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Journal of Experimental Systems

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In the first article we present, *Elaboration of Octagonal Roses to represent the wind patterns in the Port de Veracruz during the last 10 years*, by GONZALEZ-JUAREZ Aníbal, AGUILAR-RAMIREZ Ana María, UTRERA-ZARATE, Alberto and MOLINA-NAVARRO, Antonio, with adscription in the Instituto Oceanográfico del Pacifico, as next article we present, *Comparative study between Biological treatment and a physicochemical treatment for the removal of Butyl Acetate in industrial residual effluents*, by CARRILLO-CABRERA, Roxana, RODRIGUEZ-MORALES, Jose Alberto, LEDESMA-GARCIA, Janet and AMARO-REYES, Aldo, with adscription in the Universidad Autónoma de Querétaro, as next article we present, *Thermodynamic analysis of a combined gas-steam cycle without and with afterburner*, by CASADOS-LÓPEZ, Edzel Jair, CASADOS-SÁNCHEZ, Alvaro, ESCAMILLA-RODRÍGUEZ, Frumencio and CORTÉZ-DOMÍNGUEZ, Cristóbal, with adscription in the Universidad Veracruzana, as next article we present, *Rupture voltage in mineral oil using the megger OTS 60pb equipment to determine its quality and use in transformers*, by ESCAMILLA-RODRÍGUEZ, Frumencio, LAGUNA-CAMACHO, Juan Rodrigo, RÍOS-HERNÁNDEZ, Sara Anahí and JIMÉNEZ-CRISTÓBAL, Juan Daniel, with adscription in the Universidad Veracruzana.

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Elaboration of Octagonal Roses to represent the wind patterns in the Port de Veracruz during the last 10 years

Elaboración de Rosas Octagonales para representar el comportamiento del viento en el Puerto de Veracruz durante los últimos 10 años

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Abstract

The Port de Veracruz and its surroundings are affected by meteorological phenomena such as the passage of frontal systems, among others. The main objective of this writing is to carry out continuous monitoring to categorize wind behavior, in order to determine patterns in the last 10 years. Therefore, climatological records of the intensity and direction of the average wind speeds are presented; wind data from three Automatic Meteorological Surface Stations (EMAS) of the Meteorological Observation Network of the Secretariat of the Navy, one of the National Meteorological Service (SMN) and two buoys of the National Oceanic and Atmospheric Administration (NOAA) were processed and analyzed. The results indicated that the North (N) direction predominately governs during the cold front season, while the East (E) winds predominately govern during the warm months (June, July, August and September). The maximum gusts, which can be an important factor in accidents, especially when their intensity exceeds 20 knots, affect various human, maritime, agricultural and livestock activities and tourism.

Resumen

El puerto de Veracruz y sus inmediaciones se ven afectados por fenómenos meteorológicos como el paso de sistemas frontales, entre otros, el objetivo primordial del presente trabajo es efectuar la constante observación y evaluación para caracterizar el comportamiento del viento, con el fin de determinar la tendencia en los últimos 10 años. Por lo anterior, se presentan registros climatológicos de la intensidad y dirección del viento promedio; se procesaron y analizaron datos de viento provenientes de tres Estaciones Meteorológicas Automáticas de Superficie (EMAS) de la Red de Observación Meteorológica de la Secretaría de Marina, una del Servicio Meteorológico Nacional (SMN) y dos boyas de la Administración Nacional Oceánica y Atmosférica (NOAA). Los resultados indicaron que la dirección Norte (N) predomina durante la temporada de frentes fríos, mientras que los vientos del Este (E) lo hace durante los meses cálidos (junio, julio, agosto y septiembre). Las ráfagas máximas, que pueden constituir un factor importante de accidentes, especialmente cuando su intensidad supera los 20 nudos ya que afecta a diversas actividades humanas, marítimas, agropecuarias y turismo.

Octagonal roses, wind, wind power   **Rosas octagonales, viento, energía eólica**

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Introduction

Wind is the movement of air in any direction and its magnitude can vary from a calm state to very intense winds (Tai, 2015); it is considered one of the most relevant variables due to its importance in different economic sectors. Such as maritime energy to mention one example; as wind can exert considerable force on some structures, such that some shipping operators limit operations when winds exceed 15 to 20 knots due to the formation of wind waves and the discomfort of crew and passengers, as well as threats to their safety (WMO, 2018). High winds create hazardous working conditions for personnel on exposed decks and affect survey platforms, loading and unloading operations, helipad, module access and general deck operations (WMO, 2018). For this reason, safety and security in Mexican ports must be strengthened and legal certainty must be provided to the maritime community.

