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Journal of Innovative Engineering

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Presentation of Content

In the first article we present, *Localization of structures under the forest canopy through three-dimensional imagery acquired with remote sensing*, by TORRES-GARCÍA, Eduardo, MARTÍN DEL CAMPO-BECERRA, Gustavo Daniel, YÁÑEZ-VARGAS, Israel and SERAFÍN-GARCÍA, Sergio Alejandro, with adscription in Centro de Investigación y de Estudios Avanzados (Cinvestav), Centro Aeroespacial Alemán (DLR) and Universidad Politécnica de Juventino Rosas, as the netx article we present, *Development of a web system for the record of Clinical History in patients of the State Center for Critical Care in Salamanca Gto*., by AGUILAR-DURÓN, Rebeca Eugenia, GALLEGOS-GALINDO, Juan Heriberto, YAÑEZ-VARGAS, Juan Israel and QUINTANILLA-DOMÍNGUEZ, Joel, with adscription in Universidad Politécnica de Juventino Rosas, as the netx article we present, *Analysis of heat transfer in a helical exchanger using different correlations*, by HORTELANO-CAPETILLO, Juan Gregorio, TÉLLEZ-MARTÍNEZ J. Sergio, MARTÍNEZ-VÁZQUEZ, J. Merced, ZUÑIGA-CERROBLANCO José Luis, with adscription in Universidad Politécnica de Juventino Rosas, as the netx article we present, *Simulation of cyclohexane production using free software DWSIM*, by SOTO-CASTRO, Luis, CORTÉS-CAMPOS, M. de Lourdes, MARTÍNEZ-VÁZQUEZ, J. Merced and RODRÍGUEZ-ORTIZ, Gabriel, with adscription in Universidad Politécnica de Juventino Rosas and Universidad Politécnica de Guanajuato.

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Content

Article **Journal of Innovative Engineering**
June 2022 Vol.6 No.18 1-9

Localization of structures under the forest canopy through three-dimensional imagery acquired with remote sensing

Localización de estructuras por debajo del follaje selvático a través de imágenes tridimensionales adquiridas mediante percepción remota

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Abstract

Numerous ancient cultures in Mexico (e.g., Maya, Zapotec, Olmec, etc.) disappeared, leaving behind their legacy. These cultures inherited temples and archaeological remains, discovered in some cases by chance or through scientific expeditions. Most of the discovered structures were covered by vegetation layers, which made them very difficult to identify. By instance, Mexico’s south-east, where the Mayan culture settled, is known for being a densely forested area. The tropical forest ‘Selva Lacandona’ is located in this region. Consequently, this work suggests using synthetic aperture radar (SAR) tomography (TomoSAR), as a technique for searching structures under the forest canopy. TomoSAR retrieves three-dimensional imagery from illuminated scenes. When an adequate wavelength is chosen (i.e., L-, P-band), TomoSAR detects the several vegetation layers in forested areas and the topography beneath. Furthermore, TomoSAR is also capable of locating structures hidden under the forest canopy, which could be the case of ancient temples or archaeological vestiges.

Archaeological structures, Remote sensing, Synthetic aperture radar, Tomography, Vestiges

Resumen

Numerosas culturas antiguas de México (por ejemplo, maya, zapoteca, olmeca, etc.) desaparecieron, dejando atrás su legado. Estas culturas nos heredaron templos y vestigios arqueológicos, descubiertos algunas veces por casualidad o mediante expediciones científicas. Muchas de las estructuras descubiertas estaban ocultas bajo capas de vegetación, lo que hacía muy difícil su identificación. Por ejemplo, el sureste de México, donde se asentó la cultura maya, es conocido por ser una zona densamente boscosa. En esta región se encuentra la "Selva Lacandona". En consecuencia, este trabajo propone el uso de tomografía a partir de radar de apertura sintética (TomoSAR, por sus siglas en inglés), para la búsqueda de estructuras bajo el dosel selvático. TomoSAR construye imágenes tridimensionales de aquellas escenas iluminadas. Cuando se elige una longitud de onda adecuada (es decir, banda L o P), TomoSAR detecta las distintas capas de vegetación que componen las zonas boscosas y la topografía por debajo. Además, TomoSAR también es capaz de localizar estructuras ocultas bajo el dosel selvático, como podría ser el caso de templos antiguos o vestigios arqueológicos.

Estructuras arqueológicas, Percepción remota, Radar de apertura sintética, Tomografía, Vestigios

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Introduction

In Mexico, numerous ancient cultures such as the Maya, Zapotec and Olmec, left us several archaeological remains, including large pyramids. For example, the archaeological zone of Toniná, in the municipality of Ocosingo, Chiapas (Kelly, 2001). The exploration of wooded areas in search of ancient temples or archaeological remains is very complicated due to the characteristics of the terrain. For this reason, remote sensing is often used. In recent years, important archaeological discoveries have been made using modern remote sensing techniques. For example, using laser image detection and ranging (LiDAR) technology, it was possible to discover Maya buildings hidden under the Guatemalan jungle (Inomata *et al*., 2020).

Many of the structures discovered in Mexico, either by chance or through scientific expeditions, were covered by layers of vegetation, which made their identification very difficult. Southeastern Mexico, where the Maya culture settled, is known to be a densely forested area. This region is home to the "Selva Lacandona", one of the most important tropical forests in the world. Figure 1 shows the physiographic distribution of the Lacandona rainforest (B. Gabriela, 2014).

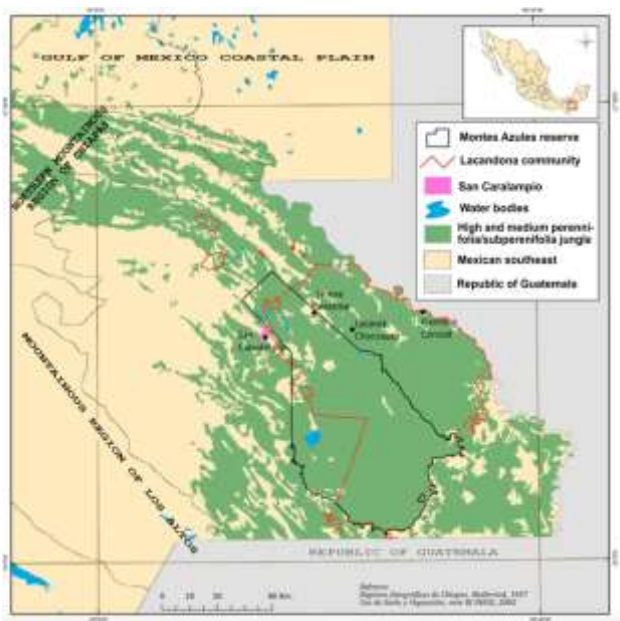

Figure 1 Physiographic map of the Selva Lacandona *(B. Gabriela, 2014)*

Following this order of ideas, this work suggests the use of synthetic aperture radar tomography (TomoSAR) as a viable alternative for the search of structures covered by the forest canopy. TomoSAR constructs three-dimensional images of those illuminated scenes. When an appropriate wavelength (i.e., L-, P-band) is chosen, TomoSAR detects the different layers of vegetation that make up the forested areas and the topography underneath. In addition, TomoSAR is also capable of locating structures hidden under the forest foliage, such as ancient temples or archaeological remains.

Reigber and Moreira (2001) were the first to practically demonstrate the use of TomoSAR for the generation of three-dimensional images from a set of two-dimensional synthetic aperture radar (SAR) images. The work of Nannini *et al*. (2009) contributed to TomoSAR in three ways: through the development of algorithms for the TomoSAR processing chain, through the detection of targets hidden under vegetation, and finally, by estimating the minimum number of acquisitions (SAR images) needed to achieve tomographic results.

Martín del Campo *et al*. (2018) compares various three-dimensional image forming techniques (tomography), from a collection of SAR images. The work focuses on the reconstruction of vertical structures in forested areas, being able to separate the contributions of topography and various vegetation layers. Demonstrative experiments were carried out using real data provided by the German Aerospace Center (DLR).

The main objective of this work is to show the feasible use of TomoSAR for the detention of archaeological remains covered by the jungle canopy, as might occur in southeastern Mexico. A scene is simulated, in which a structure is hidden under several layers of vegetation. Subsequently, through two focusing techniques [matched spatial filter (MSF) and Capon] a three-dimensional image is constructed, where it is easy to recognize the hidden structure. A graphics processing unit (GPU) is used to speed up the processing time of the algorithms.

ISSN 2523-6873

June 2022 Vol.6 No.18 1-9

The paper is organized as follows. First, the basic concepts of SAR are presented; then, the theoretical foundations of TomoSAR are explained; subsequently, the simulations, aimed at verifying the stated objective, are presented; finally, the results are described and the paper concludes.

Synthetic aperture radar

Remote sensing is the collection of information about an object, area or phenomenon (usually by means of a sensor), without being in direct contact with the object, area or phenomenon from which the information is acquired (Reddy, 2014). For the scope of this paper, we will focus on the formation of images as a consequence of remote sensing. For this purpose, use is made of active and passive sensors. Passive sensors measure natural energy from the sun such as reflected sunlight or thermal radiation; while an active sensor does not require an external energy source to function (Curlander and McDonough, 1992).

Within the group of active sensors are SAR systems. The latter work in different frequency bands within the microwave spectrum. Table 1 shows the most common frequency bands for a SAR system (Curlander and McDonough, 1992).

Band	Wavelength (cm)	Frequency (GHz)
Ka	0.8 – 1.1	40.0 - 26.5
K	1.1 – 1.7	26.5 - 18.0
Ku	1.7 – 2.4	18.0 - 12.5
X	2.4 – 3.8	12.5 - 8.0
C	3.8 – 7.5	8.0 - 4.0
S	7.5 – 15.0	4.0 - 2.0
L	15 – 30	2.0 - 1.0
P	30 - 100	1.0 - 0.3

Table 1 Most common frequency bands for a SAR system

Being an active sensor, SAR has the advantage of working both day and night. Moreover, for longer wavelengths (e.g., C, S, L and P), its operation is independent of weather conditions. Unlike an optical sensor, for example, SAR has the ability to look through clouds. The degree of penetration increases with wavelength. For example, L- and P-bands are able to penetrate through tree foliage.

Some of the most common applications of SAR, for a given frequency band, are listed below. P-band: biomass, soil moisture and as high penetration radar. L-band: agriculture, forestry management and soil moisture. C Band: oceanography and agriculture. X-band: agriculture, oceanography and as high resolution radar. Ku-band: glaciology (snow cover mapping).

Figure 2 describes the basic geometry of a SAR system. The sensor is mounted on a moving platform, emitting electromagnetic pulses and capturing the echoes. The platform moves in the azimuth direction, while the pulses are transmitted in the range direction. The antenna's impression on the earth's surface is usually called *swath*, while its range is called *swath* width. The synthetic aperture is the distance in orbit between the entrance and exit of the *swath*, with respect to a reference point on the earth's surface.

