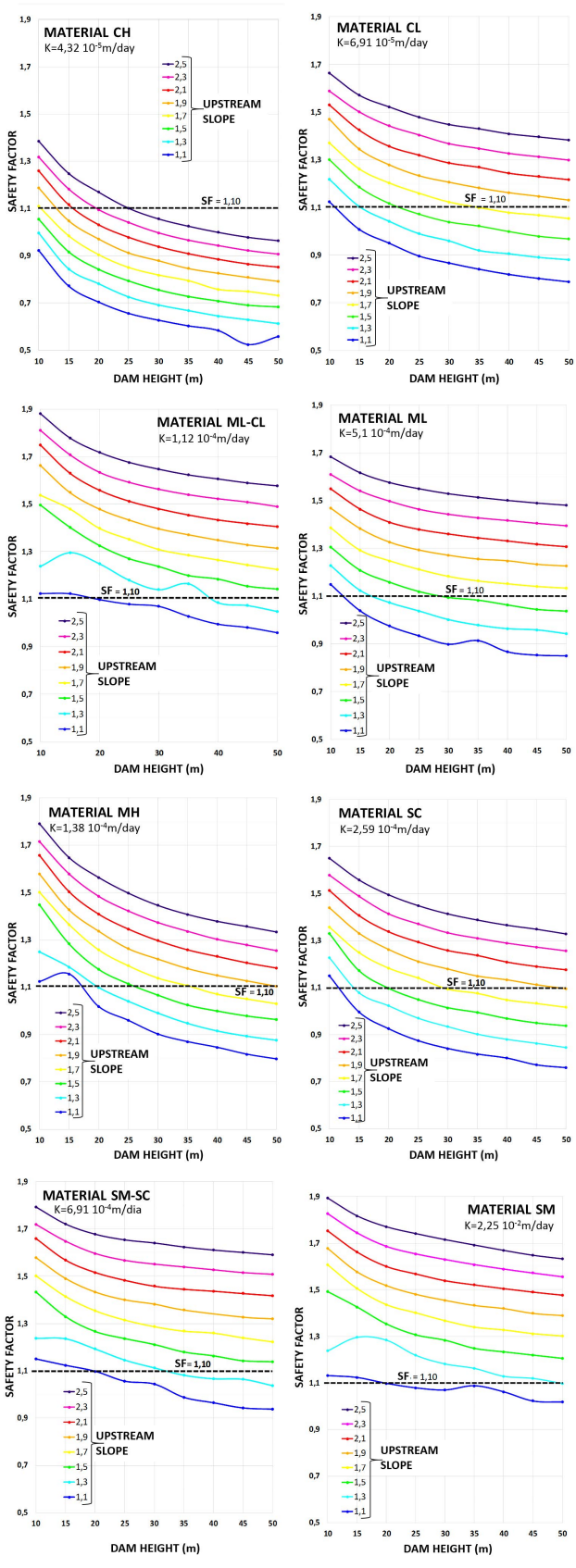

Figure 6. Safety Factor x Dam Height.
Source: Authors

Table 5. Minimum U/S Slope for a SF = 1,1

Minimum U/S Slope - SF = 1.10								
H (m)	CH	CL	ML-CL	ML	MH	SC	SM-SC	SM
10	1,64	1,05	0,54	0,96	0,91	0,93	0,58	0,44
15	2,05	1,30	0,70	1,24	1,00	1,34	0,99	0,67
20	2,30	1,46	0,93	1,31	1,30	1,51	1,09	0,87
25	2,49	1,57	1,12	1,46	1,46	1,63	1,19	1,02
30	2,63	1,65	1,18	1,53	1,59	1,72	1,25	1,10
35	2,74	1,71	1,27	1,55	1,69	1,78	1,34	1,15
40	2,83	1,76	1,33	1,59	1,77	1,83	1,37	1,20
45	2,86	1,79	1,37	1,62	1,83	1,88	1,41	1,25
50	2,96	1,82	1,41	1,64	1,89	1,92	1,43	1,27
USBR	4,0	4,0	3,5	3,5	3,5	3,0	3,0	3,0

Source: Authors

In Table 5 above, it can be observed that all the values of minimum upstream slope obtained with the consideration of the transient flow and suction are well below the values recommended by the USBR (2002); as expected, it is quite conservative.

This suggests that, eventually, the final construction situation may be the determining factor for the upstream slope of a homogeneous dam.

Table 6. Maximum dam height for a SF = 1,1

Maximum Dam Height (m)								
SLOPE	CH	CL	ML-CL	ML	MH	SC	SM-SC	SM
2,5	26,35	351,51	1328,76	1982,70	138,44	200,38	8665,68	4058,20
2,3	20,47	176,58	599,55	701,76	95,02	121,66	2324,12	1756,41
2,1	16,26	97,64	290,42	254,62	67,93	73,20	646,45	807,99
1,9	12,61	55,71	162,91	122,41	48,73	47,17	239,57	365,99
1,7	9,79	35,38	102,36	57,25	36,18	30,85	114,13	166,91
1,5	7,80	23,18	60,09	30,29	27,65	21,63	58,73	93,20
1,3	6,46	15,47	37,77	17,78	18,98	14,77	33,23	49,03
1,1	5,31	10,33	23,70	11,27	13,87	10,69	18,75	33,13

Source: Authors

Table 6 shows that CH soils are the least recommended for upstream slopes, because they have lower maximum heights for each analyzed slope -as explained below in the comparison of results- while the others are quite adequate.

Comparison results

In order to provide a basis for comparison, simplified stability analyses were carried out, considering instantaneous drawdown conditions without taking into account the transient flow and suction effect in the upstream slope.

The pore pressure for such simplified analyses came from a water table along the upstream slope associated to the permanent regime water table inside the embankment.

The analyses were carried out only for SC soil with the same effective resistance parameters and without the suction plot.

In addition, analyses were also performed without the foundation layer in order to evaluate the effect of the presence of this material on the stability of the upstream slope. Figure 7 shows the adopted geometric model.

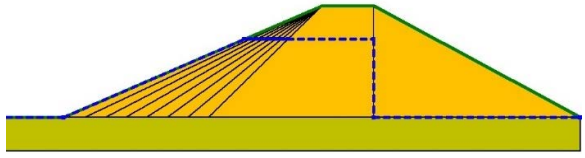

Figure 7. Simplified Analysis Model.
Source: Authors

The simplified analysis results are presented in Table 7 for both geometries, along with the ones from the analyses considering transient flow regime and suction, the latter highlighted in red.

It can be seen that CH-type soils, among the evaluated ones, are the least adequate for upstream slopes of dams where rapid drawdown is expected because safety factors greater than the unit are obtained solely for dam heights equal to or less than 20 m and 25 m, respectively with and without the foundation layer. While safety factors considering transient flow and suction are greater than 1,0 for slopes as steep as 1V: 1,7 H., using this type of soil would result in a greater use of soil volumes, which in turn would mean higher costs and execution times.

The SF curves versus upstream slope and SF versus height of the dam present a similar behavior to those obtained from analyses considering transient flow regime and suction, but with much lower safety factors, as shown in Figure 8.

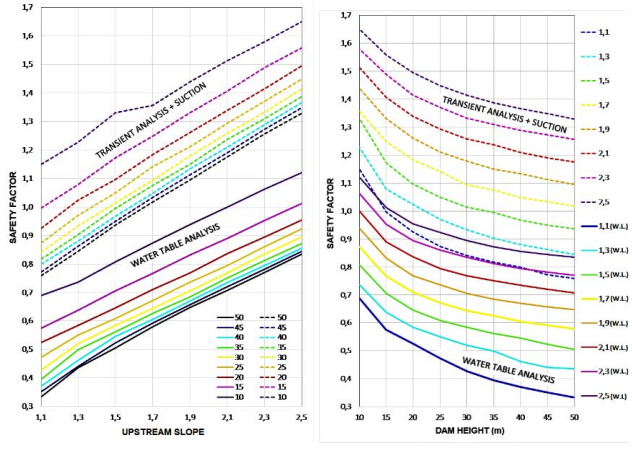

Figure 8. Simplified Analysis Model.
Source: Authors

Applying the same, previously adopted concept, it was possible to define analogous equations for the analyses with water table by defining the minimum slope and maximum height for a safety factor of 1,1.

Table 7. Results Analysis with Instant Drawdown

	H(m)	Soil Type SC – Safety Factor Upstream Slope Rapid Drawdown							
		1V:1,10H	1V:1,30H	1V:1,50H	1V:1,70H	1V:1,90H	1V:2,10H	1V:2,30H	1V:2,50H
50	Transient analyze W/foundation	0,759	0,845	0,937	1,017	1,095	1,176	1,256	1,329
	W/foundation	0,334	0,436	0,506	0,579	0,648	0,707	0,770	0,835
	Out/foundation	0,331	0,435	0,505	0,585	0,662	0,734	0,807	0,879
45	Transient analyze W/foundation	0,771	0,863	0,949	1,033	1,112	1,190	1,272	1,349
	W/foundation	0,351	0,440	0,523	0,592	0,657	0,720	0,781	0,845
	Out/foundation	0,350	0,438	0,522	0,603	0,681	0,755	0,826	0,900
40	Transient analyze W/foundation	0,800	0,880	0,968	1,048	1,133	1,209	1,289	1,366
	W/foundation	0,371	0,461	0,545	0,605	0,670	0,735	0,794	0,856
	Out/foundation	0,371	0,459	0,543	0,624	0,703	0,779	0,851	0,924
35	Transient analyze W/foundation	0,817	0,902	0,994	1,076	1,149	1,237	1,310	1,388
	W/foundation	0,395	0,498	0,562	0,626	0,685	0,705	0,812	0,872
	Out/foundation	0,394	0,486	0,562	0,651	0,730	0,809	0,881	0,955
30	Transient analyze W/foundation	0,841	0,934	1,014	1,094	1,179	1,258	1,333	1,414
	W/foundation	0,427	0,519	0,584	0,644	0,706	0,769	0,835	0,895
	Out/foundation	0,427	0,520	0,606	0,688	0,766	0,846	0,923	0,996
25	Transient analyze W/foundation	0,874	0,970	1,049	1,141	1,211	1,294	1,371	1,449
	W/foundation	0,473	0,551	0,609	0,672	0,736	0,795	0,860	0,923
	Out/foundation	0,473	0,567	0,654	0,738	0,817	0,897	0,979	1,055
20	Transient analyze W/foundation	0,925	1,023	1,097	1,183	1,262	1,338	1,414	1,495
	W/foundation	0,525	0,584	0,646	0,710	0,769	0,836	0,894	0,955
	Out/foundation	0,539	0,634	0,724	0,809	0,894	0,976	1,056	1,138
15	Transient analyze W/foundation	0,996	1,079	1,172	1,249	1,331	1,407	1,489	1,558
	W/foundation	0,575	0,638	0,705	0,767	0,832	0,890	0,953	1,012
	Out/foundation	0,647	0,748	0,840	0,930	1,017	1,107	1,190	1,273
10	Transient analyze W/foundation	1,150	1,228	1,330	1,357	1,439	1,514	1,579	1,650
	W/foundation	0,689	0,736	0,807	0,873	0,938	0,999	1,062	1,120
	Out/foundation	0,866	0,972	1,076	1,175	1,272	1,369	1,464	1,557

Source: Authors

Table 8 shows the adjusted equations, the minimum slopes for each height and type of analyses, as well as the percentual relationship between the volume with the water table alternative and the volume considering transient analysis and suction.

This allows for the evaluation of the impact on the embankment volume of the upstream slope for each one of the approaches, considering a SC-type material.

The volume corresponding to the analysis with water table ranges from 161% to 262% of the volume from the transient analyses with suction, thus demonstrating the economy that represents a more sophisticated analysis of the problem.

Table 8. Comparison available of amount volume

H(m)	Water Table Analysis			Transient Analysis + Suction			V_{WT} / V_{TRANS}
	SF = f(slope)	Correlation Coefficient	Minimum Slope (SF = 1,1)	SF = f(slope)	Correlation Coefficient	Minimum Slope (SF = 1,1)	
50	y = 0,3482x - 0,0248	R^2 = 0,9944	3,09	y = 0,4071x + 0,3189	R^2 = 0,9992	1,92	161%
45	y = 0,3464x - 0,0098	R^2 = 0,9951	3,15	y = 0,4103x + 0,3288	R^2 = 0,9993	1,88	167%
40	y = 0,339x + 0,0194	R^2 = 0,9947	3,19	y = 0,4057x + 0,3564	R^2 = 0,9997	1,83	174%
35	y = 0,3293x + 0,0573	R^2 = 0,9943	3,17	y = 0,4071x + 0,3764	R^2 = 0,9991	1,78	178%
30	y = 0,3258x + 0,086	R^2 = 0,997	3,11	y = 0,4061x + 0,4023	R^2 = 0,9995	1,72	181%
25	y = 0,3165x + 0,1327	R^2 = 0,9993	3,06	y = 0,4068x + 0,4376	R^2 = 0,9989	1,63	188%
20	y = 0,3089x + 0,1839	R^2 = 0,9999	2,97	y = 0,4016x + 0,4942	R^2 = 0,9991	1,51	197%
15	y = 0,3127x + 0,2336	R^2 = 0,9997	2,77	y = 0,403x + 0,5597	R^2 = 0,999	1,34	207%
10	y = 0,3148x + 0,3364	R^2 = 0,999	2,43	y = 0,3505x + 0,7749	R^2 = 0,9943	0,93	262%

Source: Author

Conclusions

The results demonstrated the advantages of considering the actual flow and suction conditions of the upstream slope for a rapid drawdown context. The equations correlating the minimum slope with the height of the dam represent the lower limit, to be considered once the velocity adopted in the analyses corresponds to the lower velocity defined by the USBR. It can be a valuable aid in the definition of dam geometry as much as in the construction process or schedule, and the selection of borrowing areas. As an example of the proposal, graph 9 shows the curves for the SC material, highlighting the application range.

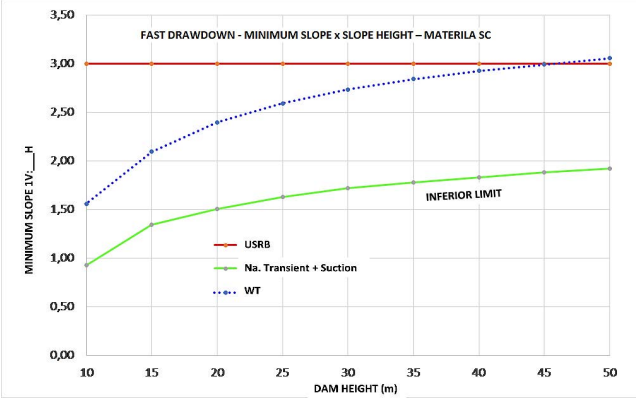

Figure 9. Safety factor x Dam height (m) – Inferior limit.
Source: Authors

A rapid drawdown transient analysis, along with a better representation of the phenomena, incorporates the apparent increase on the shear strength of the material according to its degree of saturation.

The comparison with the usual simplified analysis, presented in Figure 8, shows, for a same safety factor and dam height, much steeper inclination for the transient analysis, which means smaller volumes of material in the upstream slope and therefore a more desirable economic scenario.

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Evaluation of a New Multimodal Optimization Algorithm in Fluid Phase Equilibrium Problems

Evaluación de un nuevo algoritmo de optimización multimodal en problemas de equilibrio de fases fluidas

G. M. Platt[1], M. Escobar[2], F. C. Borges[3], and D. A. Goulart[4]

ABSTRACT

Multimodal optimization problems are commonly found in engineering problems, and their solution can be very challenging for metaheuristic approaches. In this work, the use of a recently proposed multimodal metaheuristic method was analyzed - the Multimodal Flower Pollination Algorithm - in two fluid phase equilibrium problems: (i) the calculation of double azeotropes and (ii) parameter estimation in a thermodynamic model. Two different formulations were also considered in the double azeotropy problem. In the azeotrope calculation, a statistical analysis was conducted in order to verify if the algorithm performance is affected by the the problem formulation. The computational results indicate that the methodology provides robust results and that the objective function employed affects the computational performance.

Keywords: multimodal optimization, azeotropy, refrigerant fluids, metaheuristics

RESUMEN

Los problemas de optimización multimodal se encuentran comúnmente en problemas de ingeniería y su solución puede ser muy desafiante para los enfoques metaheurísticos. En este trabajo se analizó el uso de un método metaheurístico multimodal recientemente propuesto - el Algoritmo Multimodal de Polinización de la Flor - en problemas de equilibrio de fase fluida en dos etapas: (i) el cálculo de azeótropos dobles y (ii) la estimación de parámetros en un modelo termodinámico. También se consideran dos formulaciones diferentes en el problema de doble azeotropía. En el cálculo de azeótropo, se realizó un análisis estadístico para verificar si el desempeño del algoritmo se ve afectado por la formulación del problema. Los resultados computacionales indican que la metodología proporciona resultados robustos y que la función objetivo empleada afecta el rendimiento computacional.

Palabras clave: optimización multimodal, azeotropía, fluido refrigerante, metaheurística

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Introduction

Multimodal optimization problems can be a challenging test for stochastic optimization algorithms (Platt, 2016), considering the task of locating all minimum/maximum points of the problem at hand. This kind of problem has been studied with crowding, sharing, niching and speciation techniques, among others (Thomsen, 2004; Parrot and Li, 2006; Cuevas and Reyna-Orta, 2014). In these scenarios, versions of established algorithms were developed for multimodal problems, such as the CrowdingDE (Crowding Differential Evolution), the SharingDE (Sharing Differential Evolution) (Thomsen, 2004) and the SPSO (species-based Particle Swarm Optimization) (Parrot and Li, 2006). A revision regarding these techniques was presented by Parrot and Li (2006).

Recently, new approaches have been published to deal with multimodal problems. Standing out among them — in terms of simplicity of implementation — are the Multimodal Cuckoo Search (MCS) (Cuevas and Reyna-Orta, 2014) and the Multimodal Flower Pollination Algorithm (MFPA) (Gálvez, Cuevas, and Avalos, 2017). These algorithms were tested in typical benchmark functions, but lack tests and validation in real engineering problems.

Stochastic optimization algorithms have been extensively used in many fields of engineering in the last decades (Bermeo, Caicedo, Clementi, and Vega, 2015; García Montoya and Mendoza Toro, 2011; Nagarkar and Vikhe, 2016). In this

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scenario, the present work presents some applications of the MFPA algorithm in two phase equilibrium problems: (i) an application in refrigeration; the calculation of azeotropic composition in the mixture HFC4310mee (commercially known as Vertrel XF) + Tetrahydrofuran (THF), a refrigerant fluid — refrigerant fluids are usually pure substances or azeotropic mixtures; zeotropic mixtures are avoided in refrigeration, since the composition variations arising from vaporization and condensation processes can alter the performance of the refrigerator — and (ii) the parameter estimation in the binary system acetic acid + anisole, a system with applications in the agrochemical industry. The vapor-liquid equilibrium in the system acetic acid + anisole was recently studied by Mali, Mali, Patil, and Joshi (2017). The anisole exhibits insecticide properties and has been studied in recent years (Quan, Liu, and Liu, 2018). Platt (2016) discussed the performance of two stochastic algorithms in the azeotrope calculations, yet employing a different approach to the used in this work, mainly regarding the strategies used to obtain multiple solutions.

The aim of this work is not to present comparisons between the different existing techniques to solve multimodal problems. Such comparisons have been exhaustively discussed in the literature (see Derrac, García, Molina and Herrera, 2011; Platt, Yang and Silva Neto, 2019) and the results are intrinsically dependent on the parameters used in the algorithms, which renders these analyses arbitrary under several aspects. Thus, the objective of this work is to verify the applicability, in terms of robustness or efficiency (with respect to the identification of the solutions of the problems) and ease of implementation, of the MFPA in real engineering problems. A recent analysis of algorithm comparisons (bio-inspired metaheuristics and deterministic approaches) was presented by Sergeyev, Kvasov, and Mukhametzhanov (2018). These authors conclude that both metaheuristics and determinist algorithms were capable to adequately solve distinct problems, and that, obviously, the parameter tuning of metaheuristics must be considered in such comparisons.

Description of the problems

Azeotrope Calculation

The term azeotrope refers to a thermodynamic condition where a boiling liquid produces a vapor phase with the same composition. The existence of azeotropes can occasionally cause problems in the separation of the mixture by distillation (see Shen, Benyounes, and Song, 2015).

The azeotrope calculation will be modeled with two distinct approaches, in order to evaluate the effect of the objective function (or fitness, to use a bio-inspired term). Obviously, the solution for both formulations are the same.

Formulation 1: The first approach consists in the azeotropy problem in its classical formulation, i.e., the isofugacity equations and the equality of compositions between liquid and vapor phases (azeotropy relation) (Walas, 1985):

$$\hat{f}_i^L - \hat{f}_i^V = 0, \quad i = 1, \ldots, c \tag{1}$$

$$y_i - x_i = 0, \quad i = 1, \ldots, c-1 \tag{2}$$

where $\hat{f}_i^\alpha$ is the fugacity of component i (in the mixture) in phase α, in a mixture with c components. The superscripts L and V refer to the liquid and vapor phases, respectively. The molar fractions of the component i in liquid and vapor phases are x_i and y_i, respectively. Equations (1) impose the coexistence of the phases, and Equations (2) represent the equality of compositions between liquid and vapor phases (representing pure components and azeotropes). As a condition of coexistence, the azeotropy also implies the equalities of temperatures and pressures for both phases. Since we are using only one temperature (T) and one pressure (P) for vapor and liquid phases, these conditions are implicitly attended. The fugacity of a component i in the vapor phase will be calculated considering an ideal vapor phase — which is compatible with the low pressures in the studied problems — which produces (Walas, 1985):

$$\hat{f}_i^V = P y_i \tag{3}$$

The nonideal liquid phase will be modeled by a modified Raoult's law (Walas, 1985):

$$\hat{f}_i^L = P_i^{sat} x_i \gamma_i \tag{4}$$

where P_i^{sat} is the saturation pressure of the pure fluid i and γ_i is the activity coefficient of component i. In a binary system, we obtain:

$$\begin{aligned} F_1 &= P y_1 - P_1^{sat} x_1 \gamma_1 = 0 \\ F_2 &= P(1 - y_1) - P_2^{sat}(1 - x_1)\gamma_2 = 0 \\ F_3 &= y_1 - x_1 = 0 \end{aligned} \tag{5}$$

Substituting F_3 in F_1 and F_2, a two-dimensional problem (to be zeroed) can be obtained:

$$F_i = P - P_i^{sat} \gamma_i = 0, \quad i = 1, 2 \tag{6}$$

The fitness function $\mathcal{F}$ can be produced by adding the squares of the residues of each nonlinear equation, i.e.:

$$\mathcal{F} = \sum_{i=1}^{2} F_i^2 \tag{7}$$

Null minima of $\mathcal{F}$ are the solutions (or roots, using the widespread term employed in numerical analysis) of the nonlinear system represented by Eqs. (6).

Formulation 2: Considering the approach of Bonilla-Petriciolet, Iglesias-Silva, and Hall (2009) (referred here as Formulation 2), the azeotrope calculation can be represented as:

$$\begin{aligned} F_1 &= g_L - g_V = 0 \\ F_{i+1} &= \left(\frac{\partial g_L}{\partial x_i}\right)_{T,P,x_{k(k\neq i)}} - \left(\frac{\partial g_V}{\partial y_i}\right)_{T,P,y_{k(k\neq i)}} = 0, \ i = 1, \ldots, c-1 \end{aligned} \tag{8}$$

where g refers to the dimensionless molar Gibbs free energy of mixing for the mixture ($g = \frac{\Delta G_m}{RT}$), represented by

$$g_L = \sum_{i=1}^{c} x_i \ln(x_i \gamma_i)$$
$$g_V = \sum_{i=1}^{c} x_i \ln\left(\frac{P x_i}{P_i^{sat}}\right) \quad (9)$$

for liquid and vapor phases, respectively. Again, if we consider $y_i = x_i$, $\forall i$, the azeotropy problem is solved for liquid molar fractions. The fitness function is, again, the sum of the residues of each nonlinear equation, and it can be calculated by using the same expression of Eq. (7), but now referring to the residues represented by Eq. (8).

In both cases, the molar excess Gibbs free energies (G^E) will be modeled by a Redlich-Kister model (Segura, González, and Wisniak, 2005):

$$\frac{G^E}{RT} = x_1 x_2 \left[C_1 + C_2 (x_2 - x_1) + C_3 (x_2 - x_1)^2 + C_4 (x_2 - x_1)^3\right], \quad (10)$$

where $C_k = C_k^0 + \frac{C_k^1}{T}, k = 1, 4$. In the last equation, R is the Universal gas constant and T is the absolute temperature (Kelvin). Values for the coefficients C_k^0 and C_k^1 and coefficients for Antoine's equation (for calculation of saturation pressures) are reported by Segura et al. (2005).

The activity coefficients are partial molar properties of excess Gibbs free energies, and can be calculated by (Walas, 1985):

$$\ln(\gamma_i) = \left[\frac{\partial\left(\frac{nG^E}{RT}\right)}{\partial n_i}\right]_{T,P,n_{j\neq i}}, \quad (11)$$

where n is the total amount of substance.