The port of Veracruz is the oldest port in Mexico and, historically, the most significant in the country due to its equipment for the transport of vehicles imported or exported by sea and the movement of container cargo (APIVER 2021). In addition to being the best connected of the nation, which allows supplying 15 states of the Mexican Republic, which serves more than 67 million inhabitants and also has maritime routes to more than 150 ports in the world. It is also responsible for generating 11% of the national electricity (Silva-Casarín et al., 2018) and represents 37% of the national territory (INEGI, 1988). This port and its surroundings are affected by meteorological phenomena such as the passage of frontal systems and tropical waves, which makes it necessary to constantly observe and evaluate the behaviour of the wind (Calderón, 2017).

In order to fulfil this purpose and given the lack of climate characterisation and the importance it has for the exploitation of the country's natural resources, this work proposes a study of the behaviour of winds in the Port of Veracruz over the last 10 years, considering the recommendations of the World Maritime Organisation, which suggests constant monitoring of climatological variables and their representation in the form of maps, graphs and statistics, given that they are useful for numerous activities, ranging from navigation to the planning of various operations on the coast.

In order to serve as a useful reference tool for both promoting favourable maritime development and sustainable exploitation of resources in this geographical area. On the other hand, it is relevant to carry out the study of wind behaviour in the port of Veracruz, in order to have a recent analysis with which to determine the wind trend in recent years; also complying with the WMO regulations in which it specifies about local studies, in order to observe its variability.

Methodology

In order to characterise the wind over the port of Veracruz, the meteorological stations closest to the port of Veracruz were identified, six in total, which are described in Table 1, located in Figure 1.

Station	Years	Period
Heroic Military Naval School (HENM)	10	2010-2019
Boca del Rio	9	2010-2018
Sacrificios	8	2012-2019
Oceanographic Institute of the Gulf and Caribbean Sea (IOGMC)	3	2016-2019
NOAA Buoy	6	2011-2016
NOAA Sacrificios	6	2011-2016

Table 1 Meteorological stations consulted
Source (Own Elaboration)

Figure 1 Location of stations used
Source: Google Maps

Using the Python programming language, the wind data were cleaned, creating time, speed and direction matrices, in order to homogenise them in terms of format and structure. Due to the fact that the winds recorded by the EMAS and the buoys are in time intervals of 15 min and 60 min, respectively, the following quality control actions were carried out to clean the database:

a. Anomalous data were identified within each record and were taken as missing data

b. Records indicating more than 30 days without data were considered as missing.

c. Data where the sustained wind exceeded the gust were taken as erroneous data and were not used.

After the quality control actions and through descriptive statistics, the averages were obtained, identifying the dominant wind during the day. As the data recorded the direction in degrees, the components and their equivalence in degrees were identified in a wind rose. Working with the eight classical components and defining the intervals to have homogeneous directions.

Images were produced for a better interpretation of the information. These graphics were generated with the software Inkscape, which is a vector graphics editor, and with it, wind roses were made in an octagonal shape; thus obtaining the behaviour of the wind (direction and intensity) during the last 10 years in the port of Veracruz.

Results and analysis

The representation was carried out through octagonal shaped graphs, where each side of the geometric figure represents one of the wind components. Each of these sides is the base of a bar graph representing the monthly average wind frequency and the colour, based on the Beaufort scale, indicates the maximum average sustained wind that can be expected. Also, in the central part, it is shown if there was no wind, a situation known as calm periods.

Each of the images presented below has two support elements in the lower corners to be able to interpret them correctly, 1) lower right corner: shows the Beaufort scale in km/h (Table 2), with their respective colours according to the intensity, which are used in the bars on each side of the octagonal, to show the average maximum sustained wind, 2) lower left corner the reference scale of the percentage units.