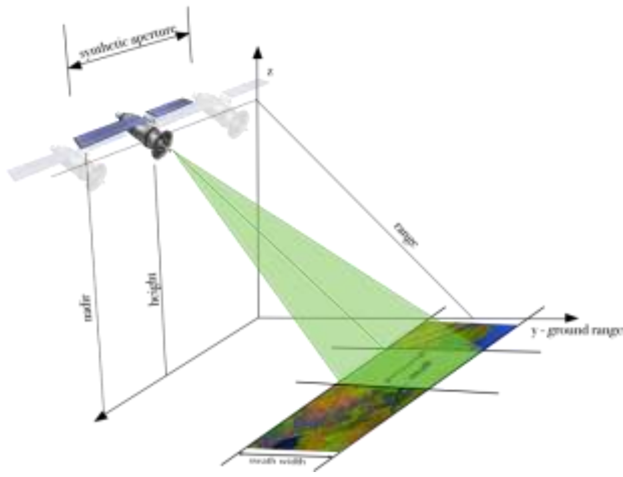

Figure 2 Geometry of a SAR system

Chirp pulses are often used to obtain fine range resolution. With a reasonable amount of transmitted power, sufficient range is achieved. A *chirp* signal has a constant amplitude and a linearly frequency modulated phase within a certain bandwidth. For each transmitted *chirp*, echoes from the entire illuminated swath are received and recorded. In this way, the observed scene information is hidden in the delay difference of the echoes. The received signals are represented by complex values, the real part being the amplitude of the received echo and the imaginary part the phase relative to the transmitted signal. Thus, the phase is directly related to the echo delay and, therefore, to the information in range.

ISSN 2523-6873

When passing over a target, the target is illuminated by the instrument and the instrument reflects the multiple pulses sent by the sensor. As the distance between the sensor and the target changes between pulses due to geometry, a specific phase shift can be observed at a certain range. The distance change roughly follows a quadratic function in time and thus causes a range-dependent phase shift in time, similar to a *chirp* pulse. This leads to the formation of the synthetic aperture.

SAR data are not interpretable by themselves; to obtain an image, they must be compressed. In the range direction, the received signal is filtered by a filter coupled to the transmitted pulse. In the azimuth direction, the phase shift effect in the synthetic aperture is used to generate a range-dependent reference function, which is then used by a matched filter to perform the azimuth compression (Moreira *et al*, 2013).

In general, the resolution in range is inversely proportional to the bandwidth *B* of the *chirp* signal,

$$\delta_{rg} = {}^{c}/_{2B} \quad (1)$$

where *c* is the speed of light. While the resolution in azimuth depends on the length (aperture) of the physical antenna *F*,

$$\delta_{az} = {}^{F}/_{2}. \quad (2)$$

SAR Tomography

TomoSAR constructs three-dimensional images of the illuminated scene using a principle similar to SAR. Specifically, TomoSAR synthesizes an aperture in the direction perpendicular to the line of sight (PLOS). Then, the resolution in elevation is inversely proportional to the tomographic aperture L_{tomo} (Martín del Campo *et al*, 2020),

$$\delta_{PLOS} = \frac{\lambda r}{2L_{tomo}}, \quad (3)$$

where λ is the wavelength and r is the distance from the ranging sensor to a particular target.

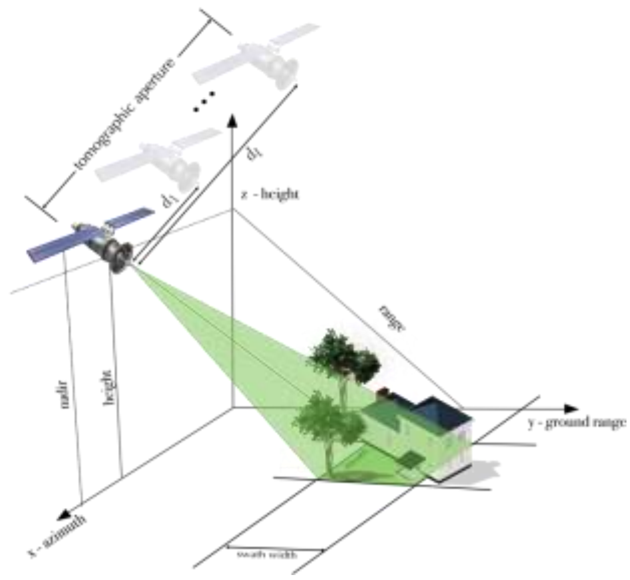

Figure 3 TomoSAR Geometry

The basic geometry of TomoSAR is shown in Figure 3. Different acquisitions at different lines of sight (heights) form a linear array of sensors. The tomographic aperture corresponds to the distance between the first and the last acquisition.

The set of the L signals collected is represented by the vector $\mathbf{y} \in \mathbb{C}^L$,

$$\mathbf{y}_{L\times 1} = \mathbf{A}_{L\times M}\mathbf{s}_{M\times 1} + \mathbf{n}_{L\times 1}. \quad (4)$$

where $\mathbf{s} \in \mathbb{C}^M$ is a reflectivity vector composed of $\boldsymbol{M}$ samples taken from $\{z_m\}_{m=1}^{M}$ positions in elevation. The vector $\mathbf{n} \in \mathbb{C}^L$ represents the additive noise; while the matrix $\mathbf{A}$ is composed of the vectors $\{\mathbf{a}_m\}_{m=1}^{M}$. For a particular position z,

$$\mathbf{a}(z) = \left[1, \exp\{jk_{z_2}\, z\}, \dots, \exp\{jk_{z_L}\, z\}\right], \quad (5)$$

with

$$\left\{k_{z_l} = \left(\frac{4\pi}{\lambda}\right)\left(\frac{d_l}{r\sin(\beta)}\right)\right\}_{l=2}^{L}, \quad (6)$$

where d_l is the distance of each sensor with respect to a main (master) sensor and θ is the angle of incidence.

According to the theory on spatial and spectral signal analysis (Stoica and Moses, 2015), parametric and non-parametric methods can be used to focus TomoSAR data. In this work, two nonparametric methods (MSF and Capon) are used, which in turn make use of the covariance matrix

ISSN 2523-6873

$$\mathbf{Y} = \frac{1}{J}\sum_{j=1}^{J}\mathbf{y}_{(j)}\mathbf{y}_{(j)}^{+}, \quad (7)$$

where J is the number of independent observations made.

MSF is defined by (Martín del Campo, 2020)

$$\mathbf{b}_{\mathrm{MSF}} = \{\mathbf{A}^{+}\mathbf{Y}\mathbf{A}\}_{\mathrm{diag}}, \quad (8)$$

where $\{\cdot\}_{\mathrm{diag}}$ is an operator that returns the diagonal vector of the argument matrix. The vector $\mathbf{b} = \{\langle|s_m|^2\rangle\}_{m=1}^{M}$ represents the backscattered power in PLOS direction, for a certain azimuth-range cell within the illuminated area. On the other hand, Capon is defined by (Martin del Campo, 2020)

$$\mathbf{b}_{\mathrm{Capon}} = \left\{\frac{1}{\mathbf{a}_m^{+}\mathbf{Y}^{-1}\mathbf{a}_m}\right\}_{m=1}^{M}. \quad (9)$$

Backscatter mechanisms are usually classified as: double bounce, volume and surface (Tebaldini, 2012). Figure 4 shows the different cases for a forest area using L-band.

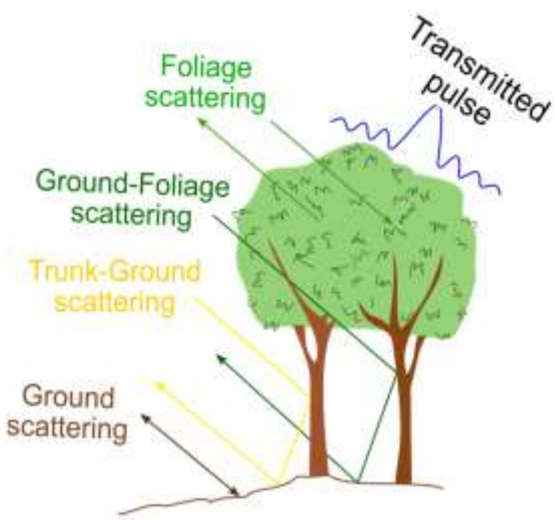

Figure 4 Backscatter mechanisms in a forest area *(Tabaldini, 2012)*

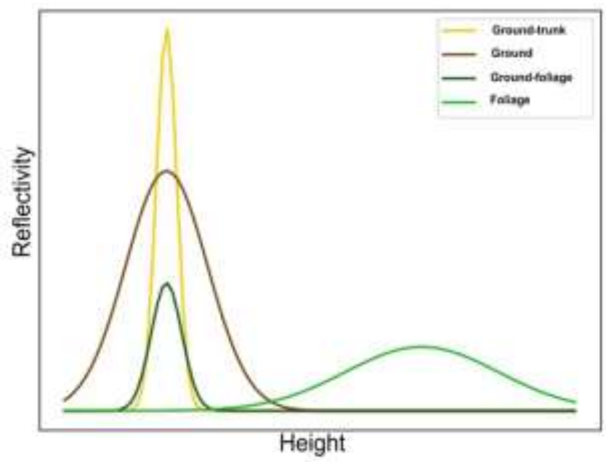

Figure 5 Distribution associated with each backscatter in Figure 4 *(Tebaldini, 2012)*

Figure 5 presents the reflectivity distribution in PLOS direction for each backscatterer in Figure 4. The different backscatterers are characterized as follows (Tebaldini, 2012). Foliage: volume backscatter with phase center located above the surface and at the level of the foliage; depending on the foliage and associated reflectivity, it spreads along the perpendicular with respect to the direction in range. Ground - Foliage: double bounce backscatter with ground phase center. Trunk - Ground: double bounce backscatter with ground phase center (higher reflectivity level). Ground: surface backscatter with ground phase center.

After focusing the tomographic data by means of MSF or Capon, the local maxima in the **b** elevation power distribution correspond to the different phase centers. In the case of Figure 5, two main phase centers are presented, one associated to the surface height and the other associated to the foliage height. If there were more vegetation layers (e.g., smaller trees or shrubs below), in addition to the surface phase center, as many phase centers as vegetation layers would also be displayed; limited by the resolution achieved.

This work shows how TomoSAR is also able to recognize the phase center of those structures below the forest canopy. Buildings, for example, are often characterized primarily with double-bounce backscatter. If there are any structures hidden beneath the foliage, TomoSAR is able to retrieve and display their phase center.

ISSN 2523-6873

Simulations

An L-band SAR sensor (0.23 m wavelength) at an altitude of 3000 m is considered. The acquisition geometry consists of 24 equidistant flights, distributed over a 120 m tomographic aperture. The distance between the targets and the main (master) sensor is approximately 4000 m, with a resolution δ_{PLOS} = 3.8 m approximately.

The covariance matrix in (7) is constructed with $J =$ 350 independent realizations. The simulated scene is composed of 4 layers (targets). For each resolution cell, each layer is composed of 100 backscatterers with equal reflectivity, following Gaussian distributions. The use of Gaussian distributions is to introduce statistical uncertainty; in this way we do not rely only on additive noise to introduce decorrelation. Multiplicative noise is not taken into account.

In the region that constitutes the Selva Lacandona, trees such as cedar and guácimo are found. The cedar reaches a height of 35 meters and a diameter of 1.5 meters; the base of the trunk is straight with small buttresses (Pennington and Sarukhán, 2005). Guácimo reaches a height of 25 meters and a diameter of 70 centimeters. It has a straight trunk, sometimes with bulges or suckers, slightly grooved at the base (CATIE, 1991).

Taking into account the characteristics of the Selva Lacandona zone, the layers are defined within certain height ranges in meters. Soil $\dot{z_1} = [0, 1.5]$, first vegetation layer $\dot{z_2} = [15, 25]$, second vegetation layer $\dot{z_3} = [28, 40]$, third vegetation layer $\dot{z_4} = [40, 52]$. The heights in each resolution cell fluctuate randomly, in order to simulate diversity, common in forested scenes.

The distribution associated with the soil has a standard deviation of 0.05 m, while the vegetation layers are characterized by distributions with standard deviations of 0.35 m. In order to demonstrate TomoSAR's ability to detect structures below the forest canopy, a building located below the tree canopy has been included.