Parameter Estimation

Parameter estimation is a very common task in many engineering fields. In the context of chemical engineering, the parameter estimation in thermodynamic models can exhibit multiple solutions, as pointed by Gau, Brennecke, and Stadtherr (2000). In these occasions, the use of deterministic algorithms, such as the Nelder-Mead Simplex (Nelder and Mead, 1965), is not advisable, since local optima can be found depending on the initial guesses, which justifies the use of stochastic approaches. Thus, parameter estimation is a good scenario to test the performance of MFPA.

Mali et al. (2017) studied the vapor-liquid equilibrium in the binary system acetic acid + anisole at 96,15 kPa. The experimental data described by them indicated a minimum boiling azeotrope in the system, close to the pure acetic acid in the compositional domain. The fitness function employed here is (Gau et al., 2000):

$$\mathcal{F} = \sum_{i=1}^{p} \sum_{j=1}^{c} \left(\frac{\gamma_{i,j}^{\exp} - \gamma_{i,j}^{\text{calc}}}{\gamma_{i,j}^{\exp}}\right)^2 \quad (12)$$

where p is the number of experimental points and c is the number of components in the mixture. The superscripts exp and calc represent, respectively, experimental and calculated data. It must be stressed that this objective function is different to that employed by Mali et al. (2017). These authors used an absolute deviation between calculated and experimental saturation pressures. The experimental data will be adjusted to the Wilson model (1964). In this problem, since we are dealing specifically with the excess Gibbs free energy model, a more detailed description of the expressions is useful. The activity coefficients calculated by this model in a binary mixture are:

$$\ln\left(\gamma_1^{\text{calc}}\right) = -\ln(x_1 + \Lambda_{12} x_2) + x_2\left(\frac{\Lambda_{12}}{x_1 + \Lambda_{12} x_2} - \frac{\Lambda_{21}}{x_2 + \Lambda_{21} x_1}\right)$$
$$\ln\left(\gamma_1^{\text{calc}}\right) = -\ln(x_2 + \Lambda_{21} x_1) - x_1\left(\frac{\Lambda_{12}}{x_1 + \Lambda_{12} x_2} - \frac{\Lambda_{21}}{x_2 + \Lambda_{21} x_1}\right) \quad (13)$$

and the parameters Λ_{12} and Λ_{21} are calculated by:

$$\Lambda_{12} = \frac{V_2}{V_1} \exp\left(\frac{-\theta_1}{RT}\right)$$
$$\Lambda_{21} = \frac{V_1}{V_2} \exp\left(\frac{-\theta_2}{RT}\right) \quad (14)$$

V_1 and V_2 are the molar volumes of components 1 and 2, respectively. The parameters (to be estimated in the optimization procedure) are θ_1 and θ_2. The experimental points are calculated by the modified Raoult's Law (Walas, 1985). The experimental data employed in the parameter estimation (as well as all the other quantities, such as molar volumes and expressions for saturation pressures) are presented in Mali et al. (2017) and, for the sake of conciseness, are not reproduced here.

Methodology

In this section, we will present a brief description of the Multimodal Flower Pollination Algorithm (MFPA), proposed by Gálvez et al. (2017). The original Flower Pollination Algorithm (FPA) was proposed by Yang (2012) and mimics the process of flower pollination. In FPA, a population (a set) of n flowers (vector of decision variables) is generated every k iteration (a generation), where each flower corresponds to a vector as a potential solution of the optimization problem. The quality of each vector is evaluated through a fitness function. At each iteration, either one of two operators is carried out for each individual population member: (i) local pollination operator, a small step, related to the exploitation of the promising regions and the accuracy of the solutions; or (ii) global pollination operator, a large step, using the Lévy Flight, responsible for exploring the domain in an effective way (Pavlyukevich, 2007). A switch probability function is used in order to randomly define which operator is to be used. Finally, a elitism strategy is applied in order to keep

the best solution (with the minimum cost function value in a minimization problem). The procedure is repeated until the maximum number of iterations (or generations) is achieved. At the end, the best solution found is a potential global optimum.

Gálvez et al. (2017) proposed a multimodal flower pollination algorithm (MFPA) enhancing the original algorithm with multimodal capabilities, in which they added the process of finding the global optimum and multiple local optima. In the MFPA, three new elements are included. The first element involves a memory mechanism, which allows an efficient registering of potential optima. The memory is a set of vectors considered as the potential global or local optima. The second element is a new selection strategy approach, in order to decide whether the solution is to be registered as potential or not, thus updating the memory. The decision to keep the solution is influenced not only by the current best solution as in the original algorithm, but also by vector solutions that are contained in the memory. The third element consists of a depuration procedure executed in order to eliminate similar solutions that may represent the same optima, resulting in a cleaner memory (with less elements). Thus, the algorithm is summarized as follows: after the generation of the new population (by local or global pollination-FPA algorithm) and the initialization of the memory with the best solution from the first population, the new selection approach is executed and the memory is updated. Afterwards, the depuration procedure is executed and the memory is updated again. At the end, all memory solutions are supposed to be optimal (globally and locally).

The selection approach uses some rules based on the cost function of the solution to capture memory elements. The fitness value of the current vector is compared to the worst memory element. The distance to the nearest element in the memory is used to decide whether the solution represents a new optimum or is similar to an existing memory element. After the memory mechanism procedure, the depuration procedure is applied, in which the memory elements in the vicinity, within a ratio that depends on the distance between the elements, are cut off. Therefore, some elements that represent the same solution are excluded and, as a result, the memory contains a smaller number of solutions. Finally, the memory elements are expected to be the local and global optimum. In this work, the switch probability (between global and local pollination) was 0,25, the population size was fixed in 50 individuals and the number of iterations (stopping criterion) was 500. These are the same parameters proposed by Gálvez et al. (2017). In fact, we are using the same set of parameters presented in the original algorithm, since a desirable property of any metaheuristic is the ability to deal with different problems without costly and difficult parametrization procedures.

Results and Discussions

Azeotrope Calculation

The azeotropic coordinates for the system HFC4130mee (1) + THF (2) at 35 kPa are $(x_1, T) = (0, 0924, 309, 45)$ (Azeotrope 1) and $(x_2, T) = (0, 255, 309, 57)$ (with T in Kelvin), as reported by Guedes, Moura Neto, and Platt (2015). As previously described as detailed by several authors (Segura et al., 2005; Guedes et al., 2015), two azeotropes appear at this pressure. We observed that the values for the azeotropic temperatures are extremely close, which can be a challenge for the algorithm.

The contour curves of the fitness functions for Formulation 1 and Formulation 2 are presented in Figures 1 and 2, respectively. Clearly, one can note visible differences between the shapes of the contour curves related to the different formulations (even considering that the solutions are the same). We investigated the effect of these differences in the robustness of the methodology used to determine the azeotropic coordinates.

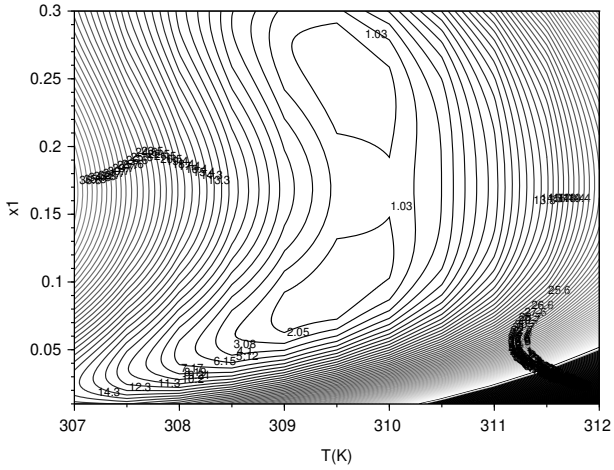

Figure 1. Contour curves for the azeotropy problem (Formulation 1).
Source: Authors

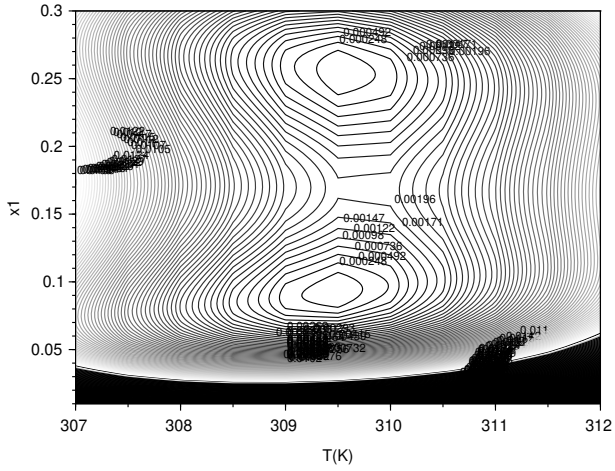

Figure 2. Contour curves for the azeotropy problem (Formulation 2).
Source: Authors

The algorithm was run 100 times for both formulations, in order to evaluate the performance of the computational framework, i.e., the capability to obtain, in a robust way, the exact number of solutions for each problem. A "run" is a typical execution of the MFPA, using random initial guesses. We noted that Formulation 1 found a larger number of roots when compared with Formulation 2. Since the problem exhibits only two solutions (roots), this behavior must be investigated. Figure 3 contains a graphical vision of a matrix containing the roots identified in each run, for both formulations. We observed that the algorithm identified (using Formulation 1, marked as blue points), in some occasions, more than two roots (up to five, in fact; an undesirable characteristic of the algorithm, related to the memory of the framework). On the other hand, using Formulation 2 (again in Figure 3, but now using black points) the algorithm found more than two solutions only in one run. But, in some runs, only one solution was identified, as indicated by the line corresponding to the second solution in Figure 3. This means that the algorithm "fails" to obtain all the solutions. The high fitness values for solutions (or roots) 3, 4 and 5 (typically non-physical solutions of the problem) indicate some kind of 'trash' in the memory of the algorithm (even using the memory depuration procedure), since we must obtain fitness values close to zero in the azeotropy problem.

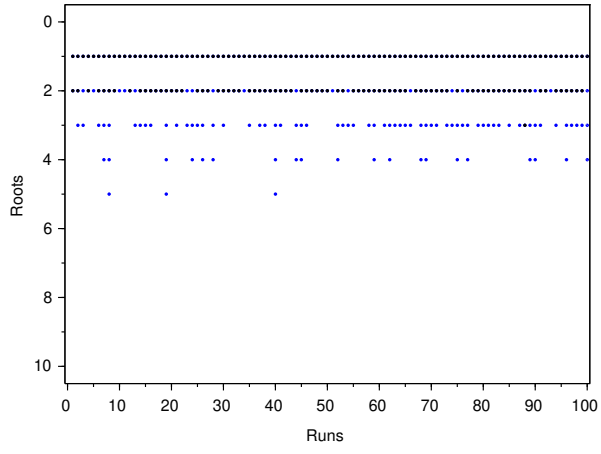

Figure 3. Matrix of roots found after 100 runs – azeotropy problem.
Source: Authors

Considering this complex situation — one formulation finds more than two solutions, while the another one identifies less than two solutions — we used a tailor-made inefficiency index (ineff), defined as follows: ineff = (number of roots found) - (number of feasible roots found). For instance, if the algorithm found four roots and only one root corresponds to a physical one, the inefficiency is ineff = 4 – 1 = 3. On the other hand, if the program identifies 2 solutions and both are physical solutions, the index is ineff = 2 – 2 = 0. Figure 4 compares the inefficiency indexes for Formulations 1 and 2. An analysis of the figure appears to indicate that Formulation 2 is more efficient when compared to Formulation 1, but some statistical analysis is necessary.

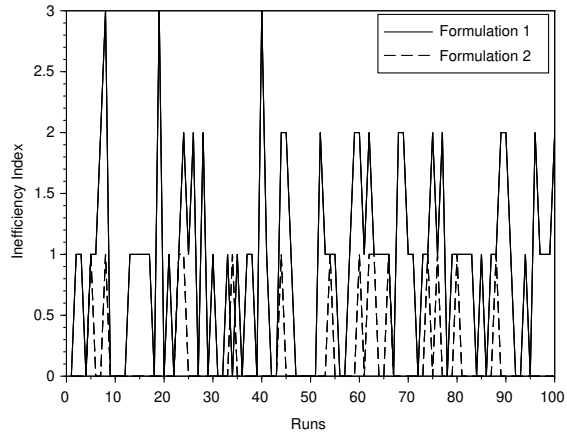

Figure 4. Inefficiency index for the azeotropy problem.
Source: Authors

Statistical Analysis

Formulations 1 and 2 were statistically compared with respect to the inefficiency at obtaining both solutions. A normality test was used to evaluate the distribution. A qualitative overview of the data can be performed by evaluating the categorized histogram (Figure 5). As observed, the data seems to be very far from normal distribution. This is supported by the Shapiro-Wilk parametric hypothesis test (Platt et al., 2019), where the p-Values obtained for samples of Formulation 1 and Formulation 2 were both below the alpha risk of 5% ($< 1 \times 10^{-5}$).

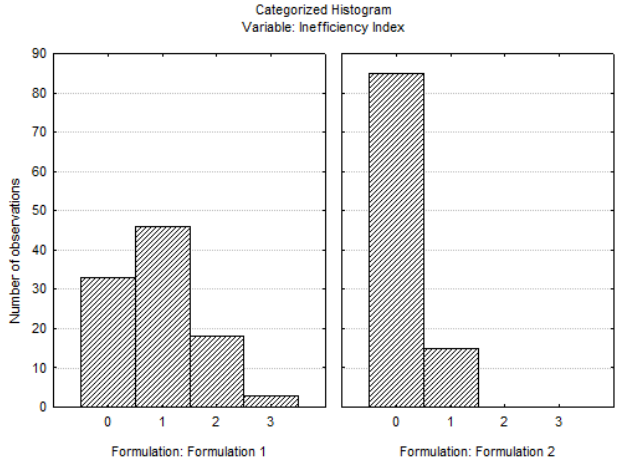

Figure 5. Categorized histogram of the inefficiency index.
Source: Authors

As the normality hypothesis does not apply, and the objective is to compare independent results, a nonparametric test for unpaired data is applicable. The Mann-Whitney U test was used to verify if is there a shift or significant differences between the two samples (Platt et al., 2019). The p-Value found for Formulation 1 versus Formulation 2 is $1,36 \times 10^{-14}$. Thus, significant differences were found between the two populations.

In order to verify how different they are, the confidence interval was evaluated. As presented in the box plot in Figure 6, Formulation 2 presents a lower inefficiency index value and more confined variability, meaning that Formulation 2 presents a better performance than Formulation 1.

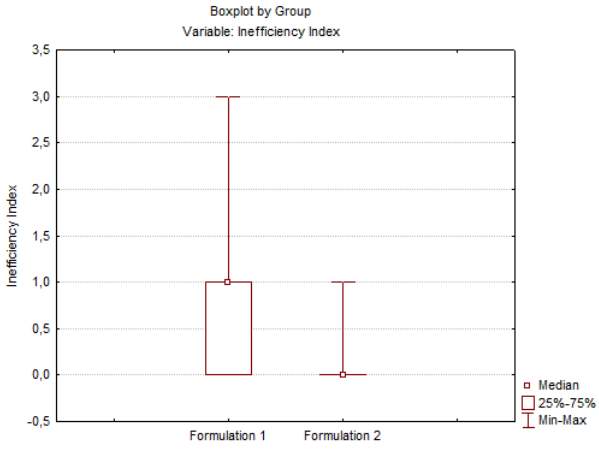

Figure 6. Boxplot of the inefficiency index by formulation.
Source: Authors

Parameter Estimation

The search is conducted in the interval $[-1000, 1000]$ for both parameters (in fact, the search for binary interaction parameters for activity coefficient models is considered an unconstrained problem). The global minimum for this problem is $\theta_1 = 426,24$ and $\theta_2 = 128,52$ (obviously, this solution is different to that presented by Mali et al., 2017, since they used different objective functions). Only one minimum is found in this problem. In spite of this, we tested the multimodal algorithm, since in many real-world problems we do not previously know the number of minima/roots for each problem. Using the same procedure described above, the algorithm was executed 100 times, in order to evaluate the capability to obtain the expected solution in a robust manner.

Figure 7 contains the matrix of identified roots in 100 runs. Again, we confirm that the memory is contaminated in some runs with repeated solutions and/or not converged points. An outlier was found in the 27th run, with 17 roots stored in the memory (this kind of anomalous situation is common in stochastic algorithms). On the other hand, the solution of the problem was accurately identified in all runs, indicating that the computational framework was capable to obtain the minimum of the problem satisfactorily.

Finally, Figure 8 depicts the vapor-liquid equilibrium diagram at 96.15 kPa for the system acetic acid (1) + anisole (2). It is noted that the bubble and dew point curves produced with the estimated parameters show a good agreement with the experimental data published by Mali et al. (2017). Furthermore, a minimum boiling azeotrope close to the pure acetic acid can be predicted.

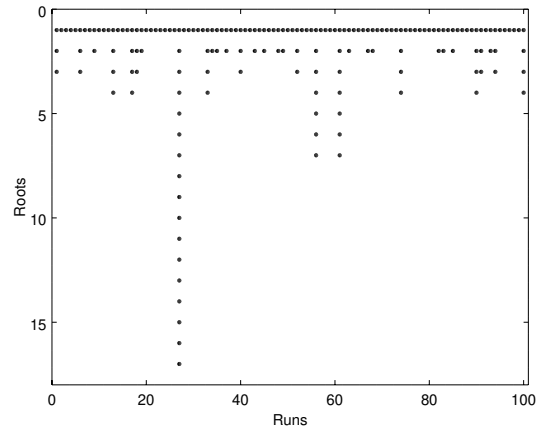

Figure 7. Matrix of roots found in 100 runs – Parameter estimation problem.
Source: Authors

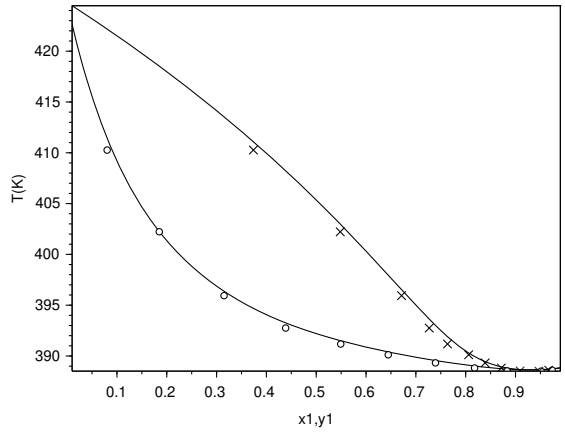

Figure 8. Phase equilibrium diagram for the system acetic acid (1) + anisole (2) at 96,15 kPa. Experimental points published by Mali et al. (2017) are represented by "○" (liquid phase) and "×" (vapor phase)
Source: Authors

Conclusions

In this work, we tested a recently proposed strategy for multimodal problems — the Multimodal Flower Pollination Algorithm (MFPA) — in two chemical engineering problems: the calculation of a double azeotrope and the parameter estimation of a thermodynamic model.

Furthermore, we formulated the azeotropy calculation problem using two approaches. The MFPA algorithm was executed 100 times for each problem formulation. The results indicated a statistical difference between the two formulations employed in the double azeotropy problem, favoring the strategy proposed by Bonilla-Petriciolet et al. (2009). In the parameter estimation problem, the algorithm identified repeated solutions, but was capable to find the minimum in all runs.

Finally, the computational results indicated that MFPA is a useful tool in real engineering optimization problems with multiple solutions.

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Production and Characterization of Activated Carbon From Coal for Gold Adsorption in Cyanide Solutions

Producción y caracterización de carbón activado a partir de carbón mineral para la adsorción de oro en soluciones cianuradas

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ABSTRACT

In this work, activated carbons were produced using coal as raw matter from seven Colombian carboniferous zones. Physical activation was performed in two stages: a carbonization stage with Nitrogen at a temperature of 850 °C and a residence time of 2 h, followed by an activation stage using steam at temperatures of 700 and 850 °C with residence times of 1,5 h and 2,5 h. From the pore volume characterization for the adsorption of gold, two activated carbons from Cundinamarca, obtained at 850 °C (1,5 h), 850 °C (2,5 h), and a commercial carbon (GRC 22) were selected. Gold adsorption tests were performed with those three activated carbons using synthetic aurocyanide solutions and a gold waste solution. The data of the adsorption isotherms were adjusted using the Freundlich adsorption model for the synthetic solution, as well as Langmuir for the waste solution. The results showed that, using a solution of 1 ppm, the activated carbons C-850-2.5 and C-850-1.5 produced the higher maximum gold loading capacities in the equilibrium (8,7 and 9,3 mg Au/g, respectively) in comparison to the commercial activated carbon (4,7 mg Au/g). Gold adsorption test using a waste solution (21 ppm of gold) showed that the activated carbon C-850-1.5 had the highest value of adsorption capacity (4,58 mg Au/g) compared to C-850-2.5 (2,95 mg Au/g).

Keywords: activated carbon, gold adsorption, microporosity, coal valorization

RESUMEN

En este trabajo se produjeron carbones activados utilizando carbón mineral como materia prima procedente de siete zonas carboníferas colombianas. La activación física se efectuó en dos etapas: una etapa de carbonización con Nitrógeno, a una temperatura de 850 °C y un tiempo de residencia de 2 h, seguida de una segunda etapa de activación, usando vapor de agua, a temperaturas de 700 y 850 °C con tiempos de residencia de 1,5 h y 2,5 h. De acuerdo con la caracterización de volúmenes de poros para la adsorción de oro, se seleccionaron dos carbonos activados del departamento de Cundinamarca, obtenidos a 850 °C (1,5 h), 850 °C (2,5 h) y un carbón activado comercial (GRC 22). Se realizaron pruebas de adsorción de oro con esos tres carbonos activados usando soluciones aurocianuradas sintéticas y una solución residual de oro. Los datos de las isotermas de adsorción se ajustaron usando el modelo de adsorción de Freundlich para la solución sintética, así como Langmuir para la solución residual. Los resultados mostraron que, usando una solución de 1 ppm, los carbonos activados C-850-2.5 y C-850-1.5 produjeron las mayores capacidades de carga de oro en el equilibrio (8,7 y 9,3 mg Au/g respectivamente) en comparación con el carbón activado comercial (4,7 mg Au/g). La prueba de adsorción de oro con la solución residual (21 ppm de oro) mostró que el carbón activado C-850-1.5 presentó el mayor valor de capacidad de adsorción (4,58 mg Au/g)) en comparación con el carbón activado C-850-2.5 (2,95 mg Au/g).

Palabras clave: carbón activado, adsorción de oro, microporosidad, valorización de carbón

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Introduction

In Colombia, South America, gold extraction, on the small and medium scales, is carried out through the Merril-Crawe process, which consists of the lixiviation of the gold mineral, using sodium cyanide solutions as solvents and zinc for further precipitation. During this process, cyanide water is produced, and both low gold selectivity and sensitivity to oxygen occurs. Adsorption-desorption with activated carbon is an alternative to the Merril-Crawe process due to its higher selectivity for gold (Sheya and Palmer, 1989). Moreover, this process eliminates further clarification and filtration due to the addition of carbon particles directly to the cyanidation pulp. Gold loss during the adsorption-desorption process is also significantly lower than that of the Merril-Crawe process, thus offering economic advantages for both major gold recovery as well as lower comparative capital and operation costs (Navarro and Wilkomirsky, 1999).

However, in Colombia, coal is extracted mainly for exportation. In 2011, only 7,61% of the extracted coal was used internally for coke production and energy generation (Ministerio de Minas y Energia, 2012). For the above, Colombian coal valorization constitutes an alternative to strengthening and promoting technological development within the Colombian carboniferous zones.

Activated carbon is a material formed by a carbon structure and a minimal concentration of other atoms such as oxygen or hydrogen. Activated carbons can be produced from diverse materials such as coconut shell, rice husks, and coal (Yahya, Al-Qodah, and Ngah, 2015). The porous structure of activated carbons is the most important physical property, and its final use depends on pore distribution (Uribe, López and Gonzáles, 2013). To produce properly activated carbon for gold adsorption, it is necessary to understand the mechanism of the aurocyanide ion attached to the carbon surface. There is no general agreement regarding this mechanism. The gold adsorption process is dominated by kinetics, not by an equilibrium constant. Moreover, it is dominated specifically by gold diffusion from the external surface to the inner surface of the activated carbon particles. (Seke, Sandenbergh, and Vegter, 2000). Diffusion through micropore structures is slow. Thus, gold reaches these spaces only at the equilibrium phase, which occurs after a long-time lapse in a carbon in pulp (CIP) plant (Pleysier, Dai, Wingate, and Jeffrey, 2008).

McDougall, Hanckock, Nicol, Wellington, and Copperthwaite (1980) proposed the most accepted mechanism of gold adsorption. It involves adsorption of an ionic pair Mn+ Au(CN)x, where Mn+ is a metallic ion. Then, there is a reduction stage, with the formation of type-species Au(CN)x on the carbon surface. This mechanism describes the aurocyanide ion adsorption without any chemical transformation. Although this mechanism is the same for acid and basic pH, gold adsorption, in terms of adsorption rate, is higher for alkaline pH, and its equilibrium constant is larger for acid pH. With low pH (< 3), gold is present in the form of aurocyanide acid, and at intermediate pH, the ionic pair and aurocyanide acid are observed simultaneously (Adams, 1989; Fleming, 1984). The ionic pair is adsorbed preferably on hydrophobic sites formed by carbon bonds overactive sites of superficial groups with oxygen or nitrogen (Jia, Steele, Hayward, and Thomas, 1998).