Scale	Speed (km/h)	Designation Colour	Designation Colour
0	0 – 1	calm	
1	1 to 5	Ventolina	
2	5 to 11	Very weak breeze (weak)	
3	13 to 19	Light Breeze (Light)	
4	19 to 28	Moderate breeze (Bonancible)	
5	28 to 38	Fresh breeze (Fresquito)	
6	38 to 49	Strong breeze (Fresco)	
7	49 to 61	Strong wind (Frescachón)	
8	61 to 74	Hard Wind (Temporary)	
9	74 to 88	Strong wind (Very strong)	
10	88 to 102	Strong Storm (Temporal)	
11	102 to 117	Very strong storm (Squall)	
12	+ 117	Hurricane storm (Hurricane)	

Table 2 BEAUFORT SCALE
Source: Directorate of Meteorology SEMAR

Figure 2 shows the percentage of wind direction for the data series 2010-2019. It should be noted that the HENM station is the most representative, as it presents the complete period during the 10 years.
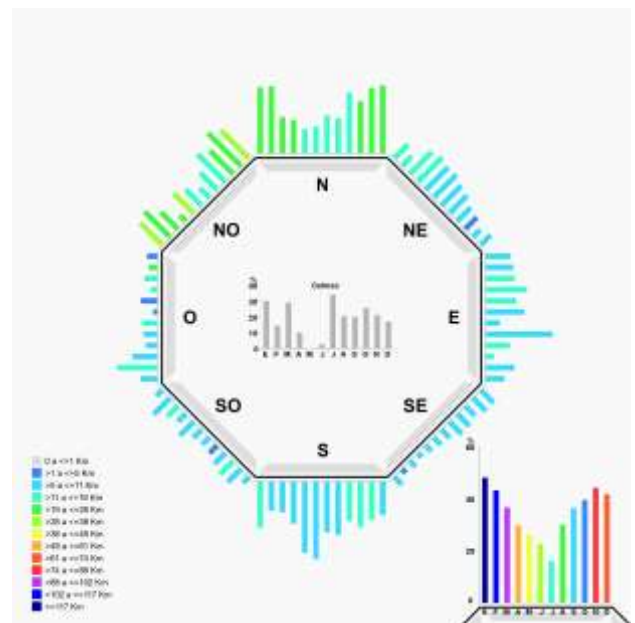
Figure 2 Percentage of wind direction at HENM station
Source: Own Elaboration

In this station there is a variation in its wind regime, none of the 8 components reaches 50 % of predominance in the year. However, the dominant direction is from the N, with a frequency of 26.2% in the month of December. But this is followed by the NW and S components, with a percentage of 18% in the month of November and 29.8% in the month of July respectively.

GONZALEZ-JUAREZ Aníbal, AGUILAR-RAMIREZ Ana María, UTRERA-ZARATE, Alberto and MOLINA-NAVARRO, Antonio. Elaboration of Octagonal Roses to represent the wind patterns in the Port de Veracruz during the last 10 years. Journal of Experimental Systems. 2021

In this EMA it is important to point out that the winds have a great variability in the wind direction, but always with a predominance of the N and S sector, since in the other quadrants they have frequencies below 15 %. Likewise, the prevailing wind direction in the last 10 years at HENM has been N.

The most notable characteristic in this place are the calms or air movement whose speed is zero or less than 2 knots, or what is the same as force 0 on the Beaufort scale, which shows that the month of May is the one with the lowest percentage of them with 0%; which indicates that throughout this month the wind is perceptible, regardless of the direction. For the rest of the months it ranges between 14.3% and 30.1%, with the sole exception of July, which is 33.9%, a circumstance that coincides with the fact that July is when the lowest wind intensity is recorded. The percentage of calms tends to increase when the secondary courses try to match the dominant ones.

Figure 3 shows the percentage of wind direction at the Boca del Río station during the 2010-2018 data period.
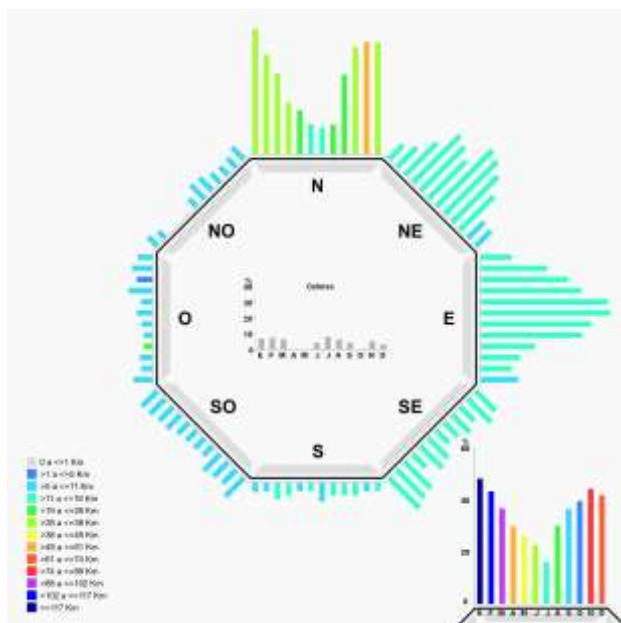
Figure 3 Percentage of wind direction at Boca del Río station
Source: Own Elaboration