The simulations were performed with the Python programming language. Use is made of a GPU, through the CuPy library, to perform matrix operations such as dot product, outer product and inverse of a matrix. The following table shows the times achieved by CuPy, in contrast to the classical NumPy library, for different data cubes [azimuth (Az) × range (Rg) × height].

	Az × Rg × Height	Time	RAM CPU	RAM GPU
Numpy Cupy	10×10×450 [samples]	4 min 6 min	2.8 GB 2.8 GB	80 MB 106 MB
Numpy Cupy	50×50×450 [samples]	20 min 30 min	3 GB 2.8 GB	406 MB 596 MB
Numpy Cupy	100×100×450 [samples]	40 min 1 hr	3.2 GB 2.9 GB	700 MB 1.5 GB
Numpy Cupy	200×200×450 [samples]	2.47 hrs 1.50 hrs	3.6 GB 3.3 GB	750 MB 1.8 GB
Numpy Cupy	500×500×450 [samples]	12.46 hrs 8.57 hrs	4 GB 3.7 GB	953 MB 2.5 GB

Table 2 Comparison between NumPy and CuPy

See in Table 2 that for small data cubes the influence of CuPy is not noticeable; on the other hand, for larger and larger data cubes, the processing time decreases considerably. A computer with the following characteristics is used: Intel Core i7 8th generation, with 32 GB of RAM and an Nvidia GTX 1050 GPU with 4 GB of RAM.

For demonstration purposes, a tomogram (focused with MSF) is presented below, superimposed on the treed area it represents. A tomogram is basically a slice taken from the focused data cube. Note in Figure 6 that the bottom layer corresponds to topography, while the upper layers correspond to tree biomass. The crown of the tallest trees, for example, exceeds 50 m.

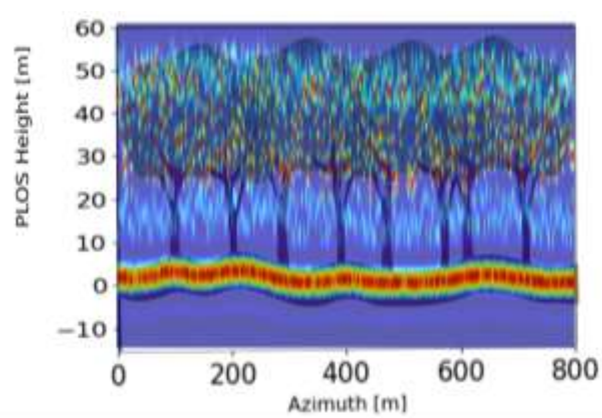

Figure 6 Interpretation of a tomogram

Results

Figure 7 shows a tomogram obtained with MSF, while Figure 8 using Capon. The power obtained by both focusing techniques has been normalized from 0 to 1. In both cases, it is possible to clearly distinguish the 4 simulated layers. Note, however, that Capon achieves a finer resolution. Figures 9 and 10 show the three-dimensional representation (renderings) of the simulated scene, for MSF and Capon respectively. Five hundred consecutive tomograms form the data cube.

In Figures 9 and 10, the structure below the vegetation layers can be clearly detected. In the case of Capon, although better resolution is achieved, one of the vegetation layers is imperceptible due to its low power levels. Finally, in order to appreciate in more detail the area where the building is located, Figures 11 and 12 present the corresponding tomograms for MSF and Capon respectively.

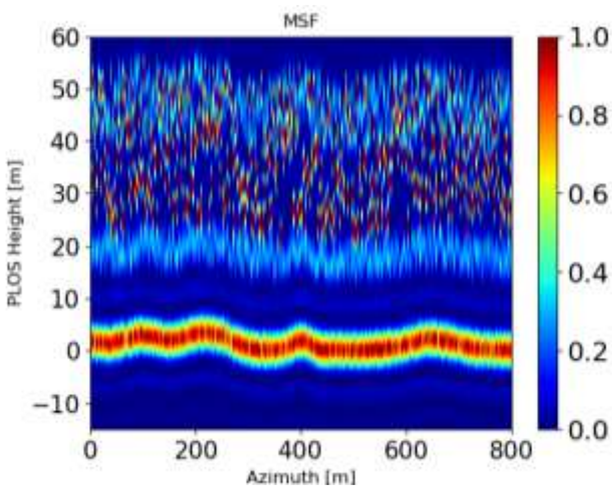

Figure 7 Tomogram obtained with MSF

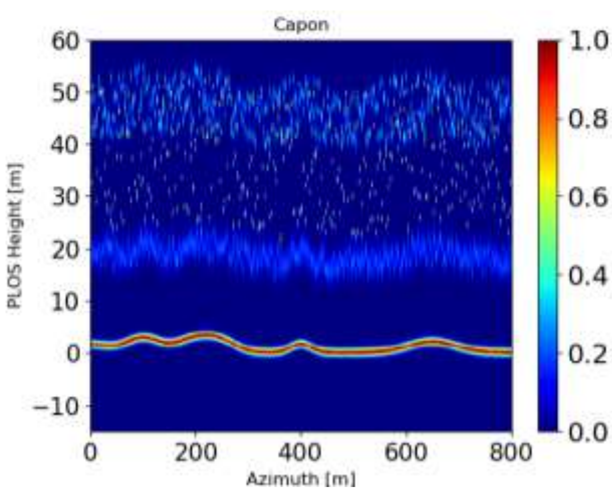

Figure 8 Tomogram obtained with Capon

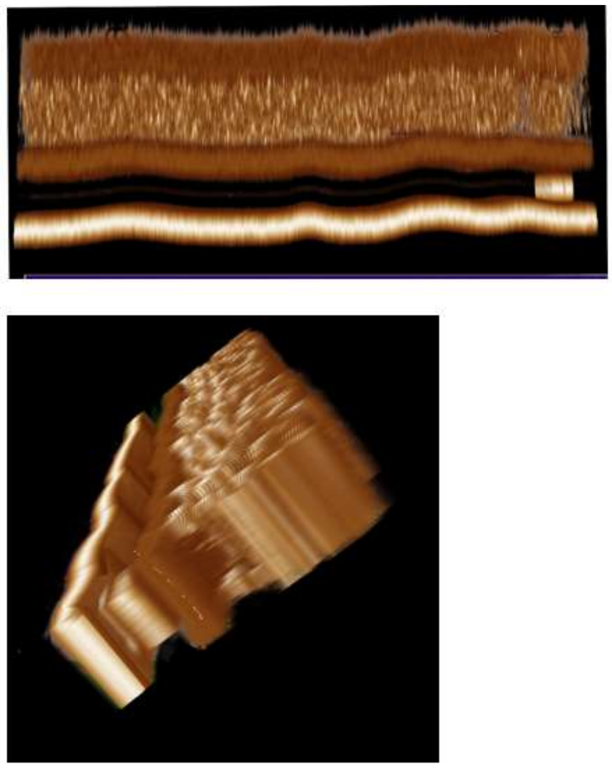

Figure 9 Render obtained with MSF

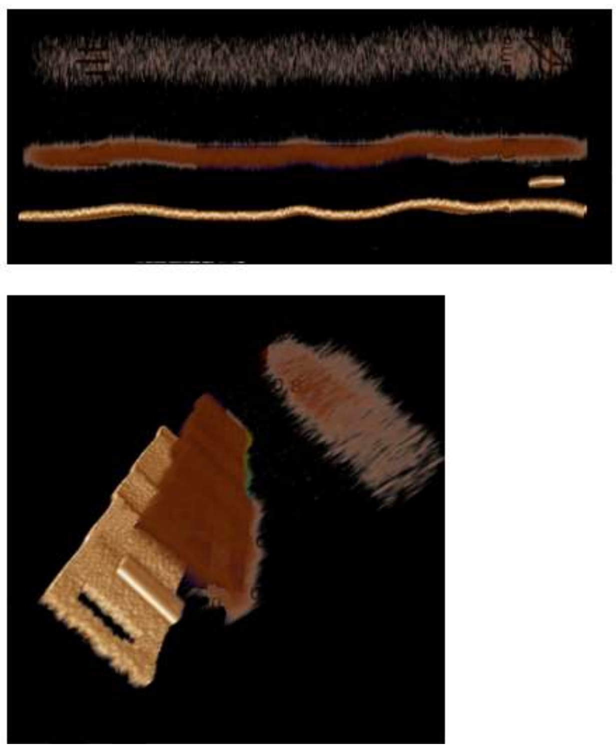

Figure 10 Render obtained with Capon

ISSN 2523-6873

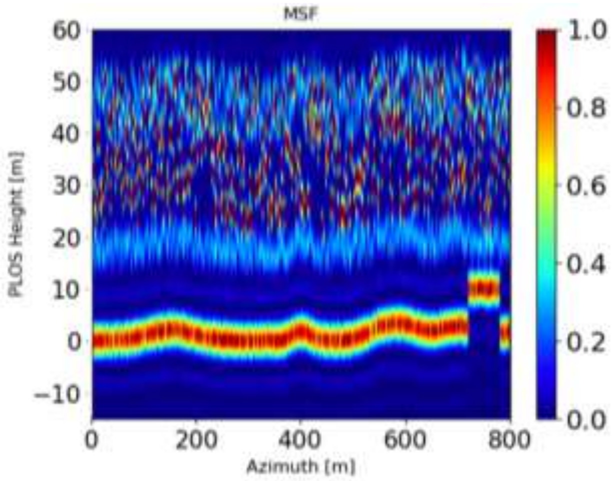

Figure 11 Tomogram obtained with MSF (hidden building)

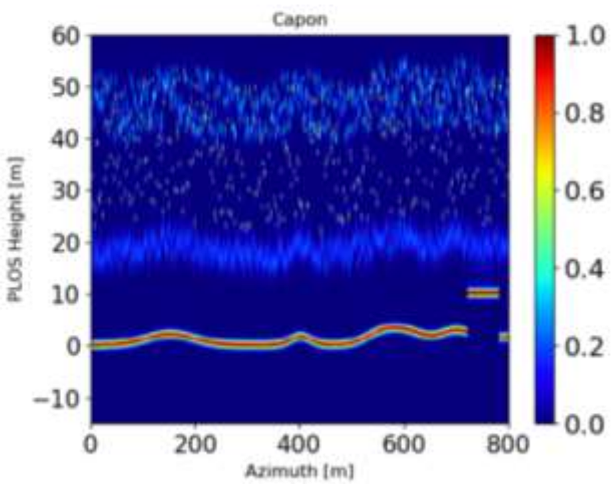

Figure 12 Tomogram obtained with Capon (hidden building)

The building is located near 800 m in azimuth. Note the abrupt change in topography when the structure is presented. For buildings like this, the backscatter of the electromagnetic wave is usually of the double-bounce type on the facade and single-bounce type on the roof.

Conclusions

The simulations successfully confirm the use of TomoSAR for the detection of structures below the forest canopy. TomoSAR being a remote sensing technique, it facilitates the exploration of jungle areas in search of archaeological remains, regardless of the terrain characteristics.

This work has made use of two of the most traditional focusing methods in this field. However, it is possible to use more sophisticated focusing techniques based on statistical regularization. Such techniques are capable of achieving significantly higher resolutions, as well as preventing *aliasing* and suppressing unwanted artifacts caused by radio interference.

Once the data cube has been correctly focused, the extraction of the local maxima of the distributions in each resolution cell constitutes a three-dimensional point cloud. From this point cloud, it is possible to apply segmentation, clustering and classification techniques to facilitate its interpretation.

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Development of a web system for the record of Clinical History in patients of the State Center for Critical Care in Salamanca Gto.

Desarrollo de sistema web para el registro de Historial Clínico en pacientes del Centro Estatal de Cuidados Críticos en Salamanca Gto.