Aurocyanide complexes adsorb to imperfections on graphite or graphene layers, whereby physical activation results are more convenient due to the formation of carbon structures that are more disordered than the carbon structures produced by chemical activation. Aurocyanide ion adsorption occurs irreversibly through the electrostatic interaction of Au $(CN)^{2-}$ on the active polar sites of activated carbon, but the ionic pair $KAu(CN)_2$occupies fewer active sites through Van der Waals forces (Yin et al., 2014).

To use coal as raw matter to produce activated carbon suitable for the gold adsorption process, the activated carbon must be produced using a physical activation that would provide it with a major number of hydrophobic sites related to the aurocyanide ionic pair (Jia et al., 1998). The superficial area should be from 600 to 900 m^2/g and they must have high porosity (Navarro and Vargas, 2010; Pleysier et al., 2008; Seke et al., 2000; Yalcin and Arol, 2002). Porosity distribution depends on coal rank due to its relationship with volatile matter and fixed carbon ratio. Thus, bituminous and sub-bituminous coal could have adequate fluidity for mesopore and micropore formation during the carbonization stage (Marsh and Rodríguez-Reinoso, 2006).

In this work, activated carbons were produced from seven Colombian coals for gold adsorption in cyanide solutions. Different morphologies of the activated carbons produced from the used coals were obtained. Proximate analysis of original coals and activated carbons was performed as well as an evaluation of the effect of the temperature and residence time during the activation stage. Mass yield, IN, and the surface area of the activated carbons were determined. Testing of our activated carbons and a commercial source using artificial and waste gold solutions was performed. Adsorption isotherms were adjusted using the Freundlich adsorption model for artificial solutions and linearized Langmuir plots were used for gold waste solutions.

Experimental section

Materials and methods

Bituminous and sub-bituminous coals from seven departments of Colombia (Antioquia (A), Boyacá (B), Cundinamarca (C), Guajira (G), Norte de Santander (N), Santander (S) and Valle del Cauca (V)) were used in this work. The coals were characterized by proximate and ultimate analyses according to ASTM standards (ASTM, 1958). The samples were crushed to particle size (< 250 μm) using a disk mill.

Activated carbons were produced in two stages. During the first one, carbonization was carried out to decrease the volatile matter content using an atmosphere of N_2, with a flow of 0,65 L/min, a temperature of 850 °C, a residence time of 2 h, and a heating rate of 10 °C/min. In the second stage, steam was used as the activating agent with a flow of 0,275 L/min. A

factorial design of 2^2 for each coal was used, with two levels of temperature (700 °C and 850 °C) and with residence times of 1,5 h and 2,5 h. Those operating temperature conditions were selected according to preliminary tests and literature review about activated carbons using Colombian coals as precursors (Benabithe et al., 2005; Navarro and Vargas, 2010; Uribe et al., 2013). Central points with duplicates were used for error estimation.

Proximate analysis was performed on activated carbons for determination of moisture, volatile matter, ash, and fixed carbon. Iodine number was used as an indicator of micropore content. Activated carbons with both the highest and lowest micropore content were selected to evaluate the effect of the micropore content on gold adsorption (Yalcin and Arol, 2002).

The characterization of activated carbons also included the determination of surface area, the mean pore size and the micropore content using ASAP 2020 Micromeritics equipment. The micropore volume was determined by the software in the summary report as a t-plot micropore area. We used the gas adsorption isotherm of N_2 at 77 K on the sample, and then performed pore size distribution analysis with the ASAP 2020 V4.01 (V4.02 E) software already installed on the instrument. The instrument was programmed to start from P/Po ~ 1e-5 and collect a large number of data points (~ 80-90) up to P/Po=1. Thus, pore size distribution could be calculated for pores from ~ 1 nm large.

The morphology of the carbons was determined by scanning electron microscopy (SEM) with JSM-6490 SEM JEOL Ltd. equipment.

Gold adsorption tests were carried out using both artificial and real gold cyanide solutions. Solutions of 5, 10, 15, 25, 35, 50 and 100 ppm Au (11,6 < pH < 11,9) were used for the artificial tests. A weight of 1 g ±1 mg of each activated carbon was added to a 50 mL solution, which was kept under constant agitation at 190 rpm for 8 h. A waste gold solution of 21 ppm Au, from Buenos Aires gold mine, in Cauca, Colombia, was used as a real cyanide solution. The gold equilibrium concentration in the remaining solution was measured by atomic absorption spectrometry. Gold load, X/M (mg Au/g), was determined by the difference between the initial and final gold concentrations. The gold load versus the equilibrium gold concentration in solution C (ppm) was adjusted to the Freundlich isotherm in order to establish the adsorption constant at equilibrium K which corresponds to the maximum gold load for these conditions. The least squares fit method was used to adjust the data.

Results and discussion

Original coal characterization

Original coals were characterized by proximate and ultimate analyses, and the results are presented in Table 1. Coal rank was obtained according to ASTM D 388-19a (2019), where Fixed Carbon (FC) and Volatile Matter (VM) are on a dry mineral matter free -basis.

Volatile matter and fixed carbon content are indicators of both carbonization degree and porosity development because, during the carbonization stage, the porosity of char is formed through the release of volatile matter. Additionally, during the activation stage, steam consumes fixed carbon from the charcoal pore walls, widening them. In this process, the limiting stage is represented by the steam adsorption onto a solid surface, which makes the distribution of fixed carbon and volatile matter determine the production of the activated carbons. (Uribe et al., 2013). For the above, the coals G and A would probably produce high surface areas. Ash content does not contribute to the development of porosity, but ash content does affect adsorption properties, as it creates inactive sites.

Some authors such as Adams, McDougall, and Hanavecock, (1987), Ibrado and Fuerstenau (1992), and Lagerge, Zajac, Partyka, and Groszek, (1999) showed that some elements such as C, H, and O affect the adsorption process. Carbon content influences gold adsorption due to its relationship with C-C bonds, which corresponds to graphite layers, where the aurocyanide ionic pair is preferentially adsorbed. Oxygen content is related to a higher reactivity: surface compounds containing oxygen are consumed more easily at high temperatures, generating spaces into the structure that allow the entrance of activating agents to consume fixed carbon, thus widening the pores (Gentzis, Hirosue, and Sakaki, 1996). According to the above, activated carbons produced from A and G coal, theoretically, may produce a higher content of macropores. In addition, H content is associated with volatile matter release (Gentzis et al., 1996; Niksa, 1995). Therefore, devolatilization capacity should be similar in all the original coals used.

Table 1 presents the rank of original coals used. In general, coals are in the rank of bituminous and sub-bituminous, with differences in volatile matter content. In terms of the fluidity of the carbon matrix at high temperatures, those ranks are similar (Marsh and Rodríguez-Reinoso, 2006). According to ASTM D388-19a (2019), the bituminous, highly volatile C coals may cause agglomeration between particles during activated carbon production.

Table 1. Proximate, ultimate analyses and rank of the original coals

	% w/w, dry basis (db)				% w/w, dry basis (db)				
Coal	FC	VM	Ash	C	H	N	O	S	Rank*
N	61,23	34,19	4,58	80,58	5,50	1,57	7,18	0,65	BHVA
C	54,48	41,27	4,25	78,62	5,80	1,68	9,21	0,61	BHVB
S	45,95	41,79	12,26	67,03	5,45	1,52	6,70	7,34	BHVC
B	45,01	36,89	18,10	66,87	5,21	1,57	7,85	0,76	BHVC
A	44,10	45,35	10,55	62,02	5,57	1,40	20,88	0,45	BHVC
G	41,53	30,50	27,97	52,80	4,42	1,14	13,76	1,36	SBB
V	34,93	36,56	28,51	56,64	4,99	1,06	7,93	1,21	SBB

BHVA, Bituminous, high volatile A; BHVB, Bituminous, high volatile B; BHVC, Bituminous, high volatile C; SBB, Sub-bituminous, B

Source: Authors

Morphology of activated carbons

Figure 1 shows the different morphologies of activated carbons produced from the used coals. There are two types of agglomeration: (1) agglomerated from coals B, V, S and N, and (2) non-agglomerated activated carbons from coals A, C and G.

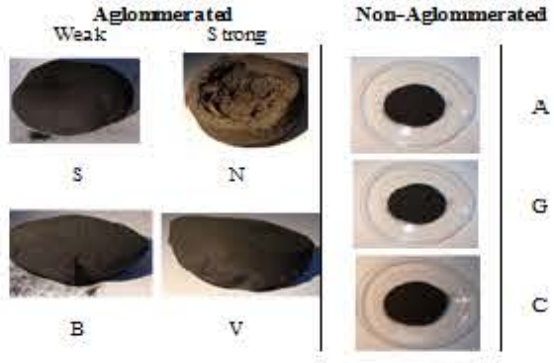

Figure 1. Morphologies of agglomerated and non-agglomerated activated carbons.
Source: Authors

Non-aglommerated morphology could be due to the low swelling index, whereas aglommerated coals have a medium and high swelling index. Activated carbons from coals B and C present a weak agglomeration, whereas V and N present a strong agglomeration. The NS coal formed activated carbons with concave shells of high volume that were melted during the process. Those different agglomerations affect the porosity and surface area, which affects gold adsorption.

Proximate analysis of activated carbons

Proximate analysis of the activated carbons is presented in Figure 2. Some differences in the properties of activated carbons were presented when they were obtained under different temperature and residence time conditions. In general, for all activated carbons, volatile matter showed a lower concentration compared to the original coals. Values of less than 10% were obtained for volatile matter, indicating that the devolatilization process was effective. This result is related to the content of hydrogen that, for all the original coals used, does not vary by more than 1%.

In general, for all the operating conditions, the coals N and C produced activated carbons with the highest fixed carbon and lowest ash contents. Those properties are followed by activated carbons from coals S, B, A, G and V.

In general, for all activated carbons, the ash content increased with temperature. This behavior is related to the increased release of volatile matter and the increased consumption of fixed carbon. The highest values of ash were displayed by the activated carbons V and G at a temperature of 850 °C. Those results matched the ash content of the original coals.

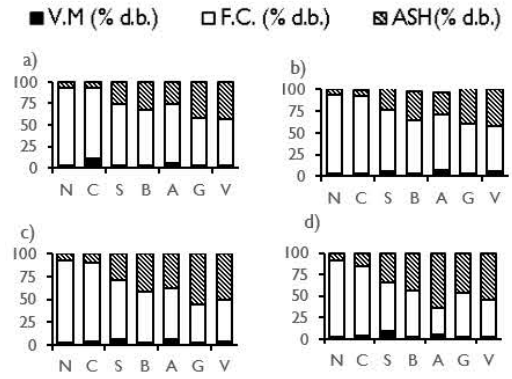

Figure 2. Proximate analysis of activated carbons from coals: a) 700 °C, 1,5 h; b) 700 °C, 2,5 h; c) 850 °C, 1,5 h; d) 850 °C, 2,5 h.
Source: Authors

Mass yield of activated carbon

Figure 3 shows the mass yield (Y, %, dry basis mineral matter-free, dbmmf) of the activated carbons obtained as a function of activation temperature and residence time. For both residence times, mass yield decreased as temperature increased. Mass yield values were approximately between 12% and 65%. Activated carbon N presented the highest mass yield at a temperature of 700 °C and at both residence times, whereas the activated carbon A presented the lowest yields under all the operating conditions. As mentioned above, coal A presented the highest O content, and its functional groups on the surface probably reacted more quickly to the activating agent, allowing greater weight loss associated with the consumption of fixed carbon. Those results agree with Ibrado and Fuerstenau (1992).

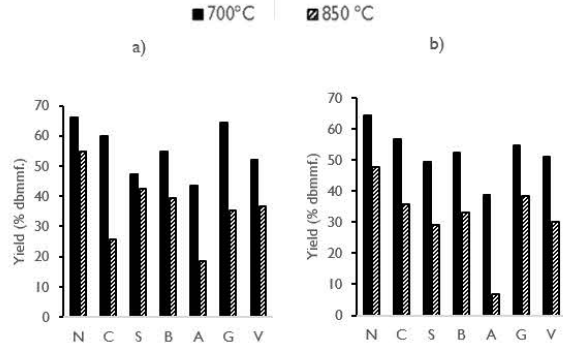

Figure 3. Mass yield of activated carbons from coals: a) 1,5 h; b) 2,5 h.
Source: Authors

A statistical analysis was carried out to evaluate the influence of the coal-type factor, the residence time and the temperature of the activation stage on the response variable mass yield. Table 2 shows the data obtained from the ANOVA for the mass yield. Although residence time was significant within the studied range, temperature was the most important variable in the process. In addition, the interaction between the temperature and the type of coal was significant, although much less important in magnitude than temperature.

Table 2. ANOVA for mass yield

Source	D.F.	F	P-value
Temperature, °C	1	171,6	0,000
Residence time, h	1	7,06	0,014
Region	6	38,83	0,000
T [°C] * Region	6	2,70	0,038
Error	24		

D.F., Degree of Freedom, F, Calculated F for F-test. P-Value, Probability value.

Source: Authors

In Figure 4, the main effects of fixed carbon and ash content on the mass yield are shown. It increased with fixed carbon content related to coal rank. Coals of high rank have low reactivity. According to the above, the highest yield was obtained for the N activated carbon.

Regarding the ash content of the activated carbons, the mass yield decreased with the increase in ash content, which can be related to an inhibiting effect caused by ash on the carbon surface, preventing steam from going through the initial pores of the charcoal. However, the ash content effect is minimal compared to the fixed carbon and temperature effect (Linares-Solano, Martín-Gullon, Salinas-Martínez De Lecea, and Serrano-Talavera, 2000).

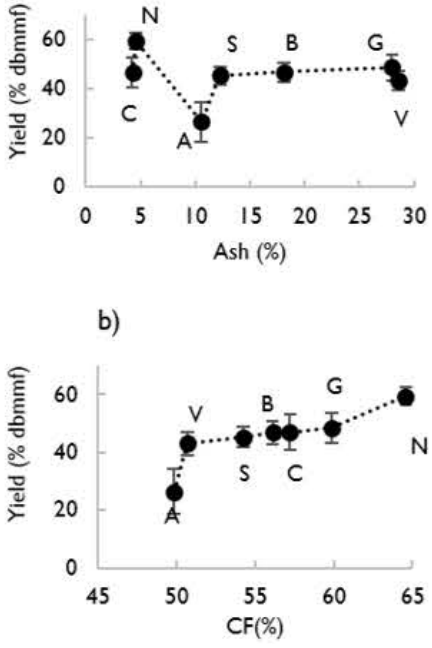

Figure 4. Main effects of ash and CF on yield (% dbmmf) as a response variable.
Source: Authors

Iodine Number (IN) of activated carbons

Figure 5 shows the IN of the activated carbons obtained under all the operating conditions. Those values of IN were in rank 40, with 910 mg I_2/g.

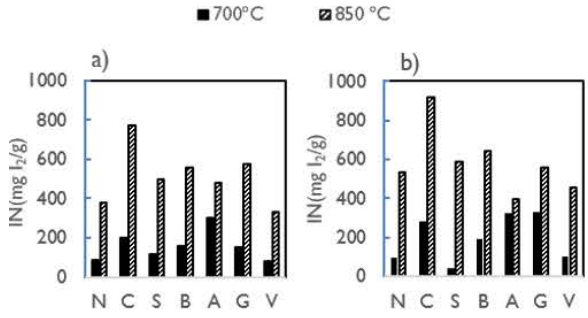

Figure 5. IN of activated carbons from original coals at temperatures of 700 and 850 °C. a) 1,5 h; b) 2,5 h.
Source: Authors

The IN figures obtained with our prepared activated carbons are in the range of values when compared to the Yalcin and Arol range of 466-440 mg I_2/g (2002). They used helzenut shells, apricot stones, and peach stones as precursors, with steam as an activator agent, and temperatures between 800-900 °C. When it is compared to commercial activated carbons, (836 mg I_2/g), produced by CECA company (Soleimani and Kaghazchi, 2008), The IN figure also fallas within the range of our activated carbons.

In general, for all the activated carbons and residence times, IN increased with the increase in activation temperature. Kiel, Sahaglan, and Sundstrom (1975) concluded that, by increasing the activation temperatures, the kinetics of reactions between the fixed carbon and steam also increased. CO and H_2 molecules produced as intermediate products during the activation process usually blocked the entrance to the inner initial porosity in the charcoal, causing an impediment for steam to react with fixed carbon on the pore surface. At higher temperatures, both molecules were consumed faster, allowing the charcoal surface to react with the steam (Uribe et al., 2013).

The two highest IN values (919 y 773 mg I_2/g) were produced with C coal at 850 °C. Even though N coal had similar characteristics, the maximum iodine number was 535 mg I_2/g. These differences in IN values are possibly related to the elastic properties of coal (Greenbank, M., and Spotts, S., 1993; Marsh and Rodríguez-Reinoso, 2006). As Figure 1 shows, activated carbon N had fused particles while C carbons did not form any kind of agglomerate. The lowest IN values were obtained with V coal, which had the highest ash content and lowest fixed carbon content.

Theoretically, all activated carbons produced from bituminous high volatile C coals (B, C, and A) should have similar characteristics. However, differences in O content (20,88%) for A coal could explain the differences observed in IN values. According to Gentzis et al. (1996), oxygen content is related to the presence of vitrinite maceral. Vitrinite is more easily broken at high temperatures, generating a porous matrix. Therefore, for the activated carbons, micropores can be formed at 700 °C but, when the temperature increases, steam is consumed by the inner fixed carbon, transforming micropores into meso- and macropores, thus generating a

lower IN. For sub-bituminous B rank, a behavior similar to bituminous high volatile C was observed. Oxygen content of G activated carbon (13.76%) was almost twice the oxygen content of V (7,93%). Therefore, during the activation process, those oxygen surface groups were consumed faster, creating wider pores for the G activated carbon.

Table 3 shows the ANOVA for IN of the activated carbons. The activation temperature was the most important factor, followed by region (coal), residence time, and the interaction between temperature and region.

Table 3. ANOVA for IN of the activated carbons

Fuente	D.F.	F	P-value
Temperature, °C	1	235,19	0,000
Time, h	1	5,08	0,034
Region	6	20,55	0,000
T [°C] * Region	6	4,94	0,002
Error	24		

Source: Authors

In Figure 6, the main effects of fixed carbon and ash content are shown. According to Kiel et al. (1975) and Uribe et al. (2013), the nature of the global reaction is endothermic, making kinetics increase with temperature. However, fixed carbon had a positive effect (from 49% to 57%). Then, a decreasing iodine number was observed. The initial positive effect may be related to fixed carbon disponibility and reactivity; sub-bituminous coal (lowest fixed carbon content) had a larger probability of allowing steam to react with the inner walls of each pore, widening them and producing lower iodine numbers. A coal developed more micropores than V, S, and B coals. This could be related to the barrier effect of ash, which inhibits fixed carbon-steam contact. The negative behavior corresponds to activated carbons when the fixed carbon content is approximately 66%, and according to Gentzis et al. (1996), higher rank coal corresponds to lower reactivity and elasticity.

Surface area of the activated carbon

The surface area of the selected activated carbons, according to the highest iodine number, was determined to compare the influence of microporosity on gold adsorption. Additionally, an activated carbon GRC 22, particle-size (6 x 12) Tyler mesh from Calgon Carbon industry, was characterized to compare it with the produced activated carbons. The BET area, micropore area, micropore percentage, pore size and pore volume results for the selected activated carbons are shown in Table 4.

According to Navarro and Vargas (2010), pore volume is high when it is higher than 0,2 cm^3/g, with a surface area between 400 and 1500 m^2/g. Therefore, only the activated carbons with the highest IN can be considered commercial-grade. A decrease in the surface area with increasing micropore percentage was observed. Except for the activated carbons B-850-2,5 and S-850-2,5, the activated carbons had the same

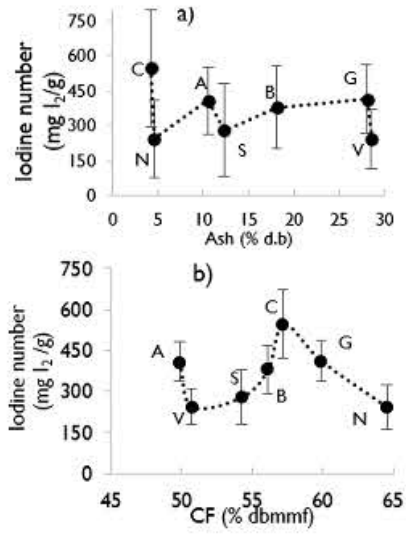

Figure 6. Main affects of ash and fixed carbon content on IN.
Source: Authors

Table 4. Surface area of activated carbons and GRC 22 (6 x 12)

Activated Carbon	BET Area (m^2/g)	Micropore Area (m^2/g)	Micropore Percentage (%)	Pore Size (Å)	Pore Volume (cm^3/g)
C-850-2.5*	773,2	369,2	47,7	36,5	0,7058
C-850-1.5	588,9	328,4	55,8	29,0	0,4265
B-850-2.5	474,9	339,3	71,5	19,9	0,2360
S-850-2.5	507,0	362,5	71,5	21,6	0,2737
G-850-1.5	427,1	363,2	85,0	20,4	0,2177
GRC 22 6 x 12	880,2	654,0	74,3	21,5	0,4735

Source: Authors

proportion of micropores, and the differences in the surface area were low.

For the activated carbons C-850-2.5 and C-850-1.5, the micropore percentage was close to 50%, which suggests that surface area is composed by larger pores such as macro- and mesopores, since pores in the external surface are formed before inner pores and, thus, they are exposed to steam for a longer time. This pore distribution could give an aurocyanide ion easier diffusion from the external to the internal area. The commercial activated carbon GRC 22 (6x12) presented a larger surface area compared to the activated carbons produced in this work, and a micropore percentage of approximately 70%.

In agreement with Navarro, Vargas, and Aguayo (2009) and Seke et al. (2000), the appropriate pore volume for gold adsorption should be larger than 0,4 cm^3/g. Using this criterion, only activated carbons C-850-2.5, C-850-1.5 and the commercial GRC 22 would be useful for this application. Therefore, gold adsorption tests with both real and artificial aurocyanide solutions were performed with those activated carbons.

Gold adsorption using artificial solutions

Figure 7 shows the adsorption isotherms for the activated carbons GRC 22, C-850-1.5 and C-850-2.5. According to Ho (2004), the isotherms are generally type II. Increasing gold concentrations in the initial solutions causes high gold adsorption in the activated carbons. However, it is difficult to find solutions with higher concentrations in industrial applications, where anything higher than 100 ppm is not applicable (Fleming, Mezei, Bourricaudy, Canizares, and Ashbury, 2011). The adsorption isotherm curves corresponding to the GRC22 activated carbon are under the other curves obtained for activated carbons C-850-2.5 and C-850-1.5, which means that our prepared activated carbons presented a higher gold adsorption compared with the commercial activated carbon used for this application.

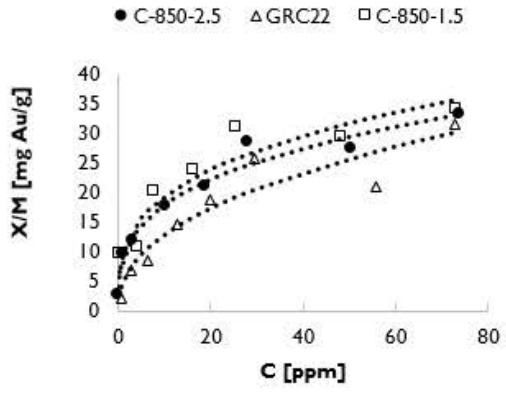

Figure 7. Adsorption isotherm for activated carbons GRC 22, C-850-1.5 and C-850-2.5.
Source: Authors

The data of the adsorption isotherms were adjusted using the Freundlich adsorption model, represented by Equation (1):

$$X/M = KC^{1/n} \quad (1)$$

where C is the concentration of gold at equilibrium, X is the mass of gold loaded in mg, M is the weight of the activated carbons, and K is the constant defined as the maximum load of the gold at equilibrium with the solution at a concentration of 1 ppm. The adjustments were made using the least squares method. Table 5 shows the values of K and n as well as the Pearson adjustment coefficient. The Pearson correlation factor was over 0,9, which means that the data adjusted well to the Freundlich model.

Yalcin and Arol (2002) reported gold equilibrium constants in the range of 23-100 mg Au/g for commercial activated carbons. Table 5 shows that the K value of GRC 22 was low compared to our activated carbons C-850-2.5 and C-850-1.5.

The highest K value (9,35 mg Au/g) was obtained with activated carbon C-850-1.5, even though C-850-2.5 had a larger surface area (773 m^2/g) and IN (919 mg I_2/g). This behavior proves that longer residence times during activation increase the ash concentration and decrease the active sites on the surface of activated carbons (Linares-Solano et al., 2000). According to Table 3, C-850-1.5 presented a higher micropore proportion (55,8%) than C-850-2.5 (47,7%),

Table 5. Adsorption constant at equilibrium according to the Freundlich model

Sample	K (mg Au/g)	n	Pearson Factor
C-850-2.5	8,73	3,2	0,98
C-850-1.5	9,35	3,2	0,95
GRC22	4,74	2,3	0,94

Source: Authors

which confirms that micropores provide the total adsorption capacity. However, the total micropore area for C-850-1.5 was the lowest, suggesting that, during gold adsorption processes, pore distribution is more important than the total micropore area.

In general, the two produced activated carbons with high IN presented higher K values than GRC 22. A larger micropore proportion in GRC 22 and a larger particle size may cause lower gold adsorption, since micropore excess in the external surface can cause lower gold adsorption in the equilibrium with the molecules of the aurocyanide ion adsorbed on the surface. This prevents the diffusion of the molecules towards the interior of the granules of the activated carbon (Gloria J. McDougall and Hancock, 1981; Qada, Allen, and Walker, 2008).