It should be noted that this station is the second with the second highest number of real data. It shows an important incidence of winds coming from the North, followed by the Northeast and East.

From the month of September onwards, the winds from the N component persist in an ascending manner, being reflected in the month of November with maximum winds of 51.7 km/h and in a descending manner that continues until the month of May. The NE and E components have an impact in the months of June, July and August. Likewise, the prevailing wind direction in the last 10 years at the Boca del Rio station is North.

Figure 4 shows the percentage of the wind direction of the station located in Isla de Sacrificios, for a period of observations 2012-2019. The most frequent direction is from the N, followed by the E.
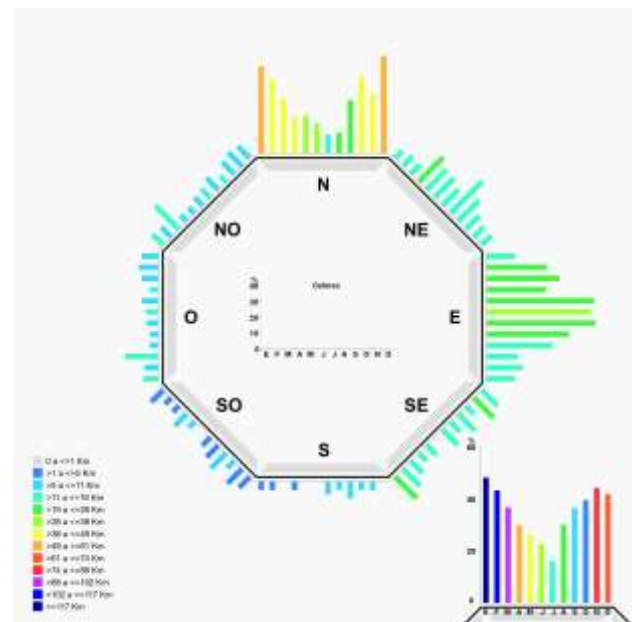
Figure 4 Percentage of wind direction at the Isla de Sacrificios station
Source: Own Elaboration

The most frequent directions are from the N and E with a percentage of 37.6% in December and 41.9% in July respectively. Winds from the SE (11.8%) reached a notable frequency in December. The directions with a medium and low frequency are S (6.7%), SW (6.0%), W (8.3%) and NW (12.9%).

In terms of wind speed, it is observed that the wind has exceeded degree 7 on the Beaufort scale, classified as strong wind; it is recorded in January and December where winds reach 54.6 km/h and 57.1 km/hr respectively; with July and August being on the opposite side of the scale. There are no calm periods.

In this season, the season of frontal systems is fully manifested and is reflected in the intensity of its winds; on the other hand, the presence of easterly winds is appreciated both in percentage and intensity in the months of June, July and August. Likewise, the prevailing wind direction in the last 10 years at the Isla Sacrificios station has been from the N component.

Figure 5 shows the percentage of the wind direction of the station located in the IOGMC, for the period 2016-2019. It is important to point out that the data processing carried out at this station is not representative of a climatology; but in addition to this, an analysis was carried out in which the lack of data is very noticeable. However, they can be used to draw conclusions about the importance of the data and the action of the city, as this station is located in the urban centre.