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Abstract

Software development is a common practice carried out for different institutions, both public and private. The purpose of these developments is to improve processes, streamline tasks and keep a record and control of the information so that it can later be used for decision making. The development of the Clinical History software for the State Critical Care Center in Salamanca Guanajuato (CECCS) by the Academy of Network and Telecommunications Engineering of the Polytechnic University of Juventino Rosas, meets the requirements requested by the CECCS. This system was requested to replace manual processes that are carried out by medical and nursing personnel; these processes will be replaced by a digital registry, where the information will be permanently recorded in a database. This system starts with the registration of the patient who enters the CECCS for hospitalization, the system will assign a file number for its control. By means of this file number, the nursing staff will generate the records of both diagnosis and medications administered in the three shifts (morning, afternoon and night), these records will be carried out by means of the sheet concept (one sheet will be recorded per day of the patient's hospitalization) where each sheet will contain six pages which contain: physiological parameters, hydric response, respiratory parameters, clinical parameters, neurological assessment, device infection risk assessment, pressure ulcer assessment, burns assessment, pharmacotherapies, intravenous therapy, diagnosis and nursing standards. This system also has a role control per user, where, depending on the user's role, are the options that can be executed within the system. There is a user authentication at the beginning of the system, so that only authorized personnel can use and register the information.

Software, System, Model, Requirements

Resumen

El desarrollo de software es una práctica común que se lleva a cabo para diferentes instituciones, tanto públicas como privadas. Estos desarrollos tienen la finalidad mejorar procesos, agilizar tareas y llevar un registro y control de la información de tal manera que posteriormente se pueda hacer uso de ella para la toma de decisiones. El desarrollo del software de Historial Clínico que se llevó a cabo para el Centro Estatal de Cuidados Críticos en Salamanca Guanajuato (CECCS) por parte de la Academia de Ingeniería en Redes y Telecomunicaciones de la Universidad Politécnica de Juventino Rosas, cuenta con los requerimientos solicitados por el mismo CECCS. Este sistema se solicitó para sustituir procesos manuales que se llevan a cabo por parte del personal médico y enfermería, éstos procesos se sustituirán por un registro digital, en donde la información se quedará registrada de forma permanente en una base de datos. Este sistema inicia con el registro del paciente que ingresa al CECCS a hospitalización, el sistema le asignará un número de expediente para su control. Mediante este número de expediente, el personal de enfermería generará los registros tanto de diagnóstico, así como de medicamentos administrados en los tres turnos (matutino, vespertino y nocturno), estos registros se llevarán a cabo mediante el concepto de hoja (se registrará una hoja por día de hospitalización del paciente) en donde cada hoja contendrá seis páginas las cuales contienen: parámetros fisiológicos, respuesta hídrica, parámetros respiratorios, parámetros clínicos, valoración neurológica, valoración de riesgo de infección por dispositivos, valoración de úlceras por presión, valoración de quemaduras, farmacoterapias, terapia intravenosa, diagnóstico y estándares de enfermería. Este sistema también cuenta con un control de roles por usuario, en donde, dependiendo del rol del usuario, son las opciones que podrá ejecutar dentro del sistema. Existe una autenticación de usuario al inicio del mismo, esto con el fin de que solamente personal autorizado pueda hacer uso y registro de la información.

Software, Sistema, Modelo, Requerimientos

Citation: AGUILAR-DURÓN, Rebeca Eugenia, GALLEGOS-GALINDO, Juan Heriberto, YAÑEZ-VARGAS, Juan Israel and QUINTANILLA-DOMÍNGUEZ, Joel. Development of a web system for the record of Clinical History in patients of the State Center for Critical Care in Salamanca Gto. Journal of Innovative Engineering. 2022. 6-18: 10-17

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1. Introduction

The computer system is a tool that is used to speed up the daily work in any work environment, it has become one of the most important activities nowadays. To carry out software development it is necessary to consider several factors such as costs, planning, difficulty, available work team, programming languages used, etc. (Gómez, M., Cervantes, J. & González, P., 2019). All of these are encompassed in a software development methodology that allows the work to be organised in the most orderly way possible.

Developing a product without a clear methodology will make the project even more complex, leading to problems, delays, errors and a bad result in the end.

As well as different institutions, organisations or companies, the Centro Estatal de Cuidados Críticos de Salamanca Gto. (CECCS), has the need to have a system that registers both the diagnosis as well as the medicines administered to the hospitalised patients in the three shifts during their hospitalisation.

There are different computer systems that can be used in health centres, however, it is necessary to highlight the importance of having a customised system. In this case, the software developed was created specifically for the needs of the CECCS, which provided us with the different needs they had in the area of patient hospitalisation, specifically in the registration and control of diagnoses and medicines, among others.

2. Methodology

For the development of the Clinical History software, a RUP (Rational Unified Process) methodology was used, where, like the rest of the methodologies, it is carried out through a series of steps or tasks that are iterative (Academy & Martinez, 2017).

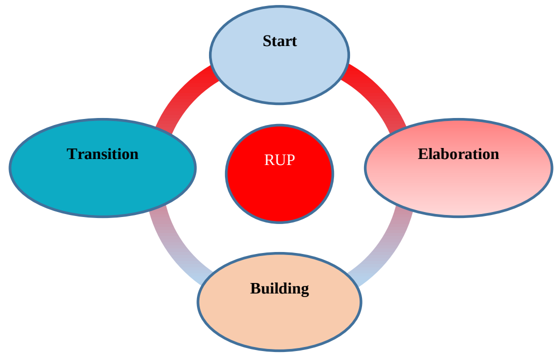

Figure 1 Life cycle of the RUP model
Source: (López, R. & Pech, J., 2015)

This methodology is characterised by being iterative, as the four phases shown in the image are executed as many times as necessary to complete the project, as shown in Figure 1, where at the end of one phase, the next phase must be continued and not the other way around (C. & A., 2020). These phases are initiation, elaboration, construction and transition, which will be executed as many times as necessary to conclude the system.

a) Initiation phase

In this phase, the client's needs are gathered through interviews with the CECCS nurses' manager, where the following requirements were identified:

No	Requirement	Type of requirement
1	Validate user access.	Functional
2	That certain people can only make changes.	Functional
3	There should be an option for certain people to consult the information only.	Functional
4	To be able to do on the computer what is captured in the manual record sheets.	Non-functional
5	That the sheets that are made manually on the computer can be recorded.	Functional
6	There should be an option for users to enter data.	Functional
7	The system can be installed on a tablet or mobile phone.	No Funcional
8	To be able to register a file for each patient.	Functional
9	Record general patient data.	Functional
10	Keep track of the number of days the patient is hospitalised.	Functional
11	Make queries of the information recorded for each patient.	Functional

Table 1 Requirements identified
Source: (Pantaleo, G., & Rinaudo, L., 2016)

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Table 1 represents the functional requirements of the system through diagrams of use cases, each of the cases are the options that the clinical history system would have. This diagram also represents the actors or users who will interact with the system, identifying the options to which they will have access in the system.

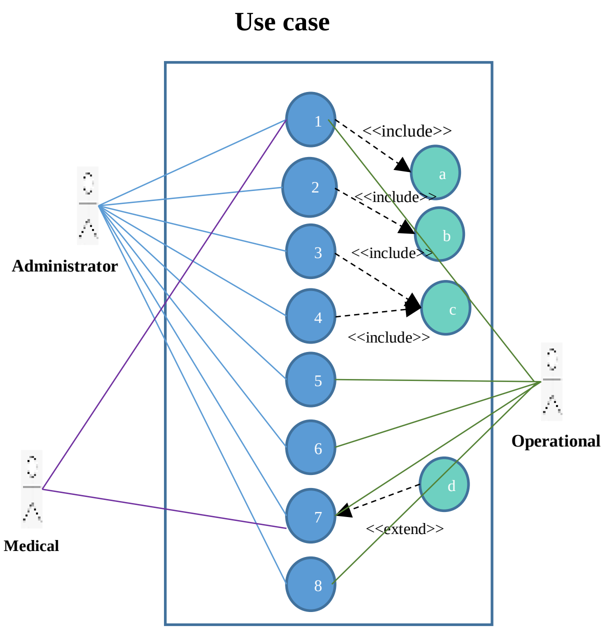

Figure 2 Diagram of use cases of the clinical history system

b) Elaboration phase

In this phase, the design of the parts of the system begins, such as the entity-relationship model that will later become the structure of the database, as well as the class diagrams, sequence diagrams and requirements for the system to be executed.

Entity-relationship model:

The entity-relationship model diagram is one of the primary tasks that must be carried out, as it is the one that will define the structure of the database, here each of the entities, attributes of each entity and the relationships between them are identified.

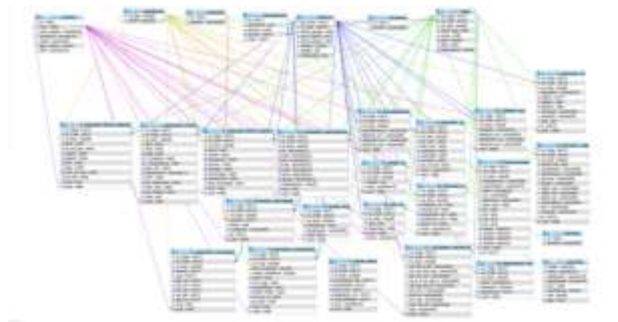

Figure 3 Entity-relationship model of the Health Record system

Figure 3 shows the relationships of the entities, which were identified after the analysis of the user requirements.

System architecture

The system architecture diagram represents the structure that the system will have, as well as its different components (Ingeniería y Arquitectura del Software | IT Campus Academy, 2017).

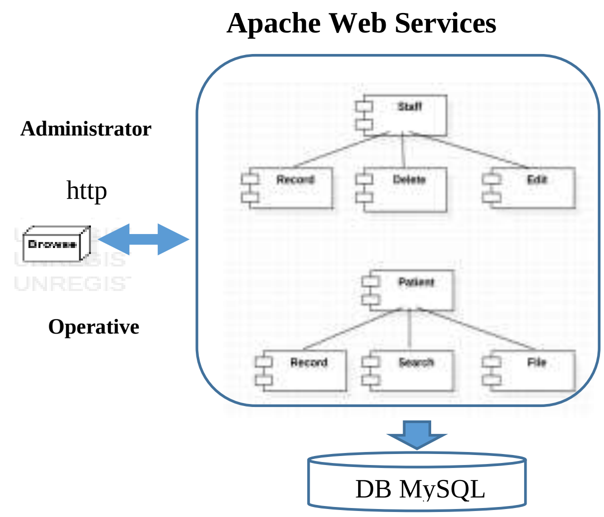

Figure 4 Architecture of the Clinical History system

Figure 4 shows the system components and their relationship with the users (Administrator, Operational and Medical), as well as identifying the browser (browse) which is the platform on which the system is executed and the database where the information generated is stored.

Sequence Diagram

Another of the diagrams that must be developed is the sequence of the system, in this diagram it is described graphically how access to it will be (Wiegers, K. & Beatty, J, 2013).

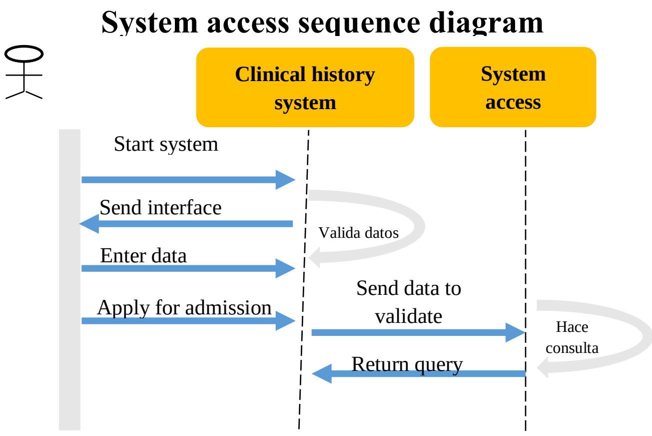

Figure 5 Sequence diagram of access to the Health Record system

Figure 5 describes the steps that will be taken for each user, regardless of role, to access the system.