The sorption capacity of the activated carbons toward gold can be seen in Table 6 compared with other carbonaceous materials prepared from different waste and coals

According to the results in Table 8, the maximum gold capacity (mg Au/g) for our prepared activated carbon has similar figures to the capacity displayed by the commercial activated carbons produced by Purogold 5992 and CECA Companies. In addition, since there is a lack of uniformity in the way in which gold maximum capacity tests are carried out, activated carbons evaluated by Yalcin and Arol, (2002) show higher capacity than ours. However, they used a higher concentration of 1000 ppm aurocyanide solution.

Particle size effect

To exclude the particle size effect over K values, additional gold adsorption tests were carried out, using C-850-1.5 and GRC 22 with the same particle size (10 x 16), with an activation temperature of 850 °C and with a residence time of 1,5 h. In Figure 8, gold adsorption isotherms are shown.

The adsorption isotherm for the sample of GRC 22 (10 x 16) was over the isotherm of the activated carbon C-850-1.5, which is contrary to the results obtained using smaller particle size (60 x 120). Table 7 shows the K, n and Pearson correlation values obtained from the two isotherms. A good match between the experimental data and the Freundlich model was obtained.

Gold adsorption using a waste solution

A gold solution from a waste stream produced in Buenos Aires gold mine, in Cauca, Colombia, was used. The

Table 6. Maximum gold load for different activated carbons

Reference	Precursor	Activation	Maximum Capacity (mg Au/g)
(Yalcin and Arol, 2002)*	Hazelnut shells	Steam at 800 °C	62
	Apricot stones	Steam at 900 °C	60
	Peach stones	Steam at 800 °C	73
	Coconut shell	Commercial, G210 from Le Carbone, France	> 100
(Benabithe et al., 2005)	Coal from Antioquia	CO_2 at 800 °C	-
(Soleimani and Kaghazchi, 2008)	Hard Shell Apricot Stones	Chemical	5,56
	Biomass, Used in gold recovery process in Iran	Commercial	5,28
	Biomass, Used in gas phase separation in Iran	Commercial	5,20
	CECA Company	Commercial	6,39
(van Deventer et al., 2014)	Purogold S992	Commercial	2,34

* Aurocyanide concentration of 1000 ppm.

Source: Authors

Table 7. Gold adsorption data for C-850-1.5 and GRC 22, 10 x 16 particle size

Sample	K (mg Au/g)	n	Pearson Factor
GRC 22 10 x 16	4,64	2,4	0,98
C-850-1.5 10 x 16	4,56	2,0	0,98

Source: Author

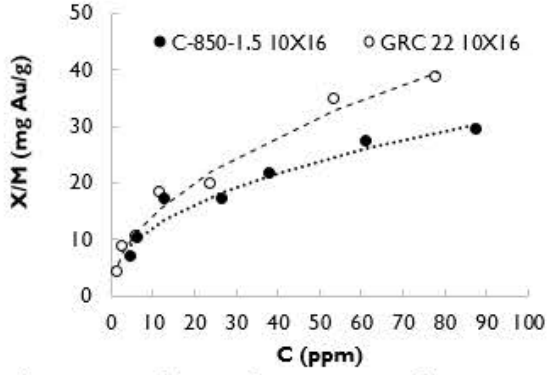

Figure 8. Adsorption isotherms of C-850-1.5 and GRC 22, Particle size 10 x 16.
Source: Authors

composition of the waste solution was 21 ppm Au, 3800 ppm Cu and 3000 ppm CN. Tests were carried out using different activated carbon loadings for the same solution. According to the Adsorption Isotherm Regional Analysis (ARIAN) model described by Abdollahi (2015), isotherms can be divided into four regions, defined by the equilibrium concentration rank. For gold adsorption tests with the waste solution, only regions I and II were identified, since the initial concentration was low. Regions I and II correspond to monolayer formation on the activated carbon.

The linearized form of the Langmuir equation (Equation 2) was used to adjust the values obtained in the adsorption tests with the waste solution:

$$\frac{C_e}{Q_e} = \frac{1}{bQ_0} + \frac{1}{Q_0}C_e \quad (2)$$

where C_e is the concentration of the equilibrium solution (ppm), Q_e is the maximum charge of gold at equilibrium (mg Au/g), and b is the Langmuir constant. To establish the adsorption favorability through the type of isotherm, the dimensionless equilibrium parameter was determined with Equation (3):

$$R_L = \frac{1}{1 + bC_0} \quad (3)$$

where b is the Langmuir constant and C_o is the initial concentration of the solution. The value of R_L indicates the type of isotherm: unfavorable (> 1), linear (= 1), favorable (between 0 and 1), or irreversible (= 0).

Tests were carried out on C-850-1.5 and C-850-2.5, and the corresponding adjustments were made according to the Langmuir isotherm. Carbon C-850-1.5 had the highest value of adsorption capacity, considering that the coal load was the highest among the others. The adjustments to the Langmuir isotherm are shown in Table 8. Moreover, R_L shows that the isotherm is favorable for the process of gold adsorption using activated carbon.

Table 8. Langmuir parameters: linear isotherm with waste solution

Activated Carbon	K	b	Pearson Factor	R_L
C-850-2.5	2,95	2,58	0.9897933	0,018804
C-850-1.5	4,58	1,12	0.9860471	0,044405

Source: Authors

Figure 9 shows that the inverse of the load was high for carbon C-850-1.5, which confirms that the tests carried out with the waste solution are a good indicator of the loading capacity of activated carbons in equilibrium.

SEM analysis of the activated carbons

To establish the differences between the surfaces of the activated carbons, SEM analysis was performed. Three photographs were taken at 100, 10 and 5 μm, which are shown in Figures 10 and 11 for carbon activated samples C-850-1.5 and C-850-2.5, with particle size 60 x 120, as well as for samples C-850-1.5 and GRC 22 (10 x 16).

In general, the activated carbon C-850-1.5 exhibited the most irregular surface and texture in comparison with sample C-850-2.5. High residence time probably generates a larger consumption of carbon walls, thus producing a smaller surface area and a longer distance between the layers, with fewer available spaces for gold adsorption. Therefore, high

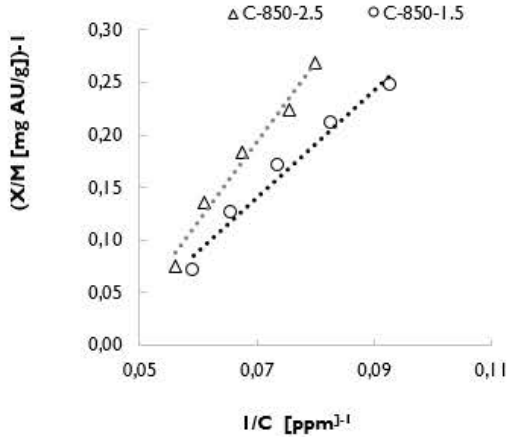

Figure 9. Adsorption isotherms of C-850-1.5 and C-850-2.5.
Source: Authors

residence time during activation has a negative effect on gold adsorption, possibly due to sample C-850-2.5 having more micropores in the inner surface of the activated carbon, whereas sample C-850-1.5 had micropores on the external surface, and the diffusional limitations decreased.

With respect to C-850-1.5 and GRC 22 with a particle size of 10 x16, the first one presented a larger amount of structural irregularity and less pore layer separation than the second one. These findings are in agreement with Pleysier et al. (2008), who showed that gold preferably adsorbs to pore imperfections formed by graphene layers. Then, an external surface formed by micropores may cause external gold saturation for the sample C-850-1.5 x 16 because there is a barrier made by adsorbed ionic pair gold molecules, preventing the gold particles from going through the pores to the inner ones.

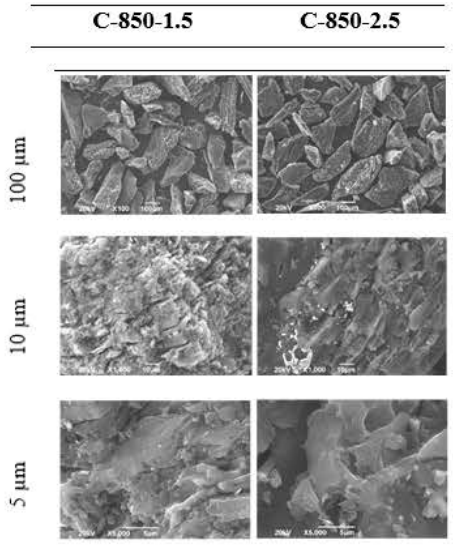

Figure 10. SEM images for C-850-1.5 y C-850-2.5 (particle size: 60 x 120).
Source: Authors

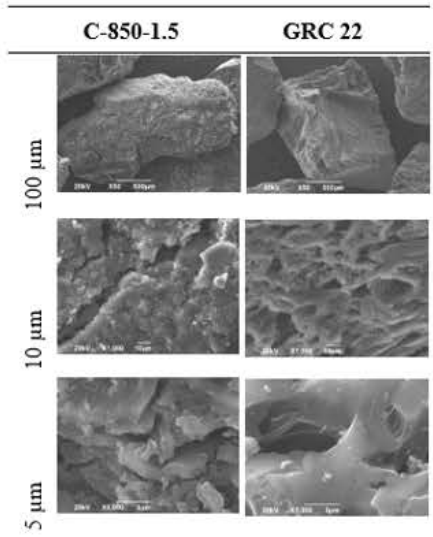

Figure 11. SEM images for C-850-1.5 y GRC 22 (particle size: 10 x 16).
Source: Authors

Conclusions

It was possible to produce activated carbons that could be applied to gold adsorption processes from Colombian coals. Their characteristics are comparable to a commercial activated carbon obtained from biomass. The IN corresponding to the activated carbon C-850-1.5 has the highest adsorption capacity of 775 mg I_2/g. The highest IN iodine is not related to the maximum adsorption capacity, since it was not possible to establish the distribution of porosity from this variable. The most important process variable during the activation, in terms of the IN, was the activation temperature since it directly affected the kinetic constant of the reactions between the carbon surface and the activating agent (steam). The appropriate activation time corresponds to 2 h, whereas the temperature should be 850 °C, since, with those values, both the IN and the yield are maximized. The particle size of the activated carbons has an influence on their adsorption capacity. When comparing C-850-1.5 with commercial GRC 22 at the same particle size, similar K values were obtained for both, indicating that the produced activated carbon has the characteristics of a commercial one used in gold adsorption. The coals, raw material for the production of activated carbons used in cyanide solutions, were adequate since the structure of this material has larger sites derived from imperfections in the graphite plates formed during the carbonization and activation, as compared to the activated carbon produced from biomass.

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SAP Algorithm for Citation Analysis: An improvement to Tree of Science

Algoritmo SAP para análisis de citaciones: una mejora para Tree of Science

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ABSTRACT

Tree of Science (ToS) is a web-based tool which uses the network structure of paper citation to identify relevant literature. ToS shows the information in the form of a tree, where the articles located in the roots are the classics, in the trunk are the structural publications, and leaves are the most current papers. It has been found that some results in the leaves can be separated from the tree. Therefore, an algorithm (SAP) is proposed, in order to improve results in the leaves. Two improvements are presented: articles located in the leaves are from the last five years, and they are connected to root and trunk articles through their citations. This improvement facilitates construction of current literature for researchers.

Keywords: Tree of science, SAP, algorithm, citation analysis

RESUMEN

Tree of Science (ToS) es una herramienta web que usa la estructura de la red de citaciones para identificar literatura relevante. ToS muestra la información en forma de árbol, donde los artículos localizados en las raíces son los clásicos, en el tronco están las publicaciones estructurales y las hojas son los artículos más recientes. Se ha encontrado que algunos resultados de las hojas pueden ser separados del tema del árbol. Por lo tanto, se propone el algoritmo SAP para mejorar los resultados de las hojas. Se presentan dos mejoras: los artículos localizados en las hojas son de los últimos 5 años, y también, estos están conectados a la raíz y al tronco a través de sus citaciones. Esta mejora facilita la construcción de literatura actual a los investigadores.

Palabras clave: Tree of Science, SAP, algoritmo, análisis de citaciones

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Introduction

Tree of Science (ToS) is a web-based tool that uses graph algorithms to optimize the search and selection of published papers. ToS was created at Universidad Nacional de Colombia (Robledo et al., Osorio-Zuluaga, and López-Espinosa, 2014), and the algorithm is explained elsewhere (Zuluaga et al., 2016). ToS is a specialized tool for researchers interested in tracking the way in which a particular topic evolves over time. Firstly, users must download Web of Science (WoS) query results. Then, they upload the file to ToS (tos.manizales.unal.edu.co). With this data, ToS shows the results in the form of a tree: root, trunk, and leaves. Papers in the roots are the classics, while those in the trunk are considered structural publications, and current papers are the leaves. In addition, ToS uses scientometric techniques to recommend relevant literature.

Scientometrics refer to the study of science, technology, and innovation from a quantitative perspective. Moreover, it focuses on the measurement of the impact of articles, journals, and institutions, along with the mapping of scientific areas (Leydesdorff, 2013). Examples include citation analysis (Koseoğlu, Sehitoglu, and Craft, 2015), co-author analysis (Ioannidis, 2015), and the impact of institutions (Singh, Uddin, and Pinto, 2015). Thus, the importance of scientometrics is based on the possibility of identifying high impact articles and main researchers, and on recognizing emerging areas of knowledge (Hood and Wilson, 2001).

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Scientometrics emerged in the 1930s with the analysis of the distribution frequency of productivity between chemistry and physics by Alfred J. Lotka (1926). After analyzing a number of publications, he concluded that the proportion of researchers making small contributions was 60%. Later, Derek J. de Solla Price (1963), known as the father of scientometrics, formulated Price's Law, which explains that 25% of scientific authors are responsible for 75% of published articles (preferential attraction model). Finally, another important initial contribution in this field was the h-index (Garfield, 1972; Hirsch, 2005), which measures the impact of papers and is well known in the scientific community nowadays. Consequently, these results showed patterns in the scientific world, which can be identified by mathematical and statistical analysis.

Currently, thanks to advances in technology, such as the Internet, it is possible to apply and develop sophisticated scientometric techniques in different fields. For example, a study in nanotechnology and nanoscience shows metrics such as the annual growth rate, authorship patterns, and an index of collaboration (Karpagam, Gopalakrishnan, Natarajan, and Ramesh Babu, 2011). Another investigation in bioenergy from biomass explains the exponential growth and changes in this field (Konur, 2012). Therefore, scientometrics have been a useful tool in recent years to identify emerging areas of science.

Although scientometrics have evolved in the last few years, one of the main challenges is to find accurate methods for the characterization of a scientific area (Koseoğlu, Sehitoglu, and Craft, 2015). For this reason, various researchers have proposed other indexes to determine the impact of publications. These include the CDS-index (Vinkler, 2011), multivariate analysis techniques, time series (Leydesdorff, 2013), and modeling techniques (Mutschke and Mayr, 2014). However, co-citation analysis has become a well-established topic in scientometrics to identify "sleeping beauty publications" (Fang, 2019 p. 307). Examples of applications of this scientometric techniques are found in reviews about obesity (Landinez, Robledo, and Montoya 2019), Corporate Social Responsibility (Duque and Cervantes-Cervantes, 2019), and in agriculture (Robledo-Buriticá, Aguirre-Alfonso, and Castaño-Zapata, 2019).

During the last years, some graph algorithms have been implemented in co-citation analysis to select relevant literature. For instance, HITS algorithm (Kleinberg, 1999) was applied to reduce ranking bias (Jiang et al. 2016) and Google's PageRank algorithm, to find the most prestigious papers (Chen et al. 2007). Nevertheless, much uncertainty still exists about tracking global knowledge using co-citation analysis (Parolo, Kujala, Kaski, and Kivela, 2019). Hence, this study seeks to improve the ToS algorithm to streamline the research process on a specific topic, in order to fulfill the need for non-conventional literature review techniques (Alulema and Largo, 2019) that other studies have proposed (Sepúlveda and Cravero, 2015).

This paper is structured as follows: First, a few basic definitions about graph theory are presented. Secondly, the methodology is described, detailing the algorithm step by step. Next, the SAP algorithm is applied to create a graph of citation analysis about Word-of-Mouth Marketing, in order to compare it with the current ToS results. Finally, conclusions are addressed, and limitations and implications are discussed.

Some basic definitions

Some basic definitions about graph theory are explained below, according to Johnsonbaugh (1999):

Definition 1 (undirected graph): A graph (or undirected graph) consists of a set of vertices V and a set of edges E, arranged in such a way that each edge $e \in E$ is associated with an unordered pair of vertices. If there is a unique edge e associated with the vertices v and w, it is written as follows: $e = (v, w)$ or $e = (w, v)$. In this context, (v, w) denotes an edge between v and w in an undirected graph and not an ordered pair.

Definition 2 (directed graph): A directed graph (or digraph) G consists of a set of vertices V and a set of edges E, arranged in such a way that each edge $e \in E$ is associated with an ordered pair of vertices. If there is a unique edge e associated with the ordered pair (v, w) of vertices, it is written as follows: $e = (v, w)$, which denotes an edge from v to w, where v is the initial vertex and w is the terminal vertex of the edge e.

Definition 3 (indegree and outdegree of vertex): Let v be a vertex of a directed graph G. The degree of entry of v, denoted by indegree (v), is the number of edges in G with terminal vertex v. The degree of output of v, denoted by outdegree (v), is the number of edges in G whose initial vertex is v.

Definition 4 (subgraph): Let $G = (V, E)$ a graph. $G' = (V', E')$ is a subgraph of G if:

1. V′ ⊆ V and E′ ⊆ E.
2. For each edge $e' \in E'$, if e' is incident on v' and w', then v', $w' \in V'$.

Definition 5 (connected graph): A graph G is connected if there is a walk between every pair of distinct vertices in the graph.

Definition 6 (connected component): A connected component of a graph G is a connected subgraph S of G such that no other connected subgraph of G contains S.

Data

In order to test the algorithm, we used data from Web of Science (WoS). This dataset contains information about articles published by journals from different areas of knowledge. From it, we can extract the citation relationships between papers, authors, publication dates, journals, volume, page, and the Digital Object Identifier (DOI). Similarly, we can create a citation graph with the papers and their references (Zuluaga et al., 2016).

SAP Algorithm

The SAP algorithm was implemented in Python with the graph package igraph. The operation of SAP is explained below.

Description

1. The SAP algorithm consists in six steps: From a subset of papers V, which is obtained from WoS, a directed graph $G = (V, E)$, with all the papers and references is generated, where each directed edge (i, j) of E is a citation from paper p_i to p_j.
2. Graph G is filtered:
   - 2.1 The largest connected component is obtained.
   - 2.2 Loops are eliminated from the graph obtained in (2.1).
   - 2.3 Duplicated edges are removed from the graph obtained in (2.2).
   - 2.4 Vertices with indegree 1 and outdegree 0 are eliminated, along with their edges, from the graph obtained in (2.3). This graph is noted by $G' = (V', E')$.

   Igraph Description:

   - 2.1 Graph.clusters(), which shows the different components of the graph, and the giant() function are used to select the largest component.
   - 2.2 and 2.3. Graph.simplify() is used to remove repeated loops and edges.
   - 2.3 Graph.vs.select() is used to select the vertices that do not have indegree 1 and outdegree 0.
3. Root classification:
   - 3.1 Vertices with outdegree 0 are selected from V'.
   - 3.2 V_{root} is defined as the set of all vertices obtained in (3.1).
   - 3.3 If r is a root, its SAP is defined as its indegree

   Igraph Description:

   - 3.1 Graph.vs.select() is used to choose the vertices with outdegree 0.
   - 3.2 Indegree() is used to determine the input degree
4. Leaves classification:
   - 4.1 Vertices with indegree 0 are selected from V'.
   - 4.2 $V_{extended\ leaf}$ is defined as the set of all vertices obtained in (4.1).
   - 4.3 Vertices whose age (time since publication) is not less than the newest vertex age less 5 of $V_{extended\ leaf}$, are selected from the vertices obtained in (4.1).
   - 4.4 V_{leaf} is defined as the set of all vertices obtained in (4.3).
   - 4.5 If v belongs to $V_{extended\_leaf}$, its SAP is defined as the number of pahts that exist between v and the roots.

   Igraph Description:

   - 4.1 Graph.vs.select() is used to choose the vertices with indegree 0.
   - 4.5 Graph.shortest_paths_dijstra() is used to identify paths between the vertices of $(V_{leaf} \cup V_{extended\ leaf})$ and the roots.
5. Trunk classification
   - 5.1 Vertices of V_{root} are selected.
   - 5.2 Vertices of (5.1) are sorted in descending order according to their SAP value.
   - 5.3 $V_{root\ selected}$ is defined as the first 10 vertices obtained in (5.2).
   - 5.4 Vertices of V_{leaf} are selected.
   - 5.5 Vertices of (5.4) are sorted in descending order according to their SAP value.
   - 5.6 $V_{leaf\ selected}$ is defined as the first 60 vertices obtained in (5.5).
   - 5.7 All the vertices that belongs to at least one path between $V_{root\ selected}$ and $V_{Leaf\ selected}$, are selected.
   - 5.8 V_{trunk} is defined as the vertices obtained in (5.7).
   - 5.9 If t is a trunk, its SAP is defined as the sum of the SAPs of the vertices that belong to $(V_{root\ selected}) \cup V_{leaf\ selected}$, and are connected with t by one or more paths.
   - 5.10 Vertices whose age (time since publication) is not older than the newest vertex of V_{trunk}, are selected from the vertices obtained in (5.8).
   - 5.11 $V_{potential\ leaf}$ is defined as the set of all the vertices obtained in (5.10).

   Igraph Description

   - 5.1 And 5.4 Graph.vs.select() is used to choose the vertices.
   - 5.2 Graph.get_all_simple_paths() is used to select the vertices between $V_{root\ selected}$ and $V_{leaf\ selected}$ to save trunk vertices and compute its SAP.
6. Tree construction: Subgraph $G = (V, E)$ of $G' = (V', E')$, where $V = (V_{root} \cup V_{leaf} \cup V_{trunk})$, and E is considered a subset of the edges of E' which only affects the vertices of V is called "Tree of Science" (Robledo et al. 2014).

Application

We compared the results from the ToS with the SAP algorithm to illustrate its operation. The similarities and differences between the two procedures are presented here.

The first step is to define the research topic, in order to obtain the data from WoS. In this case, Word-of-Mouth Marketing (WOMM) is used as the search equation for the time period from January 2001 to August 22, 2017.

Title = (marketing) AND Topic = (Word of Mouth) Indexes: SCI-EXPANDED, SSCI, A&HCI

Exactly 317 papers were extracted with these references. With this data, both algorithms were applied in order to identify the SAP improvements. Table 1 shows the difference between them. The results in the roots and trunk of both algorithms are similar: 90% and 70% respectively. However, ToS performs better in terms of number of citations: 2,819 results in the roots and 1,752 in the trunk. Despite this, SAP has an outstanding performance with more than three times the citation results from ToS.

Table 1. Differences between ToS and SAP algorithm

Similarities		Root 90%	Trunk 70%	Leaves 23%
Differences in citations	ToS	2 819	1 752	741
	SAP	666	1 001	2 442

Source: Authors

Another important result of the SAP is the age of the papers on the leaves. According to Robledo et al. (2014), leaves are current papers, and a quality indicator of an investigation is the number of recent references. Moreover, Price (1976) suggests that at least 50% of the references should be from the past five years. The SAP meets this requirement by selecting papers from the past five years for the leaves (Figure 1).

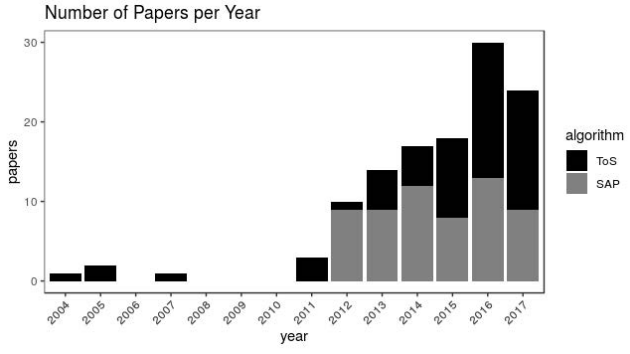

Figure 1. The number of paper per year per algorithm.
Source: Authors

Conclusions

ToS is a scientometric tool which performs the citation analysis of a graph and shows the results in a form of a tree: root, trunk, and leaves. Most of the results presented by ToS are relevant and important (Robledo et al. 2014). However, there is a lack of precision in the leaves; sometimes publications are not connected to the roots and trunk, and additionally, the leaves are occasionally not current literature. Thus, the goal of this study is to propose a new algorithm called SAP, which improves the results in the leaves.

Results show that SAP is more accurate in this field. It presents the most important current literature. However, this study is limited, and so it must be further expanded, for example, to the evaluation both of different research topics and indicators, in order to understand the pros and cons of the new algorithm.

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Surveying the Perception of the Environmental Advantages of an Adaptable Product

Investigando la percepción de las ventajas medioambientales de un producto adaptable

Marta Royo[1], Elena Mulet[2], Vicente Chulvi[3], and Julia Galán[4]

ABSTRACT

The aim of adaptable design is to create products that can easily adapt to different needs. The objective if this study is to analyze the effectivenes in communication to promote an adaptable baby stroller, in order to know the user perception of the advantages derived from its adaptability, as well as the environmental ones, and if there is correlation between them. It is also intended to determine whether age or previous experience with this type of product can influence this perception. To this effect, a study with 54 participants has been conducted. Results show that users percieve the advantages and find the adaptable design interesting. Valuation of the advantages of the product is affected by previous user experience with the need for adaptability. Valuation of the environmental benefits is independent from the degree of experiense, as well as from the age of the participants (between 30 and 45 years old).

Keywords: survey research, product lifetime, sustainable consumption, adaptable designs

RESUMEN

El diseño adaptable tiene como objetivo crear productos que puedan adaptarse fácilmente a diferentes necesidades. El objetivo de este estudio es analizar la efectividad en la comunicación realizada para promover un cochecito de bebé adaptable, en aras de conocer la percepción que tienen los usuarios tanto de las ventajas derivadas de su adaptabilidad como de las medioambientales y si existe una correlación entre ambas. También se pretende determinar si la edad o experiencia previa con este tipo de productos influyen en esta percepción. Para ello, se ha realizado un estudio con 54 participantes. Los resultados muestran que los usuarios perciben las ventajas y consideran interesante el diseño adaptable. La estimación de las ventajas del producto se ve afectada por la experiencia previa del usuario con la necesidad de adaptabilidad. La estimación de los beneficios ambientales es independiente tanto del grado de experiencia como de la edad de los participantes (entre 30 y 45 años).

Palabras clave: investigación mediante encuestas, tiempo de vida de los productos, consumo sostenible, diseños adaptables

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Introduction

Advances in technology, as well as the changing needs of the user, drive the design of new products. If these products offer more affordances, the user is quite likely to replace the old ones, even though they can still be used. Literature identifies four general product replacement motives: wear and tear; improved utility, which means improper functionality combined with the desire for an improvement in safety or economy of use; improved expression, which means improper functionality combined with the desire for an improvement regarding comfort of use or quality or design; and new desires (Van Nes and Cramer, 2006).

Products are often discarded "not because they are worn out, but because people are tired of them" (Cooper, 2005, p. 57).

Previous studies, based on interviews held with users and empathy map analyses, concluded that product replacement could be due to: (1) changes in the number or size of users; (2) changes in users' capabilities; (3) updates, repairs and technological changes; (4) the physical environment (Royo, 2016).

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Sometimes products are replaced because they are not designed to adapt to changing needs, which can be considered a particular case of improper functionality (Van Nes and Cramer, 2006). This implies that a product needs to be updated or modified to adapt to change (Pialot, Millet, and Bisiaux, 2017). In some market segments, it is usual to see adaptable products for the user's changing needs, such as the design of convertible and evolving furniture, which is essentially aimed at children. As they grow, the furniture is designed to grow with them. Initiatives have also appeared that concern the design of technological products that update and adapt themselves to meet the changing needs that arise over time. For instance, projects such as ARA and Phoneblocks aim to create modular smartphones that can be used for a whole lifetime.

Avoiding product replacement due to wear and tear is also addressed by modular design for reparability, which has recently been applied in smartphone design, like the in case of Fairphone 2, a telephone made up of different modules that can gradually be replaced, thereby extending the useful lifespan of the phone. As a next step, an expert survey on Fairphone 2 sustainability concludes that the modular design approach should be extended from reparability to upgradeability in the next version (Proske et al., 2016)

A goal of adaptable design is creating products that can be easily adapted for different requirements (Gu, Hashemian, and Nee, 2004). The benefits of adaptable design are primarily related to economic and environmental aspects. The user can adapt an existing product, rather than buy a new one, to achieve the new functional requirements. Compared with remanufacturing and recycling, an adaptable product can further extend its lifespan and reduce environmental waste (Gu, Xue, and Nee, 2009). Designers have several different methods available to them for designing adaptable products, with product architectures that provide robust support for adapting products to meet changes in functional and environmental requirements, as well as advances in technology (Levandowski, Jiao, and Johannesson, 2015; Luo, 2015; Zhang, Xue, and Gu, 2015). Since these products are prepared to adapt, they can more easily tip the balance towards longer use instead of replacement. Every time this happens, the service time increases. Hence, although they might be more expensive, a potential saving can be made in terms of the money that would be needed to replace the product with a new one.

Material production requires a large amount of energy, which is a significant source of greenhouse gas emissions and produces large volumes of waste, both in production and at end-of-life disposal. A more efficient use of materials could play a key role in achieving multiple environmental and economic benefits (Worrell, Allwood, and Gutowski, 2016). For domestic equipment, life extension may be an effective way to deliver material efficiency, depending on the rate of energy efficiency improvement for, e.g., refrigerators (Bakker, Wang, Huisman, and den Hollander, 2014) and washing machines (O'Connell, Hickey, and Fitzpatrick, 2013). In the case of refrigerators and laptops bought in 2011, the lifespan is the factor that most influences the environmental impact and therefore further efforts must be made to design for a product life extension (Bakker et al., 2014).

Material efficiency means providing material services with less material production and processing. The four major strategies for this are: longer-lasting products, modularization and remanufacturing, component reuse, and designing products with less material (Allwood, Ashby, Gutowski, and Worrell, 2011). Thus, designing with a view to prolonging the service life of materials is one of the ways to achieve greater efficiency in their use.

The huge amounts of recyclable or reusable materials that are currently being thrown away (Pérez-Belis, Bovea, and Simó, 2015) is another of the issues to be improved, since the high costs and the difficulties involved in recycling could prove to be insurmountable obstacles for many countries in the future (WBCSD 1995, 2000). The depletion of the planet's natural resources and the cost of recycling make adaptable designs coherent with new paradigms in production and consumption that tend to decouple economic value from material and energy consumption (Ceschin, 2013). According to the European Parliament, a longer lifetime for products will have positive social and economic effects (Montalvo, Peck, and Rietveld, 2016). The circular economy paradigm also endorses the need for a shift in the use of raw materials and resources. The report published by McKinsey highlights the need for a change in economic activity in product areas, by producing circular designs (Dobbs, Oppenheim, Thompson, Brinkman, and Zornes, 2017).

A study of seven nations found that using resources for the longest time possible could cut greenhouse gas emissions by up to 70% and grow workforce by about 4% (Wijkman and Skanberg, 2015). According to Stahel (2016), there are two groups of circular economy business models: those that foster reuse and extension of the service life; and those that turn old goods and waste into new and valuable resources. Shifting to a circular economy requires action on several fronts, concerning everyone from policymakers to the final user. Communication and information strategies are needed to raise the awareness of the public about their responsibility for products throughout their service lives (Stahel, 2016).

Design for sustainable behavior (DfSB) aims to influence people's everyday activities through design, increasing attention in the use phase of products and the way people behave and interact with them. Several strategies and interventions have been reported on DfSB (Boks, Lilley, and Pettersen, 2017).

A previous study was conducted with 13 senior-year industrial design students on products that prolong their useful lifespan by adapting to future needs. Firstly, the students saw pictures of a modular smart phone adaptable to last for a whole lifetime. Then, they answered a Likert scale questionnaire about the advantages they perceived in comparison to a smart phone without these characteristics. After this, 9 out of 13 students were exposed to an awareness session in which a promotional video about the global advantages of the modular smartphone was projected (https://www.youtube.com/watch?v=Mo1sNm8c2cw),

followed by a short debate. The results show that when exposed to such a session about the advantages to the user and to the environment of this type of product, the future designers get more convinced about it. These products are perceived as better in terms of frequency of use, material use and savings, and adaptability. Even though the population analyzed in this study is small, and therefore the results cannot be extrapolated, it seems to happen that providing appropriate information about this design approach may open their minds and make them start thinking about more frequently usable products with a longer service life (Royo, Mulet, Galán, Felip, and García-García, 2015).

But, how important is lifespan and product adaptability for the user? Users (design vision) or consumers (market vision) concerned about sustainability consider different criteria. A study with 81 green consumers on purchases of technology products indicates that incentives and single-issue labels would help consumers identify sustainable properties (Young, Hwang, McDonald, and Oates, 2010). Research has also been carried out to determine what environmental criteria users take into account when choosing a product, with varying results depending on the type of product. For instance, the EU Energy Label has a significant impact on the purchase of white goods in the UK, but energy efficiency is not so relevant in the purchase of small electrical appliances (McDonald, Oates, Thyne, Alevizou, and McMorland, 2009).

There is literature about the connection between product longevity and sustainable design, consumption, and production (Appadurai, 1988; Cooper, 2010). Material issues, such as costly maintenance, and social aspects, such as increased financial capital, act as barriers to extending lifetime, as has been studied in the case of furniture (Hebrok, 2014). A study about how the consumer influences product lifespans in everyday footwear, large kitchen appliances, and upholstered chairs acknowledged that consumers are uninterested in product lifespans during the acquisition phase and that few of them exhibit highly optimizing behavior toward them. This behavior is related to personal and social characteristics, such as routines and cultural expectations (e.g. rejection of consumerism) (Crilly, 2011). Research about the influence of lifespan labelling has also been considered, which led to find, in a study with nine categories of products, that it is indeed effective. Besides, this effect is higher in young consumers: the younger people are, the more they show a preference for products with longer lifespans (EESC, 2016).

According to Evans and Cooper (2016), attempts to increase the lifespan of household goods will be ineffectual if consumers are not making full use of the utility provided by them. Recent studies reveal how some products influence a behavioral change (Crilly, 2011), promote pro-environmental behavior, and enhance the user's awareness (Laschke, Diefenbach, and Hassenzahl, 2015; Sohn and Nam, 2015). For instance, interaction with products that evoke emotions can motivate users to pursue long-term goals despite immediate satisfactions and needs (Mugge, Schoormans, and Schifferstein, 2005; Ozkaramanli and Desmet, 2012).

Cox, Griffith, Giorgi, and King (2013) conclude that it is unlikely for consumer attitudes towards product lifetimes to change on their own. Instead, the market has to change to influence consumption decisions. According to Perella (2015), triggering a different behavior in customers changing perceptions is needed. Thus, it is necessary to identify user factors and apply appropriate communication strategies, one of which is storytelling (Chamberlin and Books, 2018). In a recent study, persuasive communication techniques proved to have a positive impact on retailer behavior to purchase remanufactured refrigerated cabinets for groceries (Muranko, Andrews, Chaer, and Newton, 2019).

These studies highlight the complexity involved in getting users to bear in mind all environmental aspects when choosing products. In the case of products that adapt their functionality to users' changing needs, it can be even more difficult for them to evaluate the advantages of adaptability. In this regard, previous experience with the product can be expected to result in a higher appraisal of the advantages that adaptable designs offer the user, although no data have been found to support this.

Despite the advantages for the environment and for users, who can spare themselves the purchase of new products in the medium and long term, there is no evidence for the extent to which users rate these benefits. There is no evidence either on whether previous experience has any influence on how adaptable products are valued. Gaining knowledge about this would help to define new design and communication strategies. No studies have been found that analyze the effect of communication on the perception of adaptable products. Hence the aim of this study.

This objective is divided into a set of particular objectives: first, to analyze the effectiveness of the communication of an adaptable baby stroller. Secondly, to state whether users value both the advantages derived from the adaptability of design and its potential environmental advantages. Then, to analyze whether a higher valuation of the advantages for the user also implies a higher valuation of the environmental advantages, that is, if they are related. Another aim is to determine whether the valuation of the advantages of adaptable designs depends on the age or previous experience of the need that is covered by the product's capacity to adapt one or some of its functions over time.

Materials and Methods

To achieve the aims of this research, a survey with a focus on an adaptable design was conducted. The product was chosen in such a way as to make it possible to identify the users who have not had the need to adapt the product and those who have.

For this research study, attention was focused on the childcare sector, and more especially on baby buggies, or strollers. There is a wide range of products to choose from, with large variations in prices. It has been observed that families that have two children in quick succession find it difficult to walk

them at the same time. They cannot use the stroller they bought for their first child to carry both of them.

Although there are models on the market that can be adapted from one to two children, many parents did not consider this when their first child was born. Thus, when the second child comes along, and they find themselves with the need, the most common way to solve the problem is to buy a twin, or double stroller, or to have two individual ones, which requires the presence of two adults to push them. There is also an auxiliary support, a platform that can be attached to the rear of the stroller for the older child to stand on. However, this child cannot sit down. Therefore, a better solution would be to have an individual stroller that can be transformed into a double one. An interview with a stroller manufacturing company confirmed that customers who previously bought an individual stroller were calling for a device to adapt the stroller to carry two babies or toddlers together. However, parents do not usually consider this need when they have their first child, although there are several models on the market that offer this solution (Royo, 2016).

To conduct the study, a new concept has been devised to adapt an individual stroller into one that can be used for two children. The intention of this concept is to avoid the need to buy a twin stroller and to solve the new need while using the initial stroller. With the strollers available in the market, users need to anticipate that they will need a stroller designed to adapt to this kind of situation. With the concept presented in the research, users just buy a single stroller and, if later on they need to carry two kids on, they will just have to buy a coupling to attach a second child seat.

To demonstrate the advantages of the adaptable product, original material was developed consisting in the use of storytelling to narrate a solution that allows for the adaptation of a stroller purchased in the past. This material seeks to describe in detail how the product adapts to the changing needs that arise as time goes by. In this way, users of a non-adaptable version of the product will have audiovisual information about the advantages of the adaptable design. In the video (https://vimeo.com/129596346), they can also see the environmental benefits the adaptable design has to offer, in terms of total use time of the product and the kilograms of material that could be saved per year. Figure 1 shows the script of the video developed for the study.

Participants and sample size

The sample size was calculated by applying the Bartlett equation (equation 1) (Bartlett, Kotrlik and Higgins, 2001), where n is the size of the sample and t is the value of the normal distribution for a certain level of confidence, which in this case was taken as being 85% (t = 1,44). p is the proportion that is expected to be found and, when this is unknown, the recommendation is to take a value p = 0,5; that is to say, 50%. Lastly, d is the margin of error the researcher is willing to accept, which in this case will be 10% (0,1). On substituting the values in the equation (1), a minimum sample size of 52 is obtained.

$$n = ((t)2 * (p)(1 - p))/(d)2, \quad (1)$$

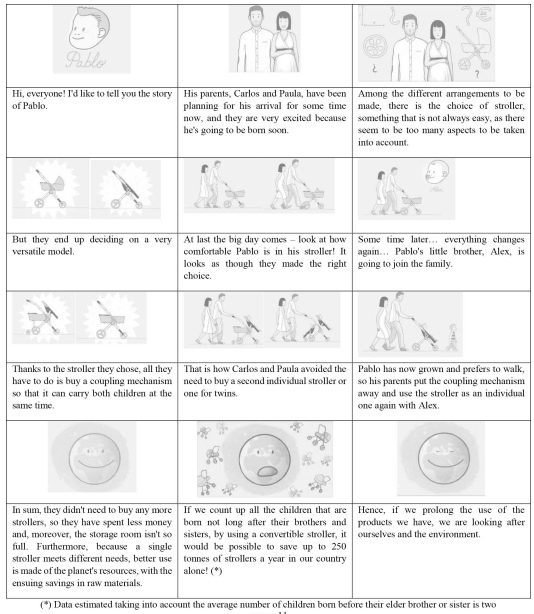

Figure 1. Storyboard to show the advantages of a convertible stroller.
Source: Authors

Participants were recruited by posting announcements about the study at five local kindergartens in the area around the experiment lab in Castellón de la Plana, Spain. In the posters parents with one single child under 18 months or less of age (type 1, non-experienced users) and parents with two children born within 24 months of each other (type 2, experienced users) were summoned to participate in a research study. Parents of twins were not recruited since their need to carry two kids is not varying in nature and is met from the beginning. The posters included mobile phone and email addresses to contact the researchers. During the first contact, the researcher confirmed if the participant fulfilled the requirements and arranged a appointment to perform the study. When the number of one of the user categories (type 1 and type 2) exceeded half of the sample size, they were told that they would be put in a waitlist. 54 parents, 37 mothers and 17 fathers, took part in the experiment to get a stroller bag in return. Due to last moment contingencies, some participants did not attend the study and people from the waitlist were required. Therefore, 28 participants from the 54 were type one users, whereas 26 belonged to type 2.

Questionnaire about perception of the adaptable stroller

Each of the 54 participants watched the animated video about an adaptable stroller, the storyboard of which can be seen in Figure 1. After that, they were asked to answer a questionnaire consisting of basic questions about previously owned strollers, followed by questions to evaluate the advantages to be gained from the adaptable design as well as the environmental advantages, which can be seen in Table 1.

Table 1. Survey questions about the advantages for the user and for the environment

Question	*Answer options*
Do you think you would have used it for longer than the stroller you had?	*Yes/No/I do not know*
Do you think you would have spared yourself the purchase of a stroller?	*Yes/No/I do not know*
How interested are you in its advantages?	*Very interested/Interested/Indifferent/ No advantages*
How much do you think this kind of design would help the environment?	
Less waste would be generated?	*A lot /quite a lot /a little or not at all*
Recycling expenses would be saved (social cost)?	*A lot /quite a lot /a little or not at all*
Reduction in consumption of raw materials?	*A lot /quite a lot /a little or not at all*

Source: Author

Finally, a personal open interview was carried out to delve deeper into their needs and opinions. The 54 participants were able to opine openly on the acquired strollers and their experiences with their purchase and use. The average duration of the interviews was about 10 minutes. They were conducted by one researcher with one user individually or two users at the same time. After few days, users were contacted by phone in order to inquire whether they had changed any of their previous opinions related to the video or the acquisition of these products.

Results

Once the experiment had finished, the answers and data obtained were analyzed. Most of the users with two children were between 35 and 39 years of age (62%), whereas users with one child were between 30 and 39 years old (37% between 30 and 34, and 37% between 35 and 39). Concerning the total number of strollers acquired, it is remarkable that 17 of the participant families have bought two and 10 have acquired three or more strollers. The most usual price for the first stroller was between 600 and 1000. It was also observed that the use of a second-hand stroller was not common, but was increasing, since a greater number of the younger participants (those with one child under 18 months) than users with two children chose to use second-hand (30% versus 15%, respectively). The users usually stored the strollers away when they did not need them (57%) and 24% lent them to friends and relatives. 8% of the surveyed have sold it, and 11% have thrown it away. None of them knew about convertible strollers for carrying one or two children.

Evaluation of the advantages of adaptable design

Regarding the advantages of using an adaptable stroller, analysis of the answers shows that 69% of the surveyed think they would have used this kind of stroller for a longer time, while 61% think they would have spared themselves the need to purchase another one. Very few of them think they would not have used it longer (7%) or that they would have avoided the need to buy a stroller (9%). When asked if they were interested in this kind of stroller, two out of three were interested (69%) and one out of four was very interested (26%).

With regard to their answers to the questions about how they perceive adaptable products could help the environment, Figure 2 shows that most of the participants think they would make an important contribution to generating less waste (72%) and to consuming fewer raw materials (65%). Half of them think that it would make quite an important contribution to reducing recycling costs (49%). Therefore, participants clearly perceive the advantages for the environment.

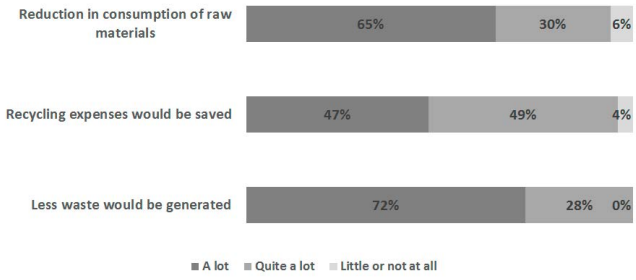

Figure 2. Participant's opinion about how they perceive adaptable products could help the environment.
Source: Authors

Analysis of the relationship between product and environmental advantages

The next step was to determine the relationship between the advantages that the user perceives for the product and those perceived for the environment. This was analyzed based on the frequency of each answer and applying the Chi2 test and calculating Cramer's V coefficient. The Chi2 test was calculated for a significance *level p* of 0,05, whereas Cramer's V coefficient ranges between a value of zero, which indicates independence, and 1, which indicates a perfect relationship between the two factors. Values above 0,30 normally indicate that there is a possible relationship between the variables.

Table 2 shows the cross-tabulated answers concerning whether they perceive the product advantages and the valuation of each of the three environmental advantages in the questionnaire. One of the participants did not answer the last two questions (Save cost of recycling and use less raw materials). In this table, the number of answers for these questions is 53.

Table 2. Cross table of the perception of product and environmental advantages

	Throw away less rubbish				Save cost of recycling				Use less raw materials			
Use longer	**Quite a lot**	**A lot**	**Little or not at all**	**Total**	**Quite a lot**	**A lot**	**Little or not at all**	**Total**	**Quite a lot**	**A lot**	**Little or not at all**	**Total**
No	1	4	0	5	1	4	0	5	0	5	5	5
Don't know	4	12	0	16	10	5	1	16	4	12	0	16
Yes	11	19	3	33	15	16	1	32	11	21	0	32
Total	16	35	3	54	26	25	2	53	15	38	0	53
Save purchase	**Throw away less rubbish**				**Save cost of recycling**				**Use less raw materials**			
No	2	2	0	4	2	2	0	4	1	3	0	4
Don't know	3	10	0	13	8	4	1	13	5	8	0	13
Yes	11	23	3	37	16	19	1	36	9	27	0	36
Total	16	35	3	54	26	25	2	53	15	38	0	53
Interested	**Throw away less rubbish**				**Save cost of recycling**				**Use less raw materials**			
Indifferent	0	3	0	3	1	2	0	3	1	2	0	3
Interested	14	21	2	37	20	14	2	36	13	23	0	36
Very interested	2	11	1	14	5	9	0	14	1	13	0	14
Total	16	35	3	54	26	25	2	53	15	38	0	53

Source: Author

Table 3 shows that, with the collected data, it is not possible to prove any relationship between the advantages of the adaptable product perceived by the user and the environmental ones, as the Chi2 value presents a level of significance p that is above 0,05 and Cramer's V coefficient does not even reach a value of 0,3.

Relationship between previous experience, age, and the perception of functional and environmental advantages

The third aim is to analyze whether the perception of the advantages depends on previous experience and age. For the more experienced users, the prevalent answer was that a convertible stroller could be used for a longer period. For users with a single baby, the most common answer was that they did not know whether they would use it any longer (50%). More than 80% of the experienced participants thought they would have used the adaptable design for longer, whereas this opinion reached 43% among the non-experienced ones.

For the second question, that is, if they thought they would have avoided the need to buy a stroller, the results were more conclusive, and most of them (61%) thought that they would. Again, a difference was observed depending on the type of user. Whereas this was almost the only answer in type 2 users (88%), those who have only one were divided in their patent opinions (50%).

The reason for this may be that those with only one child did not know if they were going to have any more children –some of them told us that they would probably have just one.

Table 3. Chi2 and Cramer's V tests on the dependence between perception of the adaptable product and environmental advantages

Variables	Chi2	p-value	Cramer's V coefficient	Interpretation
Perception of using the product for a longer period of time				
Throw away less rubbish	3,035	0,552	0,168	Independent
Save cost of recycling	4,742	0,577	0,210	Independent
Use less raw materials	3,322	0,506	0,175	Independent
Perception of saving themselves the purchase of a stroller				
Throw away less rubbish	2,597	0,627	0,155	Independent
Save cost of recycling	2,831	0,830	0,162	Independent
Use less raw materials	1,356	0,852	0,112	Independent
Perception of how interesting an adaptable stroller is seen to be				
Throw away less rubbish	4,427	0,351	0,202	Independent
Save cost of recycling	4,052	0,670	0,194	Independent
Use less raw materials	4,726	0,317	0,209	Independent

Source: Author

To test whether these results are significant, and, as they are qualitative variables, again the Chi2 test and Cramer's V coefficient were applied. The result of the Chi2 for the

relationship between longer use and previous experience shows a level of significance below 0,005 (0,003), thus reflecting the fact that there is a dependence. Nevertheless, since the number of frequencies below 5 is greater than 20% (see Table 4), this result is not reliable, since it could be a false positive. The results of Cramer's V coefficient also indicate that there may be a relationship between these variables, although the dependence is not strong. Therefore, the results of the tests presented in Table 5 show that there does seem to be a relationship. A greater number of data would be needed, however, to determine this statistically.

Table 4. Cross table of previous experience and product adaptability advantages

	Use it for a longer time				Save the need to buy a stroller			
Previous experience	**No**	**Don't know**	**Yes**	**Total**	**No**	**Don't know**	**Yes**	**Total**
No	2	14	12	26	3	11	14	26
Yes	3	2	21	28	1	2	23	28
Total	5	16	33	54	4	13	37	54

Source: Author

Regarding whether perception of the advantages varies depending on the age, taking into account two age groups –those under and over 35 years old– the results show that there is no significant relationship.

An analysis was also performed to determine whether the degree of interest in the adaptable stroller depends on previous experience. The answers to the questions show that most of the participants, 75% of non-experienced and 62% of experienced users, perceived having a convertible stroller as being "interesting" (Royo, 2016). Almost all of the users consider this design either interesting or very interesting. However, this difference is not statistically significant, since the Chi2 test showed no significant variation between the answers to this question and the type of user.