The sequence diagram is a representation of the steps that will be followed each time a user accesses the system (Booch, G., Rumbaugh, J., & Jacobson, I, 2010), it is worth mentioning that there is a sequence diagram for each of the functionalities of the system.

c) **Construction Phase**

In the construction phase, the development of the different iterations of the system is carried out (Gomez, S., & Moraleda, E., 2020). The programming tools used are: html 5, css, php, javascript, as well as the MySQL database manager. The IDE used for the development is the sublime text version 3.2.2.

d) **Transition phase**

In this phase, the system will be delivered to the CECCS for final testing in the same centre.
The main interfaces of the medical records system are described below.

e) **System access interface**

Figure 6 shows the first interface that is presented when accessing the system and where users must authenticate their access.

Figure 6 Access to the Clinical History system

Initial interface of the system where access will be by means of the professional card number for both nursing and medical staff.

The registration of these cards will be done by staff with Administrator permissions

a) Role interface for users with administrator permissions

The Administrator user is the one who has access to all system options, including adding users, changing user status from inactive to inactive, registering patients, records, creating folios and making queries, among other options.

The Administrator user, see figures 7 and 8, can access the Staff and Patient options and is the only user who can execute the options in both menus.

Figure 7 Administrator user interface Personal option

Figure 8 User interface Administrator option Patients

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b) Operator user interface

The user with operator permissions can only access the Patients menu option, where he/she can register patients, create a record, and create the necessary folios in case the patient requires hospitalisation.

Figure 9 Operator user interface Patients option

Figure 9 shows the three options to which the user with operator characteristics has access, these are: Register patient, Search patient and Create Record.

c) Medical user interface

Users with these permissions will only be able to access record consultation, as shown in Figure 10.

Figure 10 Medical user interface option Patients

Although in Figure 10, the Patients option shows three options (Register, Search, Record), users with Doctor permissions only have access to the Record option and only as a query.

This system is currently being tested by the development team. Two tests are being carried out on the system:

a) Functional Testing:

Functional testing focuses on the business requirements of an application. They only verify the result of an action and do not check the intermediate states of the system when performing that action. Integration testing is sometimes confused with functional testing, as both require various components to interact with each other. The difference is that an integration test may simply verify that you can query the database, while a functional test would expect to obtain a specific value from the database, as dictated by the product requirements (Arias, A., & Durango, A, 2016).

b) Comprehensive Testing:

Comprehensive testing replicates a user's behaviour with the software in a complete application environment. They also verify that various user flows work as intended, and can be as simple as loading a web page or logging in, or much more complex, such as verifying email notifications, online payments, etc. Comprehensive tests are very useful, but are costly to run and can be difficult to maintain when automated. It is recommended to have a few key end-to-end tests and rely more on lower level tests (unit and integration) to be able to quickly detect new changes (Gomez, S., & Moraleda, E., 2012).

These tests are carried out mainly to verify possible errors in the execution of the different options and at the same time check the full functionality of the functions assigned to each of the user types (Administrator, Operator, Doctor).

Once the above tests are completed, the system will be installed on the client's server, which will have a period of 30 days to test the system in the State Centre for Critical Care of Salamanca (CECCS), if errors occur in the execution should be reported to the development team for attention. If there are no errors, the system will be put into production at the CECCS.

3. Results

The results presented are according to the types of functional tests, this type of tests are related to the system executing the functions for which it was programmed. In the following, the results of two of the main functions of the system will be shown: system access and file registration.

Access to the system: this function is the one that will allow or not the access to the system to the different users of the CECCS, for which, each user has different permissions, administrator, operator and doctor, so that every user that requires access to the system must be registered in the system or otherwise he/she will not be able to access it.

Figure 11 System access interface

For access, the user must enter his/her ID number and password, as shown in Figure 11, to gain access to the system. These data should have been previously registered by the administrator user who has the privileges to make these registrations. After the user presses the login button, the system must validate that the ID and password are registered in the database in order to give access to the next interface. If the above data is incorrect, the system will show error in the data, as shown in figure 12.

Figure 12 Error in accessing the system

System operation: These functions allow you to record the evolution of the patient while he/she is hospitalised.

Record register: this option has the function of registering the data of the patient who will be hospitalised. To do so, the data shown in figure 13 is requested, where the patient's personal data is requested, as well as the information necessary to keep track of the patient's stay in the hospital.

Figure 13 Record register

Each record is composed of folios, each folio is the number of times that the patient has been hospitalised, each folio has a sheet number, this sheet is each of the days that the patient is hospitalised, and each sheet has six pages, each page corresponds to each of the studies.

Figure 14 shows the interface where the data of file 290-C1 are registered, Folio #1, this folio number is because it is the first time that the patient is hospitalised, Sheet #1 corresponds to the first day of hospitalisation and page #1 corresponds to the physiological parameters, these parameters are registered in the three shifts, morning which is from 08:00 to 14:00 hours, afternoon which is from 15:00 to 20:00 hours and night which is from 21:00 to 07:00 hours of the following day.

Figure 14 Physiological parameters page

Figure 15 shows page #2 corresponding to the respiratory parameters, from folio #1, sheet #1, file 290-C1.

Figure 15 Respiratory parameters

Figure 16 shows page #3, which is where the data of the resulting assessment made by the staff to the patient with respect to burns, falls and PU control presented by the patient are recorded. This page still corresponds to file 290-C1, folio #1, sheet #1**.**

Figure 16 Assessment of burn, fall and PU control

Figure 17 shows page # 4 corresponding to the diagnosis and clinical standards for nursing in nutrition from file 290-C1, folio #1, sheet #1.

Figure 17 Diagnosis and clinical standards of nursing in nutrition

Figure 18 shows page # 5 corresponding to the diagnosis and clinical standards for nursing in stress tolerance from file 290-C1, folio #1, sheet #1.

Figure 18 Diagnosis and clinical standards of nursing in stress tolerance

Figure 19 shows page # 6 corresponding to clinical notes and patient evolution from file 290-C1, folio #1, sheet #1.

Figure 19 Clinical notes and patient evolution

Conclusions

Nowadays, software development has had great importance in the institutions, in the educational, business, health, services, etc. areas, since it has been considered a fundamental aspect to improve the services and the effectiveness of the activities that are carried out in those places. It is a reality that the world is becoming increasingly competitive, the objective is to increase efficiency at the lowest possible cost and time, so implementing automation programmes has made it possible to transform the operation of the labour sector to reduce the time in the execution of daily activities.

The use of technological applications in the health sector will improve the services provided to its users, given that through these applications it is possible to keep better control of information on patients, doctors, diagnoses, studies, hospitalisation time, among other important data. Being able to store relevant information on a permanent basis means that decisions can be made more quickly regarding the health situation of patients.

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The use of software is also important in the health sector as its implementation reduces the time and errors of staff recording information and improves administrative processes.

Among the benefits of software in the health sector are the registration of the information of each person who uses it, as well as everything that has to do with the patient's consultation (doctor, diagnosis, medicine, date of consultation, etc.).

Finally, given that the sector is an institution for the care of people, it is important that it has the necessary tools to improve this care by reducing time and costs.

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Analysis of heat transfer in a helical exchanger using different correlations

Análisis de la transferencia de calor en un intercambiador helicoidal utilizando diferentes correlaciones

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Abstract

This research focuses on the evaporation process carried out in a helical exchanger where the R134a refrigerant passes through the internal diameter as primary fluid, the saturation temperatures are in the range of 10-20 oC with mass flows of 0.022 to 0.043 kg/s. Water-Ethylene Glycol 50% as secondary fluid that passes through the external diameter. Different correlations are applied to determine the convective coefficients, later the theoretical results will be compared with experimental results shown in the literature. It was observed that the coefficients increase when the quality of the coolant increases, increases

Correlations, Global transfer coefficient, Quality (x), Convective coefficients

Resumen

Esta investigación se enfoca al proceso de evaporación realizado en un intercambiador helicoidal donde el refrigerante R134a pasa por el diámetro interno como fluido primario, las temperaturas de saturación están en el rango de 10-20 ºC con flujos másicos de 0.022 a 0.043 kg/s. Agua-Etilenglicol al 50% como fluido secundario que pasa por el díametro externo. Se aplican diferentes correlaciones para determinar los coeficientes convectivos, posteriormente los resultados teóricos serán comparados con resultados experimentales mostrados en la literatura. Se observó que los coeficientes aumentan cuando la calidad del refrigerante aumenta, aumenta el número de vueltas del intercambiador y la altura.

Correlaciones, Coeficiente global de transferencia, Calidad (x), Coeficientes convectivos

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Introduction

Helical heat exchangers are characterized by the type of configuration in geometry. These are found in the food industry, in nuclear reactors and in cooling systems. One of the outstanding characteristics of this type of pipe is the helical geometric configuration of the tube, the helical curvature induces secondary flows due to the effect of centrifugal force.

Helical pipes are available in various materials such as: low carbon steel, copper, aluminum, stainless steel, among others. They can be obtained with a certain outer diameter and wall thickness, in general it is a single tube bent in the form of a helix, with a separation between turns called pitch or pitch.

The first observations of the effect of curvature on flow in helical pipes were observed at the beginning of the 20th century. Grindley and Gibson (1908) noted the effect of curvature on flow in a helical pipe when they experimented with air as the fluid.

The first work done to mathematically describe the flow in a helical pipe was done by Dean (1927, 1928). In his first work Dean, described an approximation of an incompressible fluid moving at constant speed inside a helical pipe, making a cross section in the circular section.

Although this approximation represented a qualitative result thanks to experimental observations, he was unable to demonstrate the relationship between pressure drop, flow and curvature for a helical pipe [1,2].

Wongwises and Polsongkram [3] obtain experimental results of the internal convective coefficients as a function of the quality of the refrigerant R134a in a helical evaporator, varying the heat transfer and the mass velocities. The results are compared with correlations found in the literature. Subsequently, they obtain a new correlation for the calculation of the internal convective coefficient for R134a. Cui and Li et al.,[4] experimentally and theoretically analyze the heat transfer and the boiling mechanisms in a helical exchanger with finned tube for refrigerant R134a, they obtain results of the internal convective coefficients as a function of the quality at different flows. mass and heat fluxes.

Subsequently, they develop a new correlation for this type of heat exchanger with an acceptable deviation of 13.8% with respect to the experimental data. Chen and Han et al., [5] experimentally investigated the internal convective coefficients and temperature distribution of refrigerant R134a in a helical exchanger with low mass flows and pressures.

With their obtained results, they developed a correlation to calculate the internal convective coefficients with a deviation of 3.6%. Kumar and Faizee et al., [6] carry out a numerical modeling of the transfer for internal and external flows in a helical exchanger using the governing equations of momentum, continuity and energy. Global transfer coefficients, Nusselt number, Reynolds number, and friction factors were calculated for a counterflow configuration.

A new empirical correlation was developed to calculate the Nusselt number for the coolant. In this work, an analysis of the evaporator will be carried out to obtain the internal convective coefficients of the refrigerant when there is a phase change using different correlations and the total heat transfer, then make a comparison with experimental data to validate the model.