Another analysis was performed to determine whether the experience of going from carrying one child to having to carry two has an influence on the perception of the environmental advantages. Figure 3 shows the results obtained for the three additional closed-ended questions about how users perceived the environmental advantages of a convertible stroller. The results showed that the subjects of the experiment thought this helps to reduce waste and reduces recycling expenses "a lot" or "quite a lot", and that it would greatly reduce the consumption of raw materials. Data showed that non-experienced people do perceive the environmental advantages more strongly, but the Chi2 tests ($\alpha = 0{,}005$) yielded no differences according to the type of user, nor did the Cramer's V test.

Finally, an analysis was carried out to determine whether the perception of the environmental advantages of an adaptable stroller varies depending on the age. To do so, the answers were separated into two groups: those from respondents aged over 35 years and from those under 35 years of age. In this case, results showed that the ratings of the environmental

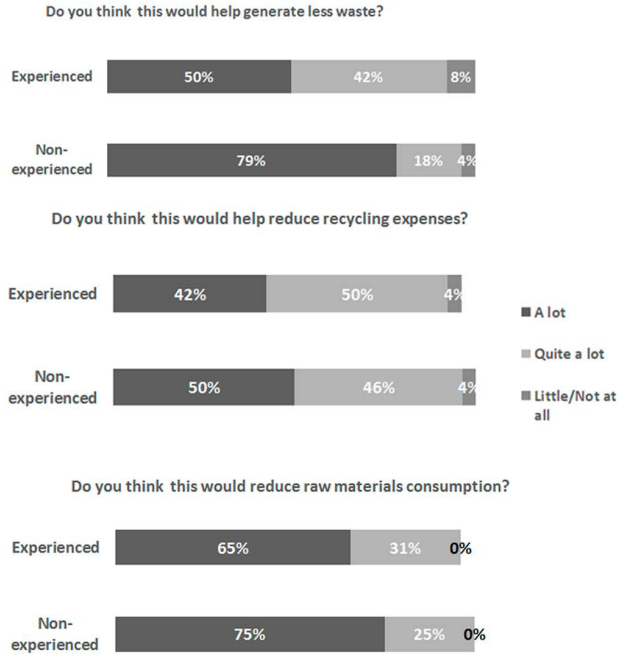

Figure 3. Participants' opinion about how they perceived the environmental advantages of a convertible stroller.
Source: Authors

advantages do not vary significantly with age (p value $< 0{,}05$, and Cramer's V test $< 0{,}3$).

Interview results

From the interviews carried out on the 54 participants, one notable finding is that half of them stated that, if they had been shown a convertible stroller like the one seen in the videos, they would have considered buying it.

30% of the interviewed (36% of parents with two children and 13% of type 2 participants) also openly pointed that the video adequately explains the evolution of the use of the stroller. 22% of them commented that the environmental subject drew their attention (32% of type 1 users and 11% of type 2 users). Moreover, 26% of the interviewed declared that the message conveyed by the storyboard leaves no room for doubts.

For many of the participants, the purchase would continue to depend on whether they know if they are going to have another child in a short period of time (24%), a question that 17% of them did not take into account at that time. They also expressed that the video made them think more about the amount of products that they buy without considering future or changing needs.

Many participants expressed that it was difficult to choose a stroller due to the lack of experience with the kind of product. One of the interviewed said: "It is very difficult to select a stroller because there is a wide range and every single model has its own particular features". Another one said: "I made an excel sheet to compile all the characteristics (folding, size, etc.) for a big number of models". It is remarkable that

a small number of participants saw an existing convertible stroller in the stores, but did not immediately notice the possibility of having to carry two kids. One of them pointed that "the salesman told me that one of the strollers was broader; therefore, it was more comfortable. But in fact it was a convertible stroller" (Royo, 2016).

All participants confirmed that they did not change their opinion when asked about it two or three days later.

Discussion and Conclusions

A study was conducted with 54 participants that provided us with interesting information regarding the perceived advantages of convertible stroller designs that adapt to future needs. The results show that when users are told about the advantages of an adaptable design and the advantages that this kind of product can have for the environment, they perceive them and consider it to be an interesting proposition. Furthermore, from the data collected it was also found that:

Both types of participants regard the concept of a convertible stroller as an interesting option. None of the respondents knew about this type of convertible strollers, which shows that their advantages are not being well promoted or communicated.

No relationship has been established between the perception of the advantages that the adaptable design offers users and the perception of the advantages for the environment.

The rating of the advantages of the product in terms of its useful lifespan and sparing the need to purchase an additional stroller does seem to have a relationship with previous experience with the need for adaptability. Therefore, further data would be needed to confirm this, although the results obtained seem to indicate that these advantages are more appropriate for those who have already chosen a stroller for one child and later found themselves with the need to carry two.

The age and the rating of the advantages of the adaptable stroller are independent of each other. This result may be biased by the fact that the older participants are also the ones who have had two children in quick succession.

The rating of the environmental advantages is independent of both the degree of experience and the age in participants between 30 and 45 years of age. Experienced users perceive the environmental benefits less. This could be due to disappointment with the number of products they have had to buy or the complexity of a single product that meets all needs.

After seeing the video, half of the users declare that if they had been shown a convertible stroller like the one in the video, they would have considered buying it. They feel that they have not been aware about the amount of products they buy. Thus, this experience has help them to be more aware about the consumerism.

This study has some limitations. The most important one is that the relationships identified are based on qualitative data. Studies where quantitative data is presented could lead to other results.

The results obtained have practical effects on communication, as they help to raise promotion campaigns of adaptable products. Stating all the advantages of an adaptable product will increase the user's interest in it, especially for those who have previously needed a product to adapt to new needs. Mentioning these products' advantages for the environment will also increase interest. In this case, the environmental aspect is more interesting for users who have not needed the adaptable product than for those who have needed it. Therefore, depending on the user to whom the product is addressed, the message should emphasize to a greater or lesser extent the user and environmental advantages.

These results are relevant to getting users to value product characteristics with long-term effects and sustainability. Choosing adaptable products is choosing products that extend their time of use, which is one of the strategies of circular economy design.

Users value an adaptable design if they are given information about the advantages it has for the environment. Still, because there is no relationship between environmental and user advantages, efforts should be made to communicate both of them. It is also very important to implement enhanced communication strategies concerning the latter, since, at least in the case of strollers, this criterion is hardly ever considered when the first child is born. This work has analyzed user perception when empathy tools as storyboard are used. These kinds of techniques, applied in addition to eco-labelling, can help to communicate the advantages derived from the adaptability and lifespan of a product. QR codes, Augmented Reality, etc. could be used to combine storyboard technique with eco-labelling.

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Heat Recovery Opportunities in a Poultry Slaughterhouse for Generation of Hot Water: A Case Study on Energy Production

Oportunidades de recuperación de calor en un matadero de aves de corral para la generación de agua caliente: un estudio de caso sobre la producción de energía

Gessen Souza Teixeira[1], Carlos Roberto Altafini[2], and Joanir Luis Kalnin[3]

ABSTRACT

The aim of this work is to highlight the possibility of energy gains through heat recovery in an industrial plant. It was carried out in a poultry slaughterhouse, which, within its processes, consumes a very high amount of energy in various forms. It shows the usage of steam, its purpose, and why there is currently such a strong dependence on this resource. Alternatives were found for complete replacement of this energy input. In addition to the heat recovery from lubricating oil of air compressors and from refrigerant desuperheating processes after the discharge of the refrigeration compressors, the most interesting alternative was a water heater powered by mixed fuel. The mass of the proposed fuel mixture was 90% made of wood chip with 10% centrifuged sludge from the company effluent treatment station. From measurements made in the productive process relative to the consumption of water for sanitation, and from the availability of residual heat from processes, a water heater working with the mentioned fuel mixture has been proposed, reaching a payback of the investment predicted up to 3 years and 7 months. The project ensured the supply of hot water without using steam at a lower cost, which also achieved significant environmental gains.

Keywords: chicken slaughtering, energy utilization, energy efficiency, heat recovery

RESUMEN

El objetivo de este trabajo fue destacar la posibilidad de ganancias de energía por médio de la recuperación de calor en una planta industrial. El trabajo se llevó a cabo en un matadero de aves, que en sus procesos consume una cantidad muy alta de energía en varias formas. Se muestra el uso del vapor, su propósito y por qué existe actualmente una dependencia tan fuerte de este recurso. Se encontraron alternativas para el reemplazo completo de esta entrada de energía. Además de la recuperación de calor del aceite lubricante de los compresores de aire y del proceso de desalentamiento del refrigerante después de la descarga de los compresores de refrigeración, la alternativa más interesante fue un calentador de agua alimentado con combustible mixto. La la massa de la mezcla de combustible propuesta era em um 90 % hecha de astillas de madera con 10 % de lodos centrifugados de la estación de tratamiento de efluentes de la compañía. A partir de las mediciones realizadas en el proceso productivo en relación con el consumo de agua para saneamento, y de la disponibilidad de calor residual de los procesos, se ha propuesto un calentador de agua que funciona con dicha mezcla, alcanzando una recuperación de la inversión prevista hasta 3 años y 7 meses. El proyecto aseguró el suministro de agua caliente sin utilizar vapor a un costo menor, lo que también logró importantes beneficios ambientales.

Palabras clave: matadero de pollos, utilización de energía, eficiencia energética, recuperación de calor

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Introduction

Certainly, the largest input of energy needed for the operation of poultry slaughterhouses is obtained from electric power, mainly for the maintenance of the refrigeration system, lighting, air conditioning and other mechanical drives (Jekainfa, 2007; Ashrafi, Bédard, Bakhtiari, and Poulin, 2015; Ferrarez, Oliveira, Lacerda, Costa, and Aparisi, 2016).

However, other inputs are also important, such as the hot water needed for sanitation in the whole environment of the industrial production process. According to Yordanov (2010), the average water consumption in slaughterhouses is around of 26,5 L/bird. Much of the hot water needed for sanitation

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can be generated by heat recovery from the plant itself. An example of this is the energy recovered in the process of desuperheating of the refrigerant after the discharge of the refrigeration compressors, and in the cooling of the lubricating oil of compressed air compressors. The hot water used to clean equipment and floor is conducted to the effluent treatment plant to be reused. Poultry wastewater contains proteins, fats, meat, blood, skin, feather carbohydrates (Seswoya, Daud, Ali, Basri, and Yunus, 2006; Yordanov 2010). These authors and others have proposed different processes for water reuse in the plant. These include filtration, ultrafiltration with selective membranes (Mittal, 2006; Bustillo-Lecompte and Mehrvar, 2015; Coskun, et al., 2016), and other state-of-the-art processes, such as ceramic microfiltration (Grant, 2017); and graphene nanofiltration as a technology of tomorrow (Chen et al., 2018).

The sludge produced at the effluent stations has been characterized, and different thermal conversion processes have been proposed to use it (Marculescu and Stan, 2011; Marculescu, 2012; Muñuzuri, Grosso, Cortés, and Guadix, 2012; Xia, Massé, McAllister, Beaulieu, and Ungerfeld, 2012; Valta et al., 2015; Coskun et al., 2016; Ferrarez et al., 2016; Lorhi, Diener, Zabaleta, Mertenat, and Zurbrugg, 2017; Oh, and Yoon, 2017; Califano, Mongiell, and Freda, 2017; Di Maria and Micale, 2017).

In addition to the aforementioned researchers, others have shown applications that value biogas production and its characteristics, such as fuel with a good energetic potential (González, Daza, and Urueña, 2007; Cacua, Amell, and Olmos, 2011), and more recent authors that identify the biomethane potential, given its high CH_4 content (Jiménez and Lozano, 2019). These renewable fuels cause little impact on the environment, being extremely useful in replacing firewood in steam and/or hot water generation and electricity within slaughterhouse activities.

Particularly, steam is used in the refrigeration industry as the dominant means of obtaining hot water for a wide range of purposes. However, there is very little study to limit its use, or even substitute it for more economical and efficient alternatives. This study introduces alternative concepts for the use of saturated steam in poultry slaughterhouses, which not only represents economic gain, but also a reduction of the environmental impact generated by the production of this raw material.

The use of industrial waste for reuse in the productive process itself is very advantageous from the economic point of view, but not limited to it. In particular, the sludge produced at the effluent treatment plant of poultry slaughterhouses is a very expensive input, due to its disposal in the environment. Therefore, using this input as part of the fuel to generate hot water for sanitation in a heater becomes an interesting option on the valorization of this by-product. This study shows that sludge can no longer be treated as waste, but as something a good quality fuel to be used in energy production.

Materials and methods

The main purpose of this work is to quantify the consumption of hot water in the refrigeration plant in order to find alternatives to obtain energy efficiency. For this purpose, adequate measuring equipment was used in each case requiring precision and applicability.

In order to determine the consumption of hot water in each application, three types of apparatus were used: in one of the points of consumption, a magnetic-inductive flow meter, mounted on the pipeline, directly measuring the flow. In cases where there was no specific meter, an ultrasonic fluid velocity meter, an ultrasound thickness gauge, and a digital caliper were used to obtain the flow value through the fluid velocity and area of the pipe cross-section. Figure 1 shows the equipment used.

Figure 1. Instrumentation used on the work.
Source: Authors

According to Spirax Sarco (2010), steam consumption can be estimated through direct steam injection, considering the total volume of cold water in the tank, the time required for heating, and the total mass of the fluid in the tank according to equation (1):

$$\dot{m}_s = \frac{m_t c_{p,w} \left(T_f - T_i\right)}{h_g t} \quad (1)$$

where $\dot{m}_s$ is the average steam consumption [kg/s], m_t is the total mass of water in the tank [kg], $c_{p,w}$ is the specific heat of the water [kJ/kg K], T_f is the final temperature of the water [°C], T_i is the initial temperature of the water [°C], h_g is the enthalpy of saturated steam [kJ/kg], and t is the time required for the initial heating [min].

In processes with direct steam injection, taking the constant renewal of water into consideration, steam consumption can be calculated through equation (2):

$$\dot{m}_s = \frac{\dot{m}_{ren} c_{p,w} \left(T_f - T_i\right)}{h_g t} \quad (2)$$

where $\dot{m}_{ren}$ is the average renewal water consumption [kg/s].

According to Spirax Sarco (2010), it is possible to estimate the consumption of steam in a heat exchanger, provided that the flow of hot water is consumed, by using equation (3):

$$\dot{m}_s = \frac{\dot{m}_{hw} c_{p,w} \left(T_f - T_i\right)}{h_{fg} t} \quad (3)$$

where h_{fg} is the specific enthalpy of vaporization [kJ/kg], and $\dot{m}_{hw}$ is the consumption of hot water [kg/s].

Results and discussion

At the analyzed poultry slaughterhouse, the pieces of equipment with the highest consumption of hot water

are the chicken scalding tank, the chiller for foot scalding tank, the defeathering machine and the hot water tanks for sanitation. The volume of the scalding tank is 18,8 m^3, and it requires a process temperature of 58 °C (T_f), an initial water temperature of 16 °C (T_i), a specific water heat of 4,186 kJ/kg K, and heating time of 60 min. Figure 2 shows the scalding tank and its dimensions in meters.

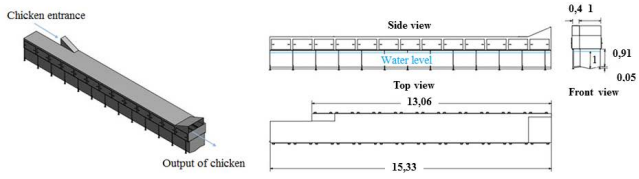

Figure 2. Scalding tank and its dimensions in meters.
Source: Authors

At the boiler outlet, the saturated steam conditions are: pressure of 0,8 MPa, corresponding to a saturation temperature of 170,41 °C; saturated steam enthalpy of 2 768,3 kJ/kg [18]; and, according to equation (1), initial steam consumption for heating of 1 194 kg/h.

Once the scalding process starts, steam injection remains only in order to maintain the temperature inside the tank, considering that each chicken passes through the equipment after that. Besides that, it takes heat from the water dragging with it a small amount of liquid, which means that there will be steam injection and continuous replenishment of water.

The replacement flow rate was directly obtained by a hydrometer installed at the entrance of the equipment, amounting to 2,05 m^3/h. The calculated steam consumption, according to equation (2) for the process of water renewal in the scalding tank, is 127 kg/h.

In the chiller for foot scalding tank, the required temperature is 61 °C, and it is obtained by direct injection of steam into the equipment, in the same way as in the scalding tank. The two devices have the same operating hours, as they are in the same sector. Thus, the start time for preheating is also 60 min.

Figure 3 shows the chiller installed in the analyzed process and its main measurements in meters for the calculation of the volume of used water, which is 0,55 m^3. From equation (1), considering the same data used for the scalding tank, varying only the required temperature, and the total mass of water, the steam consumption value for the chiller is 37,6 kg/h.

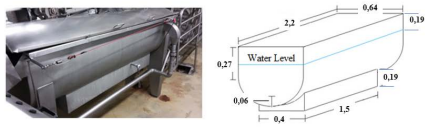

Figure 3. Chiller for foot scalding tank and its dimensions in meters.
Source: Authors

Once the process is started, the steam injection remains to maintain the temperature in the tank, considering that there is a great loss of water in the discharge of chicken feet after the scalding process.

The water inlet flow without the chiller was obtained indirectly, using the ultrasonic velocity meter on the fluid in the inlet pipe. An average value of 1,8 m/s in a pipe with a 21,4 mm outside diameter and 4,65 mm wall thickness was obtained. The calculated renewed water flow was therefore 0,74 m^3/h. With these data, and using equation (2), the required steam flow for heating renewed water was 50,7 kg/h.

Unlike the two previously presented pieces of equipment, in the machines which remove feathers, hot water comes directly from a heat exchanger. The water temperature required for this process is 70 °C.

The flow of hot water during the defeathering process was obtained by measuring the velocity of the fluid within the inlet piping of the installed equipment, which has a 33,53 mm external diameter and 4,02 mm wall thickness. The average velocity measured was 1,19 m/s, and the calculated water flow value was 2,18 m^3/h. Therefore, the estimated steam consumption for this process, according to equation (3), is 240,7 kg/h.

To calculate the steam consumption during cleaning, the total volume of the tank (33 m^3) was considered, as well as a time of 60 minutes –which is the time interval between cleanings– to reach the temperature of 48 °C. Steam consumption was obtained from equation (1) for the initial water heating before each sanitation period, which amounted to 1 596,8 kg/h.

In the first sanitized area, 36,9 m^3/h of hot water are consumed. With these data, and from equation (2), the steam consumption during the process was calculated, whose value was 1 785,5 kg/h. In the second area, the pumping rate is 61,5 m^3/h, and the calculated steam consumption was 2 975,9 kg/h.

Energy recovery (*initial phase of the project*)

In the studied poultry slaughterhouse, water flow reaches 66,5 m^3/h during the cleaning period. For this water flow, efficient heating that abides by the required parameters is a huge and risky challenge, since it can compromise the continuity of the process. For the purpose of this work, which was the whole elimination of steam in this type of industry – the main method of heating water up to this date – heat recovery was first explored in some existing equipment, fundamental for reaching the final goal.

Energy recovery in the generation of compressed air

Table 1 shows the amount of energy recovered by the system, considering the equipment data given by the manufacturer, and the fundamental calorimetric equation (4):

$$q = \rho_w \dot{V}_w c_{p,w} \Delta T_w \quad (4)$$

where q is the heat recovery by the system [kW], ρ_w is the specific mass of water [kg/m^3], $\dot{V}_w$ is the water volumetric flow rate [m^3/s], and ΔT_w is the water temperature variation [K]. With the data of table 1 and equation (4), it is possible,

through mass and energy balance in the heat exchangers, to check the available temperatures and flows, which are identified in Figure 4.

Table 1. Characteristics associated with the air compressors installed in the slaughterhouse

Equipment	Water flow (m^3/h)	Temperature difference (°C)	q (kW)
GA 30	0,27	74	22,3
GA 37 VSD	0,33	74	27,2
GA 37 ++	0,33	74	27,2
GA 45	0,4	74	33,2
Total	1,33		110

Source: Adapted from Atlas Copco (2016)

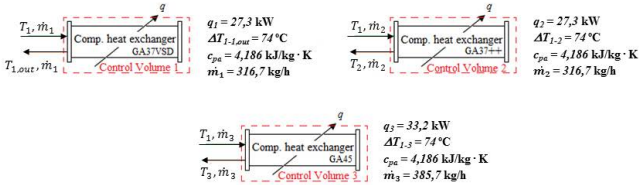

Figure 4. Water mass flow rate at the outlet of the heat exchangers of air compressors.
Source: Authors

Energy recovery in ammonia compressors

In the analyzed compressors, the principle of cooling is achieved by liquid injection, namely the direct injection of refrigerant in the low-pressure region within the compression chamber. The system consists of the injection of ammonia (NH_3) to refrigerate the lubricant oil, and the removed heat is transported to the condensers and released into the environment. The energy recovery system uses water as a cooling agent (instead of ammonia) and the heat exchanger operates within an open circuit. It means that the installation dispenses water cooling towers, since the compressor oil heat was used in the water of the production process. These two systems are shown in Figure 5.

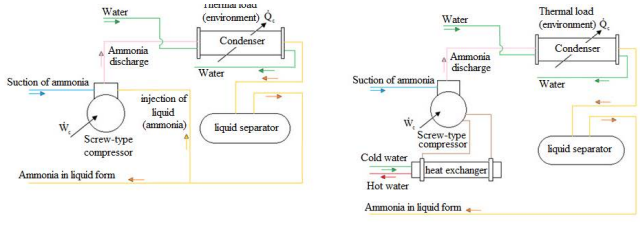

Figure 5. Ammonia compressor lubricating oil cooling system.
Source: Authors

The consumption of hot water is not continuous; it is sometimes zero during some periods of the productive process. Since the machine room operates twenty-four hours a day, six days a week, there is always a need for compressor cooling.

To circumvent this situation, a hot water "lung" was created, which comprises a water reservoir that will be used as a water tank for sanitation purposes. This prevents interruption in water flow, which can damage the lubricant oil cooling in case of low consumption during the process, besides ensuring the water feed to the production process.

According to the manufacturer's handbook, it is possible to identify the thermal load required to perform the lubricant oil cooling of all compressors, with variations due to the capacity of each equipment, as it can be seen in Table 2. Through mass and energy balance in the heat exchangers, it is possible to check the available temperatures and flows, and the thermal load of the oil must be transferred in its entirely to water.

The system was studied to provide a water temperature of 45 °C, and flow variations may occur according to the initial water temperature and thermal oil load of the compressors. Thus, according to the data in Table 2, and using equation (4), the available water mass flow rate is obtained from the outlet of the exchangers, as can be seen in Figure 6.

Table 2. Information on the thermal load available on ammonia compressors

Compressor	No. of heat exchanger	Cooling capacity (kW)	Work regime	Power (kW)	Thermal load in oil (kW)
MAYCON N250 - VMD - TS	1	759,4	-35 °C/-10 °C	223,7	116,3
MAYCON N320 - VMD - TS	2	1 011,4	-35 °C/-10 °C	223,7	157,0
HOWDEN WRV 255	3	1 254,9	-10 °C/+35 °C	372,9	290,8
MAYCON N320 - SUMIX	4	1 567,6	-10 °C/+35 °C	484,7	348,9

Source: Authors

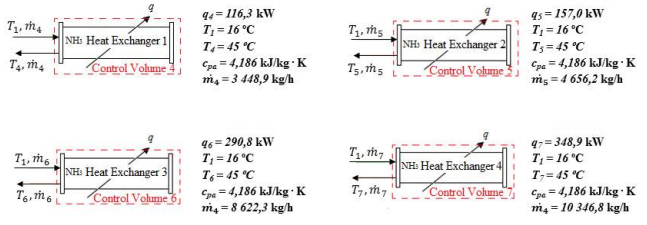

Figure 6. Water mass flow rate at outlet of the heat exchangers of ammonia compressors.
Source: Authors

Desuperheating

Desuperheating occurs in the energy recovery of the ammonia compressor discharge, i.e., before it is conducted to the condensers. The mass flow rate of ammonia depends directly on the operating regime of the machine room, in other words, the number of compressors and evaporators used during the process. Due to the climatic variations throughout the year, cold generation has seasonal operation, given that the outdoor temperature influences the condensation pressure.

A survey of the desuperheater was performed, which installed in the industrial plant during the year 2015. The values are reported in Table 3, noting the average water consumption of 17 226,7 kg/h at a mean temperature of 62 °C. Under these conditions, at an inlet water temperature of around 22 °C, hot water was obtained at 28 °C. Figure 7 shows the data for the calculation of recovered thermal energy according to equation (4).

Table 3. Data for calculation of water mass flow in control volume 8

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Average
Mass flow (kg/h) x 1000	19	19	17,5	17,5	15,3	15,3	15,3	15,3	17,5	17,5	19	19	17,3
Ammonia inlet temp. (°C)	75	75	60	60	50	50	50	50	60	60	75	75	61,7
Ammonia outlet temp. (°C)	40	40	40	40	40	40	40	40	40	40	40	40	40,0
Water inlet temp. (°C)	25	25	23	23	19	19	19	19	23	23	25	25	22,3
Water outlet temp. (°C)	43	43	40,4	40,4	26,7	26,7	26,7	26,7	40,4	40,4	43	43	28,0
Water flow (m^3/h)	21,821,8	12	12	12	12	12	12	12	12	21,821,8			15,3

Source: Authors

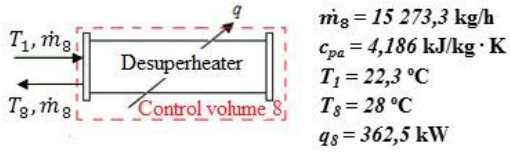

Figure 7. Water mass flow rate at the outlet of the desuperheater heat exchanger.
Source: Authors

Analysis of the thermal accumulator

It is in the thermal accumulator that the water inlet of all the heat exchangers occurs, disregarding the heat losses in the piping. Heat losses have been observed, especially in periods where there is no immediate consumption of hot water. Due to this fact, based on the performed measurements, the temperature of 38 °C was considered to be the water outlet temperature of the heater. This is shown in the nine control volumes with their involved variables in Figure 8. After analyzing the heat exchangers individually, it was possible to verify the total hot water mass flow rate $(\dot{m}_{t,w})$ that was available to the process. Furthermore, the initial and final temperatures considered for water were 16 °C and 38 °C, respectively.

$$\dot{m}_{t,w} = (2 \cdot 316,7) + 385,7 + 3\,448,9 + 4\,656,2 + 8\,622,3 + 10\,346,8 + 15\,273,3 = 43\,366,6 \text{ kg/h}$$

The thermal accumulator has the function of providing temperature stabilization, as well as storing of hot fluid in moments during the processes where there is no water consumption. In addition to the hot water inlet, a pipe was added for room temperature water influx, because the consumption of the processes is, in some periods, greater than the amount of available hot water.

Since there is a need to replace it with unheated water, it was necessary to determine the mass flow required for the process. The water pressure in the supply network at ambient temperature is 0,3 MPa, and the water density under these conditions is 997,7 kg/m^3. With this data the flow rate required by equation (5) can be determined.

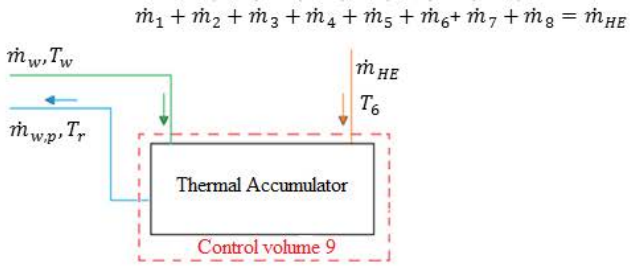

Figure 8. Control volume around thermal accumulator.
Source: Authors

$$\dot{m}_{w,p} = \rho_w \dot{V}_{w,p} \tag{5}$$

where $\dot{m}_{w,p}$ is the water mass flow rate to supply the productive process [kg/h], ρ_w is the specific mass of the water [kg/m^3], and $\dot{V}_{w,p}$ is the water volumetric flow rate that is destined for the process [m^3/h], then:

$$\dot{m}_{w,p} = 66,5 \cdot 997,7 = 66\,347,1 \text{ kg/h}$$

Since there is a mixture of hot and room-temperature water, it is necessary to perform the mass and energy balance to identify what the resulting temperature will be. Figure 9 reports the data to obtain the required result.

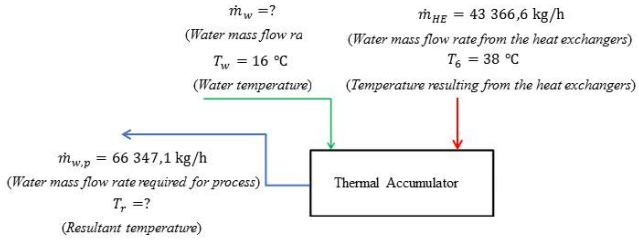

Figure 9. Resultant temperature.
Source: Authors

From the mass conservation principle for a control volume at steady state (Çengel and Boles, 2006), equation (6) indicates:

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \tag{6}$$

i.e.,

$$\dot{m}_{HE} + \dot{m}_w = \dot{m}_{w,p} \Longrightarrow \dot{m}_w = \dot{m}_{w,p} - \dot{m}_{HE}$$

where $\dot{m}_{HE}$ is water mass flow rate from the heat exchangers [kg/h], $\dot{m}_w$ is the water mass flow rate [kg/h], and $\dot{m}_{w,p}$ is the water mass flow rate for the process [kg/h]. Hence,

$$\dot{m}_w = 66\,347,1 - 43\,366,6 = 22\,980,5 \text{ kg/h}$$

From the energy conservation principle for a control volume at steady state, neglecting power, heat transfer rate, and

kinetic and potential energy effects (Çengel and Boles, 2006), equation (7) prescribes:

$$\sum \dot{m}_{in} h_{in} = \sum \dot{m}_{out} h_{out} \tag{7}$$

i.e.,

$$\dot{m}_{HE} h_6 + \dot{m}_w h_w = \dot{m}_{w,p} h_{w,p}$$

$$\therefore h_{w,p} = \frac{\dot{m}_{HE} h_6 + \dot{m}_w h_w}{\dot{m}_{w,p}}$$

From the values of the specific enthalpies of water, namely 159,2 kJ/kg (water from the heat exchangers at 38 °C), of 67,3 kJ/kg (water at 16 °C); and from the values of the mass flow rates, we have:

$$\therefore h_{w,p} = \frac{43\,366,6 \cdot 159,2 + 22\,980,5 \cdot 67,3}{66\,347,1} = 127,4 \text{ kJ/kg}$$

whose enthalpy value corresponds to a water temperature of about 30,4 °C.

Analysis of the use in the process

Analysis was performed on the consumption of hot water with its respective temperatures in the equipment, where the steam consumption analysis had already been done. In the conventional system, the processes receive water at room temperature (16 °C) and the heating is carried out, up to the desired temperature, by direct or indirect injection of steam.

A comparative reduction of steam consumption is made by replacing this water at room temperature with that from the water heater (recovery system), whose outlet temperature is 30,4 °C. The use of steam is only for temperature correction in the equipment, which requires a higher temperature than the available one. Table 4 shows the consumption of steam in the equipment in the conventional system, and in the system with energy recovery.

Table 4. Steam consumption and economy generated with the energy recovery system

Equipment	Without recovery (kg/h)	With recovery (kg/h)	Generated economy
Scalding tank (start)	1 194.0	785,5	34,20%
scalding tank (replacement)	127,0	83,6	
Foot Chiller (start)	37,6	25,6	31,90%
Foot Chiller (replacement)	50,7	34,5	
Machines to remove feathers	240,7	176,6	26,6%
Cleaning process (heating)	1 596,8	879,7	44,90 %
Cleaning process (1st area)	1 785,5	983,7	
Cleaning process (2nd area)	2 975,9	1 639,5	

Source: Authors

Economy generated and financial analysis of the first phase

In the conventional system, the daily consumption of steam was 38 123,5 kg, whereas, with the heat recovery system, consumption decreased to 23 205 kg of steam per day, saving 14 918,5 kg (39,1%). According to Spirax Sarco (2010), the steam consumption can be determined from the heat transfer rate and vice versa, according to equation (8):

$$q = \dot{m}_s h_{fg} \tag{8}$$

where q is the heat transfer rate [kW], $\dot{m}_s$ is the steam consumption [kg/s], and h_{fg} is the specific enthalpy of vaporization [kJ/kg]. Considering only the saved portion (14 918,5 kg/day), and using equation (8), a reduction of 350,7 kWh/day, i.e., a reduction of 8 416,9 kW is obtained.

Given that the price of a m^3 of firewood in the analyzed industrial plant is around US$ 17,00, and the analysis of the fuel consumption history showed that the boiler is spending on average 1,66 m^3 of wood per ton of steam produced, steam savings generated a fuel consumption of less than 24,8 m^3/day, which is equivalent to US$ 426,00/day, US$ 10 650,30 per month, and US$ 127 803,70/year.

The financial analysis was performed based on the value of the installed equipment, using the modified internal rate of return (MIRR) as a parameter, which should be at least 18% per year in the case of energy efficiency projects. Table 5 shows the values that were collected and presented for project analysis, and Table 6 shows the cash flow of the investment for ten years. Considering a financing rate of 14% per year and a reinvestment rate of 11% per year, there is a calculated MIRR of 30% per year, a value above the acceptable for approval of the investment. The discounted payback calculated for this investment was 1 year and 4 months (Blank and Tarquin, 2018).

Installation of the water heater (second phase of the project)

After the first phase, where a reduction in steam consumption of 39,1% was obtained, the second stage of this work consisted of implementing a heating system that completely suppressed the thermal energy produced by the steam boiler. The highest steam consumption of 3 394,2 kg/h at the beginning of the work decreased to 1 934,2 kg/h, which according to equation (8) demands 1 100 kW of thermal energy from the boiler, which is precisely the starting point for the dimensioning of the heater, which must fully supply this energy.

The new water heating system receives water from the thermal accumulators and, when necessary, replenishes water at ambient temperature, and it increases the heat until reaching the desired temperature. The maximum temperature required for the process is 70 °C in the defeathering machines. However, as a safety measure, since it is a new heating method, in order not to compromise the continuity of the process, a value of 90 °C was adopted as the final temperature of the water at the outlet of the heater. The maximum flow rate required in the process is 66,5 m^3/h.

The system operates six days a week without interruption, remaining with no operation from Saturday afternoon until Sunday afternoon, a period in which there is no production in the plant. Hot water is stored in a 100 m^3 tank, but at the

Table 5. Budget of the equipment used in the first phase of the project

Desuperheater			
Component	Quantities	Unitary value	Total value
Heat exchanger	1	US$ 15 858,90	US$ 15 858,90
Control system, flowmeter	1	US$ 21 472,39	US$ 21 472,39
Energy recovery in air compressors			
Component	Quantities	Unitary value	Total value
Energy recovery equipment for compressor GA 37	1	US$ 7 650,15	US$ 7 650,15
Energy recovery equipment for compressor GA 45	2	US$ 8 415,02	US$ 16 830,03
Energy recovery in ammonia compressor			
Component	Quantities	Unitary value	Total value
Heat exchanger	4	US$ 14 539,88	US$ 58 159,51
Thermal accumulator	1	US$ 16 871,17	US$ 16 871,17
Control system, pipes		US$ 15 337,42	US$ 15 337,42
		Total	US$ 152 179,57

Source: Authors

Table 6. Cash flow from the second phase investment in 1 000 · US$

↑		127,80	127,80	127,80	127,80	127,80	127,80	127,80	127,80	127,80	127,80
	0	1	2	3	4	5	6	7	8	9	10
↓	-152,2										

Source: Authors

beginning of the productive week, i.e. Sunday afternoon, the system starts with only 20% of its capacity.

The time for the system to reach the desired temperature is two hours, which is the system's thermal inertia. At the moment when the plant starts to operate, hot water is generated by the heat recovery systems, once they come into operation with the refrigeration system and with the compressed air system. There is more than 900 m^3/day of recovered hot water entering the system at 38 °C.

With the plant in full operation, the storage tank starts to operate at its maximum 100 m^3 capacity. Figure 10 shows the working condition of the heating system from the time the plant begins operating at full capacity, having already surpassed even the thermal inertia time of two hours.

The distribution of hot water for consumption points is made through valves, mixing water at 90 °C, and water at room temperature to what is required for each application service. A diagram of the entire hot water supply system for the industry is shown in Figure 11.

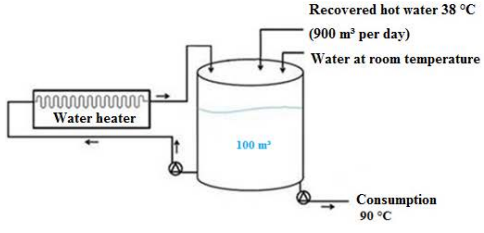

Figure 10. Operating condition of the heater with factory at full capacity.
Source: Authors

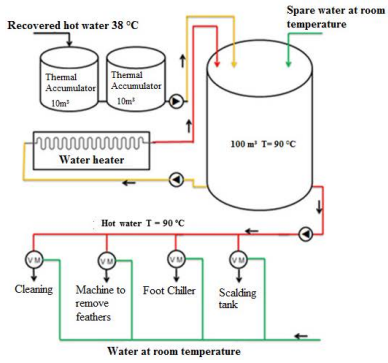

Figure 11. General scheme of the water heating system.
Source: Authors

Water heater

Based on the described assumptions, the water heater was conceived to meet the hot water demands of the plant. The heater is a mixed construction (water tube boiler in the furnace and fire tube boiler on the other passages) with a heating capacity of 2 500 kg/h, having fuel in the form of wood chip as biomass.

Savings and financial analysis generated by the use of wood chips

At the end of the first phase, the consumption of steam for heating water was 23 205,8 kg/day, and for each ton of steam produced, an average of 1,66 m^3 of firewood was spent at a cost of US$ 17,00/m^3. Considering a production of 25 days a month, the annual expenditure of firewood is around US$ 198 516,30.

The new water heating system was conceived to operate with eucalyptus wood chip, which has a density of 447,3 kg/m^3 (Ceragioli, 2013). The fuel consumption of the heater, according to the manufacturer's data, is 1 000 kg/h. The value of the wood chip used in another unit of the same company is US$ 8,80/m^3, so, considering the density of the chip and the consumption of the equipment, the amount spent per hour is US$ 19,70. For a production of 24 hours a day and 25 days a month, the annual expense is US$ 141 823,60. The use of wood chips instead of firewood generates an annual saving of US$ 56 692,60. Table 7 presents the budget of the equipment that makes up the second phase of the project.

Table 7. Budget of the equipment used in the second phase of the project

Component	Value
Water heater	US$ 165 268,40
Storage tank 100 m^3	US$ 29 141,10
Mixing valves	US$ 40 085,58
Pipes and pumps	US$ 15 337,42
Concrete base for tank	US$ 15 337,42
Total	**US$ 265 169,94**

Source: Authors

As in the first phase, the financial analysis is done from the MIRR. Table 8 shows the cash flow from the second phase investment within ten years. Considering a financing rate of 14% and a reinvestment rate of 11%, there is a calculated MIRR of 14% per year, below the acceptable value for approval of the investment. The discounted payback calculated was 6 years and 11 months.

Table 8. Cash flow from the second phase investment in 1 000 · US$

↑		56,69	56,69	56,69	56,69	56,69	56,69	56,69	56,69	56,69
	0	1	2	3	4	5	6	7	8	9	10
↓	-265,15										

Source: Authors

Source: Authors

***Use of mixed fuel* (*effluent sludge*)**

The financial analysis showed that the transition to chip wood was insufficient to allow the use of the water heater, and that to leverage the new project would require more gains beyond those obtained by the sole exchange of fuel. In this way, other inputs that could be used as fuel, at a lower cost, or even without it, were sought among some byproducts of the industrial process.

In the search for alternative fuels, the sludge from the effluent treatment station was presented as a good alternative to be used in the heater. The studied slaughterhouse produces 728 tons per month of this byproduct. It has a disposal and processing cost, and it is treated outside of the factory park. Sludge is obtained after the flotation process in the treatment of effluents, where liquids and solids are separated from the residual fluids of the production process. The damp solid is removed by centrifugation, forming the sludge itself. According to measurements made in a specialized laboratory from sludge and wood chip samples, elemental composition (%wt) and higher heating value (HHV), both in dry basis are shown in Table 9.

Table 9. Sludge and wood chip characteristics

Elemental composition (%wt, on d.b.)	Sludge	Wood chip
C	64,52	50,61
H	10,45	6,39
N	5,39	0,15
O	8,98	40,58
Ash	10,66	2,27
HHV (kJ/kg on d.b.)	29 850	18 905

Source: Authors

It is observed that the HHV of the sludge is almost 58% higher than that of wood chip. The moisture content of the samples was 79,13% for the sludge and 47,8% for the wood chip. In the work of Oh and Yoon (2017), the elemental composition (%wt) on dry basis of the sludge cake used before of the hydrothermal carbonization was C61,9%; H7,2%; N6,5%; O5,3%; Ash19,1%; and HHV of 27 700 kJ/kg. Particularly, Stan, and Badea (2017) characterize the thermo-physico-chemical properties of poultry feathers as waste from the poultry slaughterhouse, reaching a calorific value of almost 25 MJ per kg of dried feathers.

The correct disposal of sludge from the treatment of effluents is a very costly environmental liability for the slaughterhouse. In the case of the industrial unit analyzed, the sludge is processed (composting) in an outsourced company, located 90 km away, which aggravates the company's expense, since the responsibility for the sludge lies within the producing unit until the product reaches its destination.

There are 50 trips per month at a cost of US$ 117,80/trip. Hence, the sludge disposal process costs are US$ 24,00/ton. Table 10 summarizes the costs, indicating the monthly cost of sludge processing.

Table 10. Monthly costs of sludge processing

Transport			Sludge processing		
Monthly trips	Cost US$/trip	Total	Quantity kg/month	Cost US$/1 000 kg	Total
50	US$ 117,8	US$ 5 890,00	728 000	US$ 24,00	US$ 17 472,00
Total cost per month = US$ 23 362,00					
Sludge produced per month = 728 tons					
Cost per ton = US$ 32,00/month					

Source: Authors

Burning the sludge in the heater

Due to the combustion properties of the sludge, it is possible to mix it with the wood chip to form a mixed fuel for the heater. However, even with its higher calorific value (29 850 kJ/kg dry basis), its high moisture content (79,13%) limited the use of sludge to 10% of the total fuel demanded by the heater manufacturer (1 000 kg/h · 0,1 = 100 kg/h). In addition, the total amount of water presented by the fuel mixture is approximately 510 kg/h (900 kg/h · 0,478 + 100 kg/h · 0,791), corresponding to a total moisture content of 53%, lower than what is allowed by the water heater manufacturer (55%). It is important to note that considering the elemental analysis of the wood chip and sludge on a wet basis, the estimated lower heating value of the fuel mixture is 8 641 kJ/kg, still higher than that considered by the heater manufacturer which was 7 326 kJ/kg.

Savings and financial analysis generated due to sludge burning

The percentage of sludge added to the wood chip yields a reduction in the same proportion, i.e., 10%. The consumption of chip in the heater, which was designed for 1 000 kg/h, becomes 900 kg/h. The amount spent per hour will be US$ 17,70 instead of US$ 19,70. For a production of 24 hours a day and 25 days a month, spending with chip, previously of US$ 141 823,60, becomes US$ 127 641,10.

Regarding the addition of sludge to the wood chip, the economy is due to the decrease in the volume of this byproduct that is destined for external processing. The expense per ton is US$ 32,00. The use of 100 kg/h of sludge generates an annual consumption of 720 tons (100 kg · 24 h

· 25 days · 12 months), thus saving US$ 23 040,00/year (720 tons · US$ 32,00/ton).The generated savings were US$ 94 360,00/year (a result of the difference between the expenditure on firewood at the end of the first phase, US$ 198 950,00, and the expenditure on wood chips, US$ 127 641,10, plus the gain obtained with the use of sludge, US$ 23 040,00).

Fuel consumption in the mixed fuel system was 10% lower than in the heater system that only used wood chips (US$ 141 823,60 - US$ 127 641,10), and 35,7% lower than the wood burning boiler (US$ 198 516,30 - US$ 127 641,10). As the heater was kept the same, the component budget did not change, following the same items and values cited in Table 6. Table 11 shows the new cash flow considering the gains obtained with the use of sludge as fuel for ten years. Considering a financing rate of 14% and a reinvestment rate of 11% per year. The calculated MIRR value was 20% per year. The discounted payback calculated was 3 years and 7 months.

Table 11. Cash flow considering the use of sludge in 1 000 · US$

↑		94,35	94,35	94,35	94,35	94,35	94,35	94,35	94,35	94,35	94,35
	0	1	2	3	4	5	6	7	8	9	10
↓	-265,15										

Source: Authors

Conclusions

The study hereby presented dealt with applied research, in which the already known theory of thermodynamics was implemented to solve a real problem in a company of the poultry slaughterhouse segment. The main purpose of the work arose from the need to eliminate the use of steam for hot water generation, which is employed in the production process and to clean the facilities. To quantify heat recovery, all thermodynamic calculations were demonstrated.

In the first phase of the study, the energy recovery systems reduced steam consumption in 14 918,5 kg/day, i.e., a reduction of (39,1%). In this sense, the financial analysis of the first phase, with MIRR of 30% per year, leveraged the studies for the next step, which was, as already mentioned, to eliminate the use of steam in the slaughterhouse.

The water heater, operating in co-combustion mode with a mixture of wood chip and effluent sludge, despite low calorific value due to their high moisture content, provided the total supply of hot water without the use of steam. In this phase of the study, the MIRR of 20% per year and discounted payback of 3 years and 7 months validated the project by the company's financial management.

The study was successful from energetic, economic and environmental points of view. From the energetic point of view, the use of the water heater will guarantee the production of hot water without the use of steam, as is the purpose of this work. From the economic point of view, the study showed that the production of hot water can be carried out at a lower cost.

From the environmental point of view, the study showed a lower consumption of biomass, that is, 48,3 m^3/day of wood chips, against 63,28 m^3/day of firewood (a 23,7% reduction). In addition, the use of sludge from the treatment of effluents as part of the fuel provided the internal allocation of 8,2% of this byproduct (60 000 kg/month), and a gain for the industrial unit of US$ 23 040,00/year (US$ 32,00 · 720 ton).

The results found explain the presented case. However, they will be able to support new research and, thus, present similar solutions to new problems related to energy recovery. For future study, the use of effluent sludge should be taken into account as an alternative in energy production, since it is produced in large quantities at slaughterhouses and has good combustion properties, as it was shown in this work. Finally, it is also important to highlight that improving the fuel quality of the sludge from, for example, the torrefaction or hydrothermal carbonization process, will certainly enable the use of a greater amount of this waste within the co-combustion with biomass.

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Teaching Evaluation Questionnaire Validation at Escuela Politécnica Nacional, Applying the Method of Factor Analysis with Extraction of Principal Components

Validación del cuestionario de evaluación docente de la Escuela Politécnica Nacional, aplicando el método de Análisis Factorial con extracción de componentes principales

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ABSTRACT

This work validates a teaching evaluation instrument applied to professors in engineering, sciences and higher technological level programs of the Escuela Politécnica Nacional, using the method of Factor Analysis with extraction of principal components. The database used for the research was previously examined and refined due to inconsistency, eg. outliers, out of range values, etc. The result of the method described above was a reduced survey of 15 items, which was obtained from an original study of 33 items. This new questionnaire clearly identifies the four main dimensions or aspects required: teaching development and planning, teacher-student relationship, evaluation, and a global assessment question. The reduction of the evaluation scale will allow to improve the process of integral teaching performance evaluation of the faculty at Escuela Politécnica Nacional, and this method could serve as a benchmark for the teaching evaluation process of other universities that belong to the higher education system of Ecuador.

Keywords: factor analysis, teaching evaluation, questionnaire validation, principal component analysis

RESUMEN

Este trabajo valida un instrumento de evaluación docente aplicado a profesores de las carreras de ingeniería, ciencias y de nivel tecnológico superior de la Escuela Politécnica Nacional, utilizando el método de Análisis Factorial con extracción de componentes principales. La base de datos utilizada en la investigación fue examinada previamente y refinada por inconsistencia - por ejemplo, valores atípicos, valores fuera de rango, etc. El resultado del método descrito anteriormente fue una encuesta reducida de 15 ítems, que se obtuvo de un estudio original de 33 ítems. Este nuevo cuestionario identifica claramente las cuatro dimensiones o aspectos: planificación y desarrollo de la docencia; relación profesor-alumno; evaluación; y una pregunta de valoración global. La reducción de la escala de evaluación permitirá mejorar el proceso de la evaluación integral del desempeño docente del personal de la Escuela Politécnica Nacional, y este método podría servir de referencia para el proceso de evaluación de la enseñanza de otras universidades que pertenecen al sistema de educación superior del Ecuador.

Palabras clave: análisis factorial, evaluación docente, validación de cuestionario, análisis de componentes principales

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Introduction

Over the years, innovation and the appearance of new lines of research have found use incorporating new areas of knowledge as instruments of academic training. That is where the application of instruction psychology is proposed as a new teaching staff tool. This has served as a guideline for the appearance of new research that seeks to holistically understand the teaching process within the methodology and the best alternative to transmit knowledge in the classroom.

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Aparicio (2014) indicated that it is possible to interpret learning as the existing relationship between communication and interaction where interaction is seen as part of the teaching and academic development. Therefore, university professors require specific skills that allow them to enhance the quality of the teaching-learning process in the classroom. These competences enable them to achieve excellence in terms of results, which involves an evaluation culture and control of the learning process.

The normally used instruments to measure students' evaluation of their teachers, programs, and satisfaction with their instruction are known as standard rating scales. However, research on student evaluation of teaching ratings has not yet provided clear answers to some questions about their validity (Hornstein, 2017; Marsh, 2007 a,b; Spooren, Brockx, and Mortelmans, 2013; Uttl, White, and Gonzalez, 2017).

From a statistical perspective, there exist are records in Ecuador regarding the teaching performance evaluation in universities, and the existing limited evidence is of restricted nature. Nowadays, the "Ley Orgánica de Educación Superior", the law that governs the Ecuadorian educational system, establishes in the article 151 that teachers will submit to an integral periodic evaluation according to the program and teaching scale regulations of the professors and researchers of the Higher Education System and the statutory norms of each institution within it, in exercise of its responsible autonomy. The survey carried out by the students about their teachers will be considered as one of the evaluation parameters (Consejo de Educación Superior, 2018).