Methodology

The model for the helical evaporator in this work is presented in Figure 1, the input parameters are: geometric data, mass flows, inlet temperatures of R134a and the water-ethylene glycol mixture at 50% volume. The most representative output results are: the internal and external convective coefficients, outlet temperatures, height and the number of turns of the evaporator. Table 1 shows the geometric parameters of the helical evaporator.

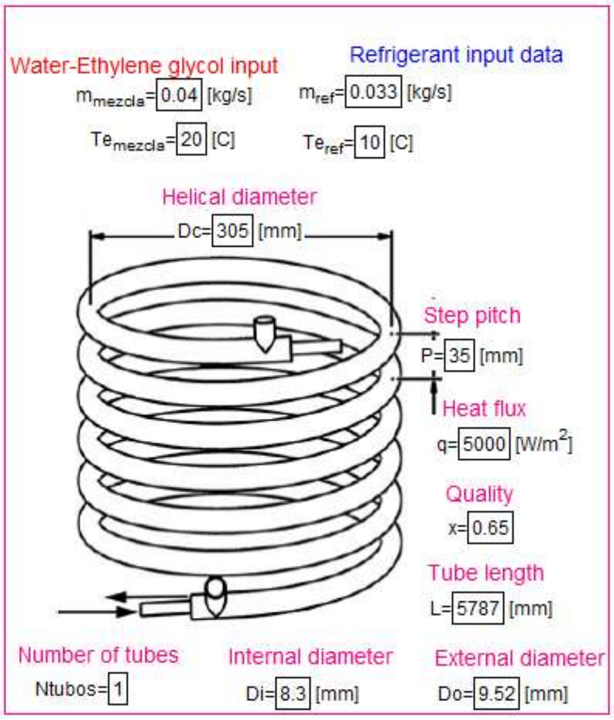

Figure 1 Geometry representation of the helical exchanger
Source: Own Elaboration

Tube length (mm	5787
Tubes external diameter (mm)	9.52
Tubes internal diameter (mm)	8.3
Spiral diameter (mm)	302
Step Pitch (mm)	35
Shell diameter (mm)	22
Number of turns	6
Spiral height (mm)	211.4

Table 1 Geometric data of the spiral heat exchanger obtained by Somchai et al. [3]

Mathematical model

For the model generated in the EES, the input parameters are: geometric data of the heat exchanger, mass flows, inlet temperatures of the shell and tubes as shown in Figure 1. In the simulation model, the thermal properties are determined. of the fluids and a calculation algorithm is applied to determine the operating conditions of the shell and tube heat exchanger outlet.

Internal convective coefficients.

The internal convective coefficients for the refrigerant R134a in the model, the following correlations are proposed, one is proposed by Jitian et al., [7] obtains an empirical correlation for R134a when there is a phase change in a helical evaporator, presented in the equation 1.

$$\frac{h_{tp}}{h_{lo}} = 2.84\left(\frac{1}{x_{tt}}\right)^{0.27} + 46162Bo^{1.15} - 0.88 \quad (1)$$

Schorck-Grossman [8] obtains a correlation shown in equation 2 for R134a when there is a phase change in the evaporator.

$$\frac{h_{tp}}{h_{lo}} = 1.11\left(\frac{1}{x_{tt}}\right)^{0.66} + 7400Bo \quad (2)$$

Zhao et al., [9] propose a new correlation to calculate the internal convective coefficient of R134a as shown in equation 3

$$\frac{h_{tp}}{h_{lo}} = 1.6\left(\frac{1}{x_{tt}}\right)^{0.74} + 183000Bo^{1.46} \quad (3)$$

Donde h_{lo} se obtiene de la siguiente manera:

$$h_{lo} = \frac{1}{41}\mathrm{Re}_{lo}^{5/6}\,\mathrm{Pr}_l^{0.4}\left(\frac{d_i}{d_{coil}}\right)^{1/12}\left(1+\frac{0.061}{\left(\mathrm{Re}_{lo}(d_i/d_{coil})^{2.5}\right)^{1/6}}\right)\frac{k_l}{d_i} \quad (4)$$

Donde el Reynolds Re_{lo} está dado por:

$$\mathrm{Re}_{lo} = \frac{Gd_i}{\mu_l} \quad (5)$$

Ishida y De la Harpe [10] propone la correlación mostrada en la ecuación 6.

$$\frac{h_{tp}}{h_l} = 1.8\left(\frac{1}{x_{tt}}\right)^{0.75} \quad (6)$$

Where hl is obtained by the following equation:

$$h_l = \frac{1}{41}\mathrm{Re}_l^{5/6}\,\mathrm{Pr}_l^{0.4}\left(\frac{d_i}{d_{coil}}\right)^{1/12}\left(1+\frac{0.061}{\left(\mathrm{Re}_l(d_i/d_{coil})^{2.5}\right)^{1/6}}\right)\frac{k_l}{d_i} \quad (7)$$

And the Reynolds number is a function of quality:

$$\mathrm{Re}_l = \frac{G(1-x)d_i}{\mu_l} \quad (8)$$

The Martinelli parameter is calculated as follows:

$$x_{tt} = \left(\frac{1-x}{x}\right)^{0.9}\left(\frac{\rho_v}{\rho_l}\right)^{0.5}\left(\frac{\mu_l}{\mu_v}\right)^{0.1} \quad (9)$$

Bell and Owhandi [11] present a modification of Chen's correlation for shell-and-tube coil evaporators.

$$h_{tp} = 0.00122\frac{k_l^{0.79}Cp_l^{0.45}\rho_l^{0.49}}{\sigma^{0.5}\mu_l^{0.29}i_{fg}^{0.24}\rho_l^{0.24}}\Delta T_{sat}^{0.24}\Delta P_{sat}^{0.75}S$$
$$+0.023\mathrm{Re}_l^{0.8}\Pr_l^{0.4}\frac{k_l}{d_i}\left(\mathrm{Re}_l\left(\frac{d_i}{d_{coil}}\right)^2\right)^{0.05}F \quad (10)$$

Where the biphasic multiplicative factor (F) is obtained as follows:

$$F = 1 \rightarrow \frac{1}{x_{tt}} \leq 0.1$$
$$F = 2.35\left(\frac{1}{x_{tt}}+0.213\right)^{0.736} \rightarrow \frac{1}{x_{tt}} > 0.1 \quad (11)$$

And the suppression factor (S) is calculated:

$$S = \frac{1}{1+2.53x10^{-6}F^{1.25}\mathrm{Re}_l} \quad (12)$$

Kumar et al., [12] develop a correlation to calculate the internal convective coefficient when there is a phase change in a helical evaporator presented in equation 13.

$$Nu_i = 0.0509\mathrm{Re}_{lo}^{0.817}\Pr_l^{0.3}\left(\frac{d_i}{d_{coil}}\right)^{-1} \quad (13)$$

Once calculating the Nusselt number, the internal convective coefficient can be obtained.

$$Nu_i = \frac{h_{tp}d_i}{k_l} \quad (14)$$

External convective coefficients.

For the external convective coefficients, a general correlation obtained by Petukov-Kirillov (1976) is proposed, where they use a relation for the helical geometry. Equation 15 is a correlation for straight tubes.

$$Nu_s = \frac{(f/2)\mathrm{Re}_{fext}\Pr_{fext}}{1.07+12.7(f/2)^{0.5}(\Pr_{fext}^{0.66}-1)} \quad (15)$$

Applying the relationship for helical geometry:

$$\frac{Nu_c}{Nu_s} = 1.0+3.6\left[1-\frac{D_e}{d_{coil}}\right]\left(\frac{D_e}{d_{coil}}\right)^{0.8} \quad (16)$$

The friction factor is a function of the Reynolds:

$$f = (1.58Ln\,\mathrm{Re}_{fext}-3.28)^{-2} \quad (17)$$

Reynolds number:

$$\mathrm{Re}_{fext} = \frac{\rho_{fext}u_{fext}D_h}{\mu_{fext}} \quad (18)$$

Where the hydraulic diameter (Dh) and the equivalent diameter (De) are expressed as follows:

$$D_h = \frac{d_o^2 - n_{tubos}d_i^2}{d_o + n_{tubos}d_i} \quad (19)$$

$$D_e = \frac{d_o^2 - n_{tubos}d_i^2}{n_{tubos}d_i} \quad (20)$$

The convective coefficient for the external side based on the Nusselt number is expressed as follows:

$$h_{fext} = \frac{Nu_c k_{fext}}{D_e} \quad (21)$$

The thermophysical properties of the water-ethylene glycol mixture are shown by means of polynomial regressions where the temperature, T, is expressed in ^{o}C.

Density (kg/m3):

$$\rho_{fext} = 1082.9 - 0.460917T$$
$$-0.00190268T^2 - 2.23388x10^{-6}T^3$$

Viscosity (kg/m-s):

$$\mu_{fext} = 0.00873992 - 0.00027T$$
$$+3.3x10^{-6}T^2 - 1.4015x10^{-8}T^3$$

ISSN 2523-6873

Heat capacity (J/kg-K):

$$Cp_{fext} = 3180.17 + 7.189T - 0.03246T^2 + 0.0000923T^3$$

Thermal conductivity (W/m-K):

$$k_{fext} = 0.3756 + 0.00083T - 2.7245x10^{-6}T^2 + 1.03x10^{-8}T^3$$

The heat flux is calculated:

$$q = \frac{Q_{total}}{A_{total}} \quad (22)$$

Once the total heat is determined, the outlet temperatures of the shell-side and tube-side fluids can be estimated by means of an energy balance using the following equation:

$$Q_{total} = m_{fext} Cp_{fext} (T_{sfext} - T_{efext}) \\ Q_{total} = m_{ref} Cp_{ref} (T_{eref} - T_{sref}) \quad (23)$$

The height of the helical evaporator is determined as follows:

$$Y = P.N_{vueltas} \quad (24)$$

Where the number of turns is calculated:

$$N_{vueltas} = \frac{L_{th}}{\pi d_{coil}} \quad (25)$$

Representing the global heat transfer coefficient as a function of the internal and external convective coefficients as follows:

$$U = \frac{1}{\frac{d_o}{d_i h_{tp}} + \frac{d_o Ln(d_o / d_i)}{2k_{mat}} + \frac{1}{h_{fext}}} \quad (26)$$

To validate the model proposed in this work, a simulation was carried out in the EES software, varying the mass flows of R134a at different inlet temperatures, while the mass flow and the temperature of the mixture remain constant.

Table 2 shows the 4 simulations carried out with the data of the inlet refrigerant to the helical evaporator, which are: temperature, heat flow and mass flow.

After obtaining theoretical results of the internal convective coefficients when the quality of the refrigerant changes, a comparison is made with experimental results provided by Somchai et al., [3]. The mass flow rate of the mixture is 0.04 kg/s at an inlet temperature of 20 ^oC.

	Simulation 1	Simulation 2
T_{eref} (^oC)	10	15
q (kW/m^2)	5	5
m_{ref} (kg/s)	0.033	0.022
	Simulation 3	**Simulation 4**
T_{eref} (^oC)	15	15
q (kW/m^2)	5	10
m_{ref} (kg/s)	0.033	0.043

Table 2 Fluid input data for the 4 proposed simulations

Results

Figure 2 shows the results of simulation 1, the behavior of the internal convective coefficients with different correlations is observed as the quality of the R134a refrigerant increases. It is observed that the results obtained with the Jitian and De la Harpe correlations are close to the experimental results obtained bay Somchai, however the results with the other correlations are not very close to the experimental ones.

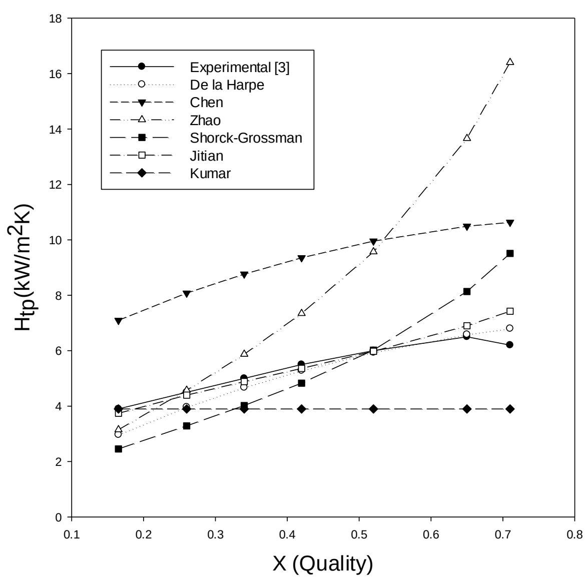

Figure 2 Results of the simulation 1
Source: Own Elaboration

Figure 3 shows the results of simulation 2. It is observed that the convective coefficients obtained with the Zhao correlation increase rapidly when the quality increases, using the Chen correlation the results are above the experimental ones. The results with Jitian and De la Harpe are the closest to the experimental ones.

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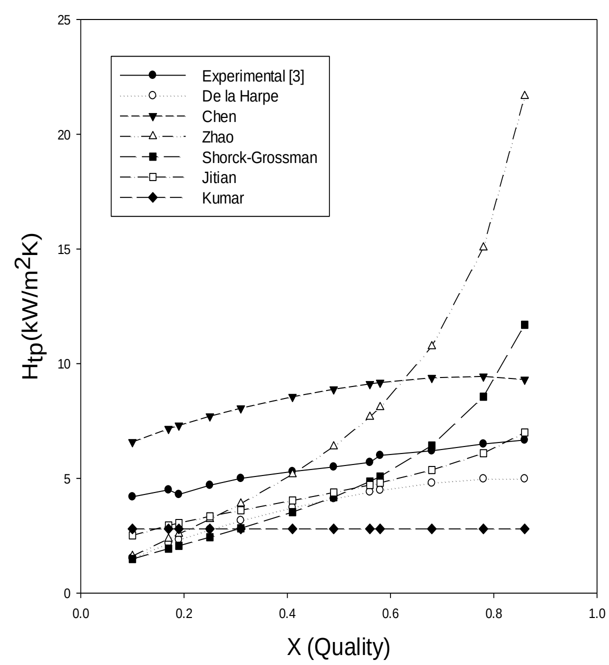

Figure 3 Results of the simulation 2
Source: Own Elaboration

Figure 4 shows the results of simulation 3, it is observed that the results obtained with Kumar are constant, since the correlation does not depend on the quality of the coolant, De la harpe and Jitian continue to be the results closest to the experimental ones.

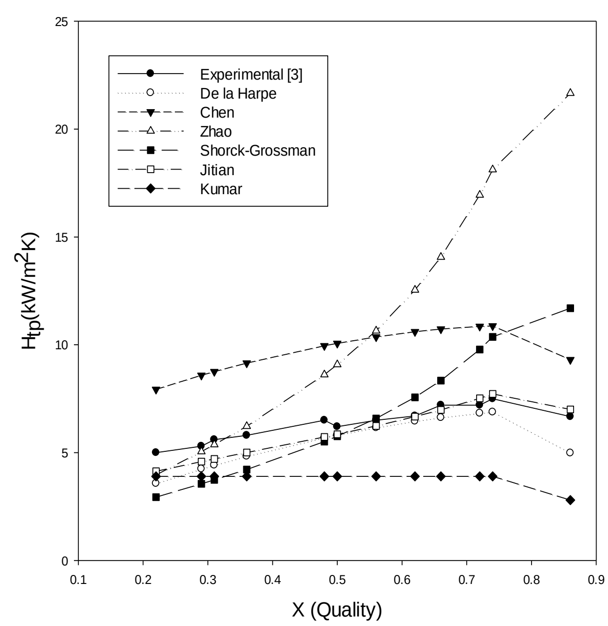

Figure 4 Results of the simulation 3
Source: Own Elaboration

Figure 5 shows the results of simulation 4, it is observed that they have the same behavior as the previous simulations.

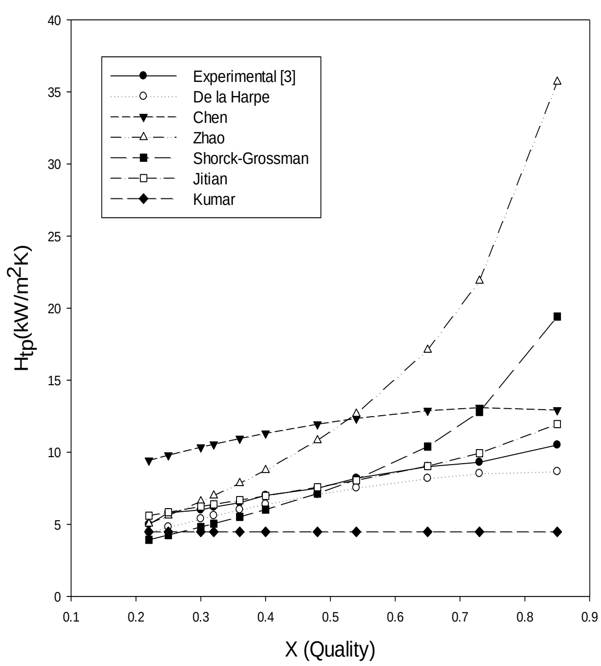

Figure 5 Results of the simulation 4
Source: Own Elaboration

The results of the internal convective coefficients obtained with the Jitian correlation are the closest to the experimental results as the quality changes. Once the model was validated, the following simulations were carried out, predicting the different behaviors of the helical evaporator using the Jitian correlation.

Figure 6 shows the results of the convective evaporation coefficients (h_{tp}) using the Jitian correlation when the helical diameter (d_{coil}) ranges from 50mm to 305mm at different qualities of R134a. The coolant input data from simulation 1 was taken. It is observed that the convective coefficients decrease as the helical diameter increases.

When the diameter is smaller, the number of turns is greater and this makes the convective coefficients higher because the R134a spends more time through the tube, as the diameter increases the number of turns decreases and the convective coefficients also decrease.

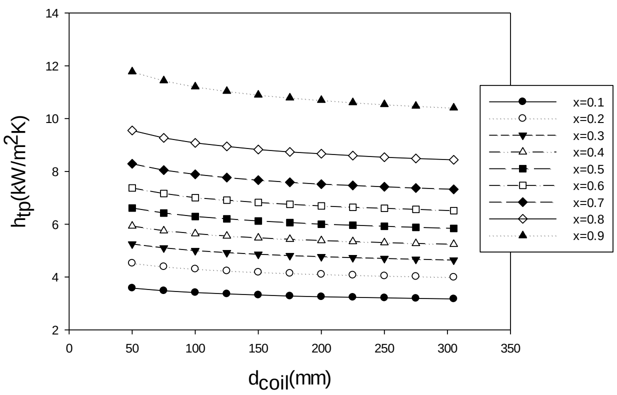

Figure 6 Behavior of the convective coefficients at different qualities and diameters of the helical evaporator
Source: Own Elaboration

Table 3 shows the results of the external convective coefficient, the number of turns of the helical and the height in the ranges of the helical diameter of 50-305 mm to the simulation 1. It can be seen that the results of the external convective coefficients are very small and as the diameter increases, the coefficient decreases. At a smaller diameter, the number of turns and the height of the helical are greater and decrease as the diameter increases.

D_{coil} (mm)	h_{fext} (W/m^2-K)	Number. Turns	Y (cm)
50	1538	36.84	128.9
75	1439	24.56	85.96
100	1385	18.42	64.47
125	1349	14.74	51.58
150	1325	12.28	42.98
175	1306	10.53	36.84
200	1292	9.21	32.23
225	1281	8.18	28.65
250	1271	7.36	25.79
275	1263	6.69	23.44
305	1256	6	21.14

Table 3 Results of the external convective coefficient, number of turns and height with respect to the helical diameter

Table 4 shows the results of the outlet temperatures of the mixture and R134a of the 4 simulations. The temperature does not change when the quality of the coolant increases.

	Simulation 1	Simulation 2
Ts_{ref} (°C)	35.68	53.4
Ts_{fext} (°C)	14.3	14.3
	Simulation 3	**Simulation 4**
Ts_{ref} (°C)	40.69	54.44
Ts_{fext} (°C)	14.3	8.6

Table 4 Results of the outlet temperatures of both fluids

Figure 7 shows the representation of results obtained with the EES software. It is observed that it calculates the internal convective coefficients using the different correlations, external convective coefficient, the total area, the heat transfer and the outlet temperatures.

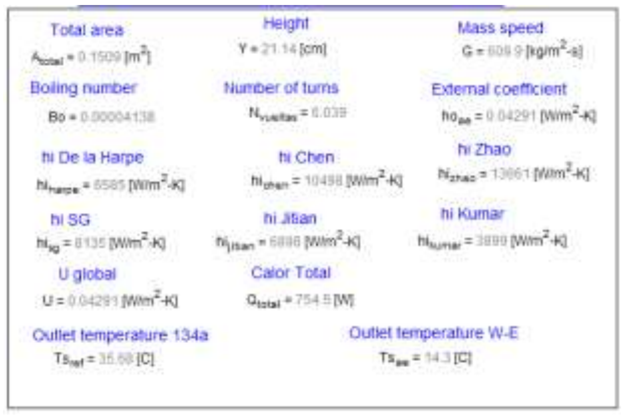

Figure 7 Final results obtained with the software EES
Source: Own Elaboration

Conclusions

The results of the internal convective coefficients for R134a obtained with Jitian and De la Harpe were the closest to the experimental results. Using the Chen and Schorck-Grossman (S-G) correlations, the results are above the experimental ones and the results with the Zhao correlation have a very large increase in the coefficients as the quality increases. The results with the Kumar correlation were consistent since this equation does not depend on the quality of the coolant and is an average in general. When the helical diameter is reduced to 50 mm, the convective coefficients for R134a are higher because the number of turns and the height of the evaporator increase, in turn the coefficients decrease when the diameter increases up to 305 mm.

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Nomenclature

A_{total}	Total heat transfer area.
Bo	Boiling number.
Cp_l	Heat capacity of liquid R134a.
Cp_{fext}	Heat capacity of wáter-ethilene glycol.
d_i	Internal diameter of the tube.
d_o	External diameter of the tube.
d_{coil}	Helical diameter of the tube.
D_h	Hydraulic diameter of the tube.
D_e	Equivalent diameter.
f	Tube friction factor.
G	Mass speed.
h_{tp}	Internal convective coefficient of R134a.
h_{fext}	External convective coefficient of mixture.
i_{fg}	Difference of liquid-steam enthalpies.
k_l	Liquid thermal conductivity of R134a.
k_{mat}	Material thermal conductivity.
L_{th}	Tube length.
m_{ref}	Mass Flow of R134a.
m_{fext}	Mass Flow of wáter-ethylene glycol.
$N_{vueltas}$	Number of turns.
Nu_i	Internal Nusselt number.
Nu_s	External Nusselt number.
Nu_c	Helical external Nusselt number.
P	Step pitch.
Pr_l	Liquid Prantl number of R134a.
Pr_{fext}	Prantl number of the water-ethylene glycol.
Q_{total}	Total heat.
q	Heat flux.
Re_l	Luiquid Reynolds number of R134a.
S	Suppression factor.
T_{eref}	Inlet temperature of R134a.
T_{sref}	Outlet temperatura of R134a.
T_{efext}	Inlet temperatura of water-ethylene glycol.
T_{sfext}	Outlet temperatura of wáter-ethylene glycol.
U	Overall heat transfer coefficient.
u_{fext}	Velocity of water-ethylene glycol.
x_{tt}	Parameter of Martinelli

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x	R134a quality.
Y	Height of evaporator.