The current assessment instruments were designed considering the components established in the program and teaching scale regulations of the professors and researchers of the Higher Education System, such as self-assessment, co-evaluation, and hetero-evaluation. Some of the items are taken from other SET rating scales, like the SEEQ (Marsh, 2007a), STERS (Toland and De Ayala, 2005), and SET37 (Mortelmans and Spooren, 2009), and are adapted to the characteristics of the Escuela Politécnica Nacional. In general, the technical validation of the evaluation instrument is not considered as a criterion to guarantee the quality of the application of the instrument. The integral assessment of teacher performance is an essential component that allows a professor to enroll as Assistant Professor or Associate Professor. The requirements include a qualification of at least 75% of the score in the performance evaluation during his last two academic periods. Additionally, according to article 96 of the regulation (Consejo de Educación Superior, 2017), the academic staff will be dismissed if they have obtained:

1) an integral evaluation performance of less than 60% for two consecutive times, and
2) four integral performance evaluations of less than 60% throughout their career.

In addition, it establishes that the main titular teachers will be promoted to the next level if they comply with other requirements such as having obtained a score of at least 80% in the performance evaluation of their last two academic periods (Consejo de Educación Superior, 2017).

The proposed methodology arises as a necessity to validate the instruments to evaluate the teaching staff at the Escuela Politécnica Nacional of Ecuador. This validation is applied to teachers of engineering, sciences and higher technological level programs, using the method of factor analysis with extraction of major components. This research considers the reliability and validity requirements that questionnaires must have with Likert opinion rating scales (Alaminos and Castejón Costa, 2006).

The most used method to extract the initial factors of the matrix of correlation observed variables is the principal component method. It is characterized by an analysis of the total variance of the set of observed variables. The purpose is to discover the main components that define this set. Both factor analysis and principal component analysis are multivariable data reduction techniques.

The main metric characteristics to determine the accuracy of an evaluation instrument (questionnaire) are reliability and validity. Reliability is the property that designates the constancy and precision of the results obtained by an instrument when applied on different occasions. On the other hand, validity refers to whether the instrument can measure what it is intended to measure (Carvajal, Centeno, Watson, Martínez, and Sanz Rubiales, 2011). Reliability can be estimated by four means: internal consistency, stability, equivalence and inter-judge harmony. The method of choice is internal consistency, which uses the Cronbach Alpha (α) statistical test. The objective of this approach is to compare the variability of each item against the total variability of the instrument.

Currently, a line of work has been developed to reduce the length of scales already used or to elaborate new scales with a reduced number of items. The lack of time for their application , fatigue, and possible stereotyped responses in scales that are too long or that are part of a set that is applied within the same study, among others, has led to proposals of short scales (Gogol et al., 2014; Lafontaine et al., 2016). These scales have to be small enough to allow for a rapid assessment of purposed constructs, but large enough to ensure appropriate reliability, validity, and accurate parameter estimation.

The objectives of the present work are two: on one hand, to analyze the construct validity of the teaching-learning questionnaire, and on the other hand, to propose a reduction of that scale, conserving its psychometric properties.

Finally, the development of this research leads to improvements and appliance of new strategies for the teacher evaluation instrument. Additionally, these methods allow to identify the most relevant items and constructs. The result of this validation is the design of a questionnaire whose application brings accurate information that will improve the quality of the Higher Education System of Ecuador.

Mathematical Model

In factor analysis, a linear model is assumed:

$$X = \mu + LF + \varepsilon$$

where

$X(p \times 1)$ is the observable random vector, with mean vector μ and covariance matrix Σ;

$L(p \times m)$ is the matrix of factor loadings;

$F(m \times 1)$ are common factors, unobserved values of factors which describe major features of members of the population;

$\varepsilon(p \times 1)$ are error specific factors, measurement error and variation not accounted for by the common factors;

μ_i is the mean of variable I;

ε_i is the ith specific factor;

F_j is the jth common factor; and

L_{ij} is the loading of the ith variable on the jth factor.

We assume that the unobservable random vectors F and ε satisfy the following conditions:

F and ε are independent;

$E(\varepsilon) = 0$ and $Cov(\varepsilon) = \Psi$; where Ψ, is a diagonal matrix; and $E(F) = 0$ and $Cov(F) = 1$.

Thus, the factors are assumed to be uncorrelated. This is called the orthogonal factor mode.

Factoring, given the model: $X = \mu + LF + \varepsilon$

The implied covariance structure for X is,

$Cov(X) = LL' + \Psi$

If, $V(X_i) = l_{i1}^2 + \cdots + l_{im}^2 + \Psi_i$ and;

$Cov(X_{(i)}, \ldots, X_{(k)}) = l_{i1}^2 l_{k1}^2 + \cdots + l_{(im)}^2 l_{km}^2$

Furthermore, $Cov(X, F) = L$ so that $Cov(X_{(i)}, \ldots, F_{(j)}) = l_{(ij)}$

The portion of variance of the ith variable that is explained by the m common factors is called the communuality of the ith variable: $\sigma_{ii} = h_i^2 + \Psi_i$ where σ_{ii} is the variance of X_i, i.e., the ith diagonal of Σ; $h_i^2 = (LL')_{ii} = l_{i1}^2 + \cdots + l_{(i2)}^2 + l_{(im)}^2$ is the communality of X_i; and Ψ_i is the specific variance or uniqueness of X_i.

Note that the communality h_i^2 is the sum of squared loadings for X_i (Harman, 1968).

In this case, thirty-three items or quantitative variables are presented, so the factor analysis technique is applied with the extraction method of main components to obtain two dummy variables that allow to relate and summarize the teaching staff survey. This allows to evaluate the relevant aspects of the teacher, within the teaching-learning process.

Methodology

Analysis of the original information regarding its relevance and validity

An exploratory analysis is made of the data obtained from the application of the evaluation instruments of 33 items with 5 answer choices (see Table 1), which were carried out by 6 110 students of the engineering, science and higher level technological programs for the professors of the Escuela Politécnica Nacional. These students were enrolled in 8 faculties and schools, studying 24 different degrees. The higher percentage of male students is representative of the population of students of polytechnic studies, in which 68,60% were male and 31,40% were female. The average age was 22,30 years old. These 6 110 students attended 1 380 different subjects which were distributed into 1 812 class-groups. The teacher sample consisted of 670 teachers, who represented a varied sample in terms of age, category, and teaching experience. More than half of these teachers were male (62,80%). The application of the scale of 33 items was carried out at the end of semester 2017-A (October 2017-March 2018), before the students knew their final grades. All teachers were evaluated by the students in the same term. All students had to evaluate the teachers to be able to access their final grades. The student teaching evaluation was conducted through an electronic platform, obtaining 19 527 records (original data matrix) in which the data were recorded (the same student was able to evaluate several professors since he/she took several subjects).

From the **original data matrix**, a correlation matrix is elaborated between all the considered variables (items). Several tests are carried out to determine if it is pertinent, from a statistical point of view, to carry out factor analysis with the information available from the correlation matrix. The main tests are:

The Bartlett sphericity test: it is based on chi-square distribution, where high values lead to rejecting the null hypothesis (H_0) that states that the variables are not correlated within the population. Thus, Bartlett's test of sphericity determines whether the correlation matrix is an identity matrix, which would indicate that the factorial model is inadequate. If the significance value (p-value) is less than 0,050, we reject the null hypothesis (H_0) and continue with the factor analysis.

The Kaiser-Meyer-Olkin Index (*KMO*): it allows the comparison between the magnitude of the observed correlation coefficients and the magnitude of the partial correlation coefficients. The KMO statistic varies between 0 and 1. Those less than 0,500 indicate that factor analysis is not required for the data in question.

The partial correlation coefficient: it describes the linear relationship between two variables while controlling the effects of one or more additional variables. These coefficients should tend to zero, when they are lent for factor analysis (Montoya O. 2005).

Table 1. Evaluation instrument of 33 items in 5 constructs

N°	QUESTION	N°	ANSWER
I	**DIDACTICS**	**IV**	**EVALUATION CRITERIA**
1	Did the teacher clearly explain the objectives and themes, indicating their interrelation and contribution to professional profile?	17	Has the teacher used objective methods to evaluate students?
2	Did the teacher select class activities appropriately, depending on the objectives?	18	Has the evaluation been used to reorient student learning?
3	Has the teacher been clear in his/her explanations and presentations?	19	Has the teacher considered aspects that are not merely cognitive?
4	Has the teacher related theoretical fundamental concepts and principles with practice?	20	Does the teacher evaluate fairly and impartially?
5	Does the teacher solve the difficulties that arise?	21	Has the minimum grade to approve the course been explained and why?
6	Does the teacher show the mastery of the subject?	22	Were the objectives defined in a clear and concise form?
7	Does the lecturer demonstrate planning his/her lectures before the class presentations?	23	Are the evaluation events related to the teaching taught?
8	Is the teacher creative and dynamic in the classroom?	**V**	**TEACHER-STUDENT RELATIONSHIP**
9	Does the professor show that he/she is up-to-date in the subject that is imparted?	24	Did the teacher ascertain that the students understand what they were being taught?
II	**RESOURCES**	25	Did the teacher encourage the initiatives coming from the students?
10	Does the teacher prepare didactic material additional to the textbook and makes it known?	26	Did the teacher create an environment of participation?
11	Does he/she organize didactic experiences such as visits, excursions, projects, discussions?	27	Did the teacher maintain a cordial relationship with the entire group of students?
12	Has the complementary, recommended or used material been interesting?	28	Did the teacher create an environment of trust and work during class?
13	Does he/she use means that benefit the learning process?	29	Has the teacher motivated students and increased their interest about the subject?
III	**METHODOLOGY**	30	Does the teacher have an attitude of availability outside the class?
14	Did the teacher use different teaching methods properly?	31	Has the teacher openly accepted the suggestions made by students?
15	Has the teacher used a varied methodology?	32	Was the teacher attentive with the evolution of the students?
16	Has the teacher explained the methodologies for evaluating the course?	33	Excluding limitations that are not due to the teacher, could he/she be considered as a good teacher?

Source: Author

Extraction of Main Components

Interpretation of the main components is often difficult, so the initial extraction is rotated to achieve a solution that facilitates it. Varimax with Kaiser Normalization (Kaiser, 1958) is the rotation method that uses the orthogonal rotation of factors previously normalized. In other words, it maintains the independence between the rotated factors. This method achieves that each rotated component presents correlations with only a few variables. Therefore, this method minimizes the number of variables with high loads by one factor and is adequate when the number of components is reduced.

Results

Statistical analysis of teacher evaluation instruments

Bartlett's sphericity test was applied before using the multivariate factor analysis technique in order to verify if the correlation matrix is an identity matrix, which means that the correlations between the variables are zeros. The test consists of an estimation of the chi-square indicator, where high values lead to rejecting the null hypothesis. The test must have a significance value lower than the 0,050 limit, which would indicate that the variables are not correlated within the population. Table 3 shows the result of the Bartlett's Sphericity test that is 0,000. This demonstrates that the null hypothesis is rejected. Therefore, factor analysis is applicable in this case.

The analysis tool that was used was the Kaiser-Meyer-Olkin test (KMO). It is an index that compares the magnitude of the correlation coefficients observed with the magnitude of the partial correlation coefficients, eliminating the effect of the remaining variables included in the analysis. Since the partial correlation between two variables must be small when the factorial model is adequate, the denominator must increase a little compared to the magnitude of the correlation coefficients observed if the data corresponds to a factorial structure, in which case KMO will have a value close to 1.

Table 3 shows the result of the KMO test using the SPSS statistical analysis software, which has a value of 0,990, very close to the unit and therefore fulfills the requirement.

Table 2. KMO and Bartlett Tests

KMO and Bartlett tests		
Kaiser-Meyer-Olkin measure of sampling adequacy		0,990
Bartlett's sphericity test	Chi-square Aprox.	338 959,305
	gl	528
	Sig.	0,000

Source: Authors (data analysis performed by SPSS v.22)

The partial conclusion that can be reached about this first part is that the two types of analysis on the pertinence and validity of the data matrix are satisfactorily verified.

Now, we proceed with the second part, which consists of extracting the principal components by grouping the 33 items or original variables into new variables called "factors". It is based on an exploratory analysis and shows that there is a large number of stereotyped responses, defined as those in which students respond with a single type of score along

the whole scale, be it 1, 2, 3, 4 or 5. The data from these students is eliminated and, finally, the number of records on which the analysis is based is 15 771.

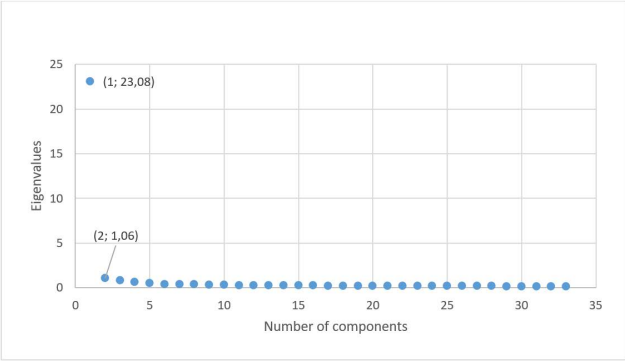

Figure 1. Sedimentation chart
Source: Authors

The results of the factor analysis of the sample reveal the existence of two factors, dimensions, or different constructs, as can be seen in the sedimentation chart in Figure I. These are chosen when the components have eigenvalues greater than 1.

The total variance explained in Table 3 analyzes in detail the selection of the two components, factors, or constructs: factor 1 explains 70% of the variation in the scores of the scale, and factor 2, 3,20%. Only the first two factors have eigenvalues greater than 1 and explain 73,20% of the original problem, resulting in a loss of 26,80% of the original information due to the fact that the survey has a very high number of items, among other aspects.

Factor 1 is composed of items 17 to 33. All the items have high saturations between them and the factor (0,780 to 0,680). This is related to the factor or set of items. The items with higher load or saturations are, in this order, items 32, 28, 31, 30, 25, 26, 24, 29, 27, 33, 22, and 20, to the less representative 23, 18, 19, 21 and 17.

Given that all these items refer to the teacher-student relationship, this factor can be called *Teacher-Student Relationship* and *establishment of a good learning environment*.

Extraction Method: Principal Component Analysis Rotation Method: Varimax with Kaiser Normalization

Factor 2 is composed of items 1 to 16. All the items have saturations or high relationships between each one of them and the factor (0,761 to 0,670); the items with higher loads or saturations are, in that order, the items 3, 4, 5, 2, 6, 7, 1, 9, and 8. In addition, these items refer to what may be called *Planning, mastery, and clarity in the explanation of the subject*.

Given that Factor 1, displays a greater variance percentage than Factor 2, this indicates that the students of the Escuela Politécnica Nacional give the greatest importance to the teacher-student relationship, or, in other words, perform the assessment of the teacher depending on the quality of this relationship, to a greater extent than the aspect of *Planning, mastery and clarity in the explanation of the subject*.

Table 3. Factor loadings and total variance explained

Rotated Component Matrix	Loadings	
	Factor 1	Factor 2
Item32	**0,782**	0,407
Item28	**0,780**	0,398
Item31	**0,789**	0,405
Item30	**0,787**	0,407
Item25	**0,784**	0,414
Item26	**0,770**	0,405
Item24	**0,767**	0,427
Item29	**0,759**	0,442
Item27	**0,759**	0,467
Item33	**0,757**	0,427
Item22	**0,727**	0,494
Item20	**0,723**	0,470
Item23	**0,723**	0,490
Item18	**0,722**	0,494
Item19	**0,712**	0,455
Item21	**0,705**	0,483
Item17	**0,689**	0,507
Item15	0,643	**0,697**
Item14	0,643	**0,695**
Item16	0,622	**0,690**
Item13	0,618	**0,686**
Item12	0,597	**0,680**
Item11	0,525	**0,673**
Item2	0,399	**0,759**
Item4	0,430	**0,760**
Item3	0,415	**0,761**
Item7	0,442	**0,756**
Item5	0,453	**0,760**
Item1	0,369	**0,755**
Item6	0,417	**0,758**
Item9	0,454	**0,747**
Item8	0,506	**0,699**
Item10	0,547	**0,670**
Initial eigenvalues	23,100	1,100
% of Total Variance	70	3,200
Total Variance		73,20%
Sum of charges to the square of the extraction	23,100	1,100
% of Total Variance	70	3,200
Total Variance		73,20%
Sum of charges to the square of the rotation	13,300	10,800
% of Total Variance	40,400	32,800
Total Variance		73,20%

Source: Authors

Another requirement that any questionnaire or rating scale must meet is reliability. If all the items amount to or contribute to measure the same, the reliability will be high. As indicated above, the most used statistical tool to calculate reliability is Cronbach's Alpha (α) internal consistency coefficient. It evinces an adequate reliability when α values range from 0,650 to high values such as 0,800 and above.

To do this, the reliability of each of the factors obtained in the factorial analysis was calculated using Cronbach's α internal consistency coefficient; being α = 0,970 the reliability of Factor 1, and Factor 2, α = 0,950. I was very high in both cases.

Given that it is possible that both factors or aspects are related, the total reliability of the 33 item scale, that amounted to α = 0,980, was obtained. This implies that a total score of the scale can be obtained, as well as scores for each of the previous factors or sub-scales.

Once it is confirmed that the reliability of each of the sub-scales is very high, it is possible to determine which item contributes more to the reliability of the scale and which items are redundant. Moreover, these can be eliminated without decreasing the reliability of the scale.

The sub-scale/*Factor 1*, composed of 17 items, has a reliability α = 0,970. If redundant items are eliminated, this scale can be reduced to 6 items: 26, 28, 30, 31, 32, and 33, with reliability α = 0,950, which is still very high.

The sub-scale/*Factor 2*, composed of 16 items has a reliability α = 0,950. If redundant items are eliminated, this scale can be reduced to 5 items: 3, 4, 5, 6, and 7, with reliability α = 0,930, which remains considerably high.

Thus, the 33-item questionnaire can be reduced to about 11 items without loss of validity or reliability α = 0,960, and with practically the same informative value as the original evaluation instrument . These items would be, as indicated in Table 4:

Factor 1/scale 1: Items 26, 28, 30, 31, 32, and 33. 27 and 29 could also be included in this order, with reliability α = 0,960.

Factor 2/scale 2: Items 3, 4, 5, 6, and 7. We could also include 9, with α = 0,940 and 2, with α = 0,940 in this order.

Table 4. Reduced questionnaire of 11 items

Factor	Items	(∝) Cronbach	Additional Items	(∝) Cronbach
1	26, 28, 30, 31, 32, 33	0,979	27,290	0,961
2	3, 4, 5, 6, 7	0,959	9,200	0,945, 0,944

Source: Authors

Then, the question that arises is: What happens with the other items and with the other theoretical aspects included in the scale as *Resources, Methodology and Evaluation*?

The answer explains that they contribute very little to the assessment of the teaching staff, given what the selected items of the reduced scale do.

However, the dimensions or aspects related to *Resources, Methodology and Evaluation* are important enough to be included in the scale, for which it is necessary to incorporate items that better represent these dimensions than the previous scale of 33 questions.

Therefore, a factor analysis was carried out to determine the extent to which the dimensions or aspects of *Resources, Methodology and Evaluation* influence the results, thus forcing the appearance of four factors, out of which two are new: *Evaluation, Methodology-Resources* and –two factors that had previously appeared– *Teacher-student relationship, and Planning, mastery and clarity in the subject's explanation*. Table 5 summarizes the variance parameters, factor loadings, as well as the Cronbach's Alpha internal consistency coefficients (α) for each aspect.

Table 5. Factorial analysis forced to 4 factors

Factor	Variance	Items	Factor loadings	(∝) Cronbach	Appearance
1	70,98%	24-33	0,720-0,620	0,970	Teacher-student relationship
2	3,72%	1-9	0,730-0,580	0,960	Planning, mastery and clarity in the subject's explanation
3	2,85%	16-23	0,680-0,460	0,950	Evaluation
4	2,28%	10-15	0,770-0,600	0,950	Methodology-resources

Source: Authors

Proposal of a reduced scale

Based on the information displayed in section A, it is considered convenient to better define the items on the *Evaluation* and *Methodology-Resources* aspects. To do this, 15 items are proposed, since they commonly appear in most universities (Alaminos and Castejón, 2006). This scale could include the most effective items of the original questionnaire, along with some new items introduced from other questionnaires, based on the theoretical dimensions of the aspects that are to be measured (Casero, 2008).

The analysis of the data obtained is structured in four aspects or dimensions: *Teaching Development and Planning*, *Teacher-Student Relationship*, *Evaluation* and a *Global Assessment question*, as indicated in Table 6, which shows each question with subscripts that express the following information:

1 = combined items of the aspects in the original questionnaire.

2 = relevant items of the original questionnaire.

3 = New items included

The analysis of the proposed reduced scale observed in Table 6 indicates that two of the included items, related to the *Teacher-student relationship,* were the same ones as in the original questionnaire because they provide relevant information about the evaluation to the professor. In addition to this table, there are items, such as 7, 12, and 15 that

Table 6. Reduced scale proposal

Aspect	N	Question
Planning and Development of Teaching	1	Does the teacher present and explain at the beginning of the period the contents (syllabus), methodologies and teaching activities, evaluation system, presentation of works, etc.?[1,2]
	2	Does the teacher demonstrate that his classes are based on the learning objectives and the syllabus of the subject?[1]
	3	Does the teacher demonstrate that he prepares and plans his classes (activities, methodologies, resources, evaluation, etc.)?[1]
	4	Does the teacher demonstrate mastery of the topics discussed in class?[1,2]
	5	Is the teacher clear in his expositions and explanations? Are the taught topics understood?[1,2]
	6	Does the teacher meet the established schedule?[1]
	7	Does the teacher use different didactic resources (for example, books, posters, maps, photos, slides, articles, videos, software, etc.) as support for the teaching of the subject? The resources and materials used or recommended are useful to take the course (bibliography, slides, virtual campus material, etc.)?[3]
	8	Does the methodology used by the teacher facilitate the learning of the subject and encourage interest in it?[1]
Teacher–Student Relationship	9	Has the teacher created an environment of trust and work in class?[2]
	10	Is the teacher accessible and willing to attend out of class consultations?[1,2]
	11	Has the teacher been made suggestions that he openly accepted? Has the teacher created an atmosphere of class participation?[2]
Evaluation	12	Are the evaluation events related to the topics presented in the course? Is the evaluation adjusted to the contents studied during the course?[3]
	13	Does the professor respect the weighing established by the institution that no evaluation must exceed 40% of the total score?[1]
	14	Does the teacher comply with the review of tests and/or previous exams the record of grades?[1]
	15	Does the teacher make the correction of the evaluations to the students? In the exams and work we the students have the possibility to know the mistakes made and comment on their valuation?[3]
Global Valuation	15/16	Excluding limitations that are not due to the teacher, can he/she be considered a good teacher?[2]

Source: Author

include two alternatives, which coincide in their meaning, but are expressed differently. Therefore, for those questions, it is necessary to choose between the options when applying the new survey.

From the results, two possible options are proposed for item 11, which are items 31 and 26 of the original questionnaires, offering the possibility of choosing between one or the other, since both alternatives have practically the same importance.

Finally, regarding item 16, which is related to the *Global Assessment* is included in the questionnaire to evaluate the general performance of the professor. However, as it not a relevant aspect, it can be considered as a replacement to item 15.

Discussion and conclusions

The first objectives of the present work were to analyze the construct validity of the teaching-learning questionnaire. Factor analysis revealed that the scale was composed of two factors. However, when factor analysis was forced to 4 factors, the theoretical structure of the initial questionnaire was exactly reproduced.

The second objective of the present work was to propose a reduction of the teaching evaluation questionnaire. It is difficult to reduce a questionnaire while maintaining the fundamental aspects of teaching. However, if the objective is to reduce the questionnaire even further to condense it to 13 items, for example, it is recommended to eliminate item 2, which covers the *Planning* aspect, as well as items 14 and 15 that refer to the grading methodology. In addition, it would be optimal to eliminate item 16. These changes are proposed while taking into that the questionnaire would maintain the desired margin of reliability.

For the validation of the reduced questionnaire proposed in Table 6, the data obtained from a large sample would be subjected to the same analysis, along with other techniques such as Confirmatory Factor Analysis and Item Response Theory Analysis (TRI).

The items with the highest saturations are those that best define the factor, while the items with low saturations define the factor less accurately. Based on this, for the original questionnaire of 33 items, Factor 1 has a high level of saturation -within the range of 0,780 to 0,689- and determines a positive teacher-student relationship, as well as a good learning environment. Similarly, Factor 2 has a high saturation level and describes the planning, mastery and clarity in the explanation of the subject, leaving the rest with low saturation levels.

Based on reliability tests with Cronbach internal consistency coefficients (α) and Bartlett's sphericity test, it is concluded that the two types of analysis about the relevance and validity of the matrix data are satisfactorily verified, which means that the original matrix data is reliable. In addition, all the questions have relevant information for the analysis of communalities.

The results obtained satisfy all the objectives established in this research paper and offer a proposal for a tool used for student evaluation of the university's teaching staff, based on the opinions of lecturers and students. The contribution that this work aims is to do is to present an available instrument to be used by universities and polytechnic schools, especially at the Escuela Politécnica Nacional, to validate and reduce the teaching evaluation questionnaires. The positive results of this study confirm it is possible to enter to a new phase for teaching evaluation using a new and well-defined survey.

A limitation of the study is that the assumption of randomness for factor analysis was not followed, because the questions are not arranged in a random order. On the other hand, another limitation is that the construct validity was examined but not the criterion of validity, for example, correlating the questionnaire scores to some external criterion.

In addition to the validation analysis of the teacher evaluation instrument, it is recommended to carry out a multi-dimensional analysis including aspects of gender, academic record, admission examination score, subjects, degrees, among others, in order to relate the scores in the scales to other variables and their correlations.

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