Greek Symbols

μ_l	Liquid viscosity of R134a.
μ_{fext}	Viscosity of water-ethylene glycol.
ρ_l	Liquid density of R134a.
ρ_{fext}	Density of water-ethylene glycol.
σ	Surface tension.

Article
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Simulation of cyclohexane production using free software DWSIM

Simulación de la producción de ciclohexano mediante la utilización del software libre DWSIM

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Abstract

Cyclohexane is mainly used as a precursor to cyclohexanol and cyclohexanone. Caprolactam and adipic acid are obtained from them, which are used to produce nylon-6 and nylon-66. Cyclohexane is a volatile, colorless, flammable, non-corrosive, non-polar liquid whose most notable physical property is its insolubility in water and the azeotropes it forms with a variety of chemical products. The most common method of obtaining cyclohexane is the hydrogenation of benzene. The production of cyclohexane in the current market is closely linked to the demand for such a product, as well as the importance of the raw material from which it is obtained, specifically benzene. In the present work, the design of a cyclohexane production plant from the hydrogenation of benzene is presented. For the simulation and modeling of the plant, the DWSIM tool has been used. The starting data was taken from the Aspen Plus Costing manual of 1988, with this simulation the results obtained from the free software DWSIM and the commercial software ASPEN Plus were compared.

Simulation, DWSIM, Cyclohexane

Resumen

El ciclohexano se emplea principalmente como precursor del ciclohexanol y la ciclohexanona. De ellos se obtienen caprolactama y ácido adípico, que sirven para producir nylon-6 y nylon-66. El ciclohexano es un líquido volátil, incoloro, inflamable, no corrosivo, no polar cuya propiedad física más destacable es la insolubilidad en agua y los azeótropos que forma con variedad de productos químicos. El método más común para obtener ciclohexano es la hidrogenación de benceno. La producción de ciclohexano en el mercado actual está íntimamente ligada con la demanda que presenta tal producto, así como con la importancia que posee la materia prima de la cual se obtiene, en concreto el benceno. En el presente trabajo se presenta el diseño de una planta productora de ciclohexano a partir de la hidrogenación de benceno. Para la simulación y modelado de la planta se ha hecho uso de la herramienta DWSIM. Los datos de partida fueron tomados del manual Aspen Plus Costing de 1988, con esta simulación se compararon los resultados obtenidos del software libre DWSIM y el software comercial ASPEN Plus.

Simulación, DWSIM, Ciclohexano

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Introducción

It is known that the methodological procedure to solve a problem in engineering consists of representing it in a correct and precise way, to obtain a substitution of the real system by a more adequate one for the formal treatment. In general, the logical-mathematical tools provide a useful framework to represent by means of a system of symbols and rules, the behavior of real systems.

The scientific method helps us to consolidate laws and theories in different areas of knowledge, which are understandable by means of differential equations, for example. In other words, we are able to recreate a new system, of which we know its rules and symbols, such as of which we know its rules and symbols, as the result of a process of abstraction from the environment [1].

Process simulation using computer software has become popular among researchers today. However, publications related to this field using open source as its simulation platform have not yet been seen [2], so the present work shows the results obtained with the free simulation software DWSIM and compares them with those obtained using ASPEN Plus.

The existing processes for obtaining cyclohexane comprise all those developed at the industrial level to meet market demands. These processes differ mainly in several aspects: nature of the catalyst, operating conditions, reactor design, heat dissipation, extractant agent [3].

Regarding their production, there are two commercial alternative methods:

1. Extraction of cyclohexane from crude oil streams.

Cyclohexane can be distilled directly from naphtha. The starting concentration of cyclohexane in the naphtha fraction of crude oil is in the range of 0.5% to 5% by volume. The presence of several hydrocarbons with a boiling point in the same range, such as n-hexane, isohexanes, methylcyclopentane, benzene and dimethylpentanes, makes the recovery of cyclohexane from crude oil by fractional distillation or recrystallization difficult and expensive.

The difficulty of separating cyclohexane from naphtha is highlighted by the fact that in 1991 only one company, Phillips Petroleum, produced cyclohexane by distillation. Despite this, cyclohexane is manufactured through simple distillation with 85% purity by weight in commercial quantities by fractionation of naphtha from natural gasoline, then this stream can finally be treated in extractive distillation columns, where it is possible to obtain cyclohexane with a purity of 98% purity.

2. Hydrogenation of benzene.

It is based on the catalytic hydrogenation of benzene, forming cyclohexane as a product. Benzene hydrogenation is not only of great interest to the petroleum industry but also to the environment. The U.S. Environmental Protection Agency (EPA) under the Clean Air Act requires that gasoline contain less than 1.0% by volume of benzene. To comply with this regulation, refiners have implemented various techniques to reduce benzene levels in gasoline, which otherwise contains approximately 2 to 3% benzene [4].

Most of the cyclohexane is obtained by hydrogenation of benzene. Therefore, in this work, this process is analyzed. The 90% of the cyclohexane produced that is obtained by hydrogenation of benzene is used in the production processes of nylon 6 and nylon 66, although it is also used to produce esters, plasticizers, synthetic lubricants, polyurethanes and as a food acidulant, but the quantities of total cyclohexane produced in the world for these uses is low [5].

Since the last century, several industrial processes using this method have been invented; all of them are based on provoking the hydrogenation reaction, and then purifying and conditioning the final product [6].

Process description

In the cyclohexane production process, one of the most important parameters is the starting feedstock. The hydrogenation of benzene requires a high purity of the feedstock, benzene. Nowadays, the purity of the raw material is not an impediment to the development of the reaction since sufficiently advanced technologies are available to obtain benzene of very high purity.

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Catalytic hydrogenation is a reversible, highly exothermic reaction, as shown below:

$$C_6H_6 + 3H_2 \leftrightarrow C_6H_{12} \quad (1)$$

This benzene hydrogenation process comprises two main phases:

1. Reaction phase for the transformation of the feedstock into the process of interest.

2. Purification and conditioning process of the final product obtained.

For the simulation, data collected from a plant presented in a course on Modeling and Simulation of Chemical Processes (DIQUIMICA, 2012-2013) and by the Aspen Plus Costing manual of 1988 [7] will be taken.

The process is composed of the equipment necessary to carry out the basic reaction and separation operations. The benzene fed to the plant can come from the following sources:

1. Catalytic reforming of naphtha.

2. Desalkylation of toluene

3. Recovery of gasoline from pyrolysis plant ethylene pyrolysis, coke oven

4. Selective disproportionation of toluene [8].

In the feed enters a first stream of hydrogen (H) rich gas with a minimum amount of impurities, such as nitrogen and methane, with a molar flow of 313 kmol/h; a second stream of pure liquid benzene, with a molar flow of 100 kmol/h; both streams enter a mixer at a pressure of 330 psi, the mixture of the streams is preheated to the reaction temperature and pass through a conversion reactor, as observed in Figure 1. A conversion of 99.8 % benzene was established.

Figure 1 Schematic of the benzene hydrogenation process

The reactor product is taken to a separator, at a temperature of 120ºF, where the purification of the product begins, with the separation of the liquid stream and the gas stream. What comes out in the vapor phase is hydrogen, and the liquid phase is processed to obtain a cyclohexane of higher purity.

Methodology

In the simulation, the hydrogen-rich gas stream was considered to have a purity level of less than 100%, the impurities are formed by two components, nitrogen (N) and methane (CH4). The mole fractions of the input components were: 97.5% H2, 2% CH4 and 0.5% N2.

The steps followed were:

1. Determine the components in the plant along the process:

2. Choice of the thermodynamic method; it represents the crucial part, since an erroneous selection leads to deviations in the estimation of the properties of the substances that correlates with important perturbations in the global calculation of the process. In this case the thermodynamic method chosen is the Soave-Redlich-Kwong (SRK).

3. Equipment specifications, at this point the process input variables were selected.

Results

The components that were present during the simulation are shown in Table 1.

Compounds
Benzene (C_6H_6)
Hydrogen (H_2)
Nitrogen (N_2)
Methane (CH_4)
Cyclohexane (C_6H_{12})

Table 1 Compounds used in the simulation

The simulated equipment and their input specifications are shown in Table 2.

Equipment	Specifications
Mixer	Input current Output current
Heat exchanger	Heater Spray pressure: 0 Pa Efficiency: 100%. Outlet temperature: 330 °F
Reactor	Co-inversion reactor Conversion reaction Base component: benzene Phase: mixture
Flash Separator	Type: adiabatic Temperature: 120 °F Pressure: 310 psi

Table 2 Equipment specifications

The simulation results are shown in Table 3.

Property	Vapor	Product	H_2	C_6H_6
Temperature (°F)	120	120	120	100
Pressure (psi)	310	310	335	15
Molar flow (kmol/h)	10.112	103.48	313	100
Mole fraction H_2	0.4986	0.007	0.975	0
Mole fraction C_6H_6	0.0006	0.002	0	1
Mole fraction C_6H_{12}	0.0203	0.9623	0	0

Table 3 Simulation results

Table 4 shows the comparison of the results obtained with DWSIM and ASPEN Plus.

Component	DWSIM	ASPEN Plus
Benzene	0.002	0.0013
Hydrogen	0.007	0.004
Cyclohexane	0.9623	0.9679

Table 4 Comparison of the results obtained with DWSIM and ASPEN Plus, shown in mole fraction

The input parameters in both simulations were the same: comparing the results shows a difference of 5.79% in the mole fraction of cyclohexane in the output stream; therefore, considering that both programs are an approximation of reality, the difference is not significant.

Conclusions

In this work the simulation of a plant that produces cyclohexane by the hydrogenation of benzene was carried out, for the simulation real data obtained from the bibliography were taken.

In addition the results of the simulations were compared with the programs DWSIM and ASPEN plus, the first one is a free use software and the second one is commercial. The results obtained are similar.

The advantages of DWSIM, besides having no cost, is that the interface is more user-friendly, which allowed the simulation to be carried out step by step and to instantly correct the exact point where the error is generated and to continue editing until completing the simulation, a situation that cannot be done in ASPEN Plus, since it is necessary to carry out the entire simulation, compile the project and then look for the errors.

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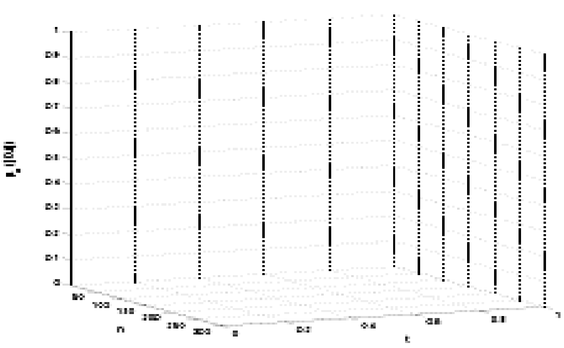

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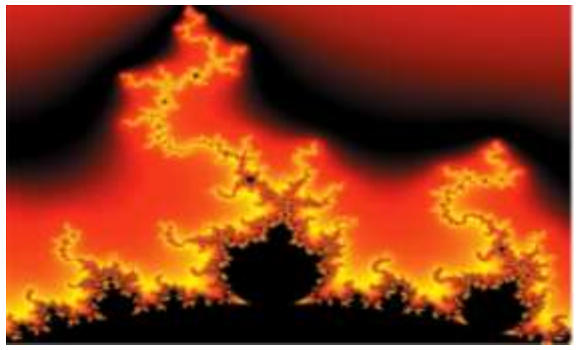

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