But it stands out that the direction with the highest percentage is from the N and NE, with an average of 33.9 % in December and 53.8 % in July respectively. The calm periods are below 15 %, in the months of February, March, April and August. In terms of speed, the highest intensities are observed in December with 19 km/h. The lowest speeds are in December with 19 km/h. The lowest speeds are in the month of August.
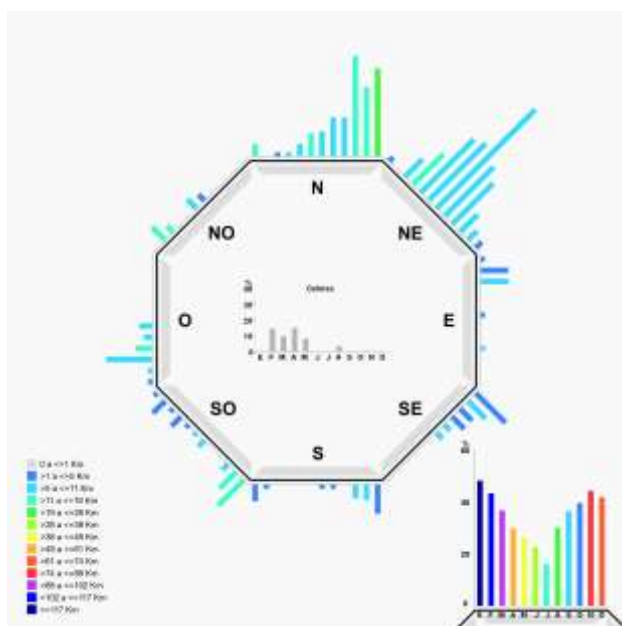
Figure 5 Wind direction percentage of the IOGMC station
Source: Own Elaboration

In the analysis of this EMA, it is made clear that, given the lack of data, it is very difficult to characterise a variable; but this is not the objective of the study, which is why we do not go into detail regarding the characteristics of the station itself. However, the prevailing wind direction over the last 10 years at the IOMC station is NE.

Figure 6 shows the percentage of the NOAA Buoy wind direction in which there was wind by component, using all the observations for the period 2011-2016. The graph confirms, on the one hand, the dominance of N winds throughout the year, which reach their maximum percentage in the month of January; and on the other hand, winds from the Northeast and East as the second dominant component. The rest of the directions are considered secondary because they are below 20 %.
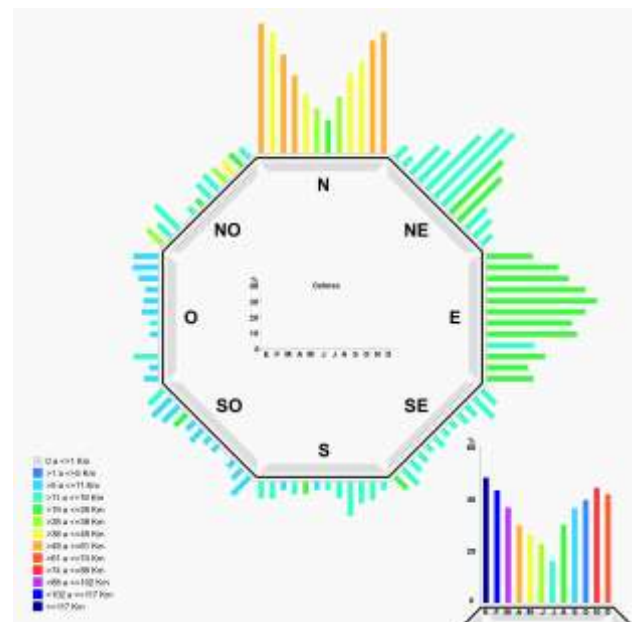
Figure 6 Percentage of wind direction at NOAA Buoy
Source: Own Elaboration

The directions with the highest frequency are N, NE and E with a percentage in December (50.0%), in July (38.7%) and May (32.6%) respectively. The directions with a low frequency are SE (3.2%), S (3.2%), SW (3.3%), W (3.2%), and NW (3.2%). At this station the wind speeds are observed to exceed degree 7 on the Beaufort scale (Table 2), classified as strong wind; it is recorded in November, December, January, April and May where the winds exceed 55 km/h. July is the month with the lowest wind intensity. Likewise, the prevailing wind direction over the last 10 years at the NOAA buoy is from the north.

Figure 7 shows the percentage of wind direction at the NOAA Sacrificios station, using data from 2011-2016. It can be seen that the most frequent direction is N during the winter months, which have the highest intensities with values between 49 and 74 km/h on average during that period; while the NE and E directions also occupy the second position, but unlike the first, these occur mostly during the summer months, as they are influenced by the trade winds. The percentage of calms is nil.

Figure 7 Percentage of wind direction at the NOAA Sacrificios station
Source: Own Elaboration

The most frequent directions are N and NE and E with a percentage in January (48.4%), in July (34.9%) and May (23.7%) respectively. Winds from the SE (17.2%) reached a notable frequency in December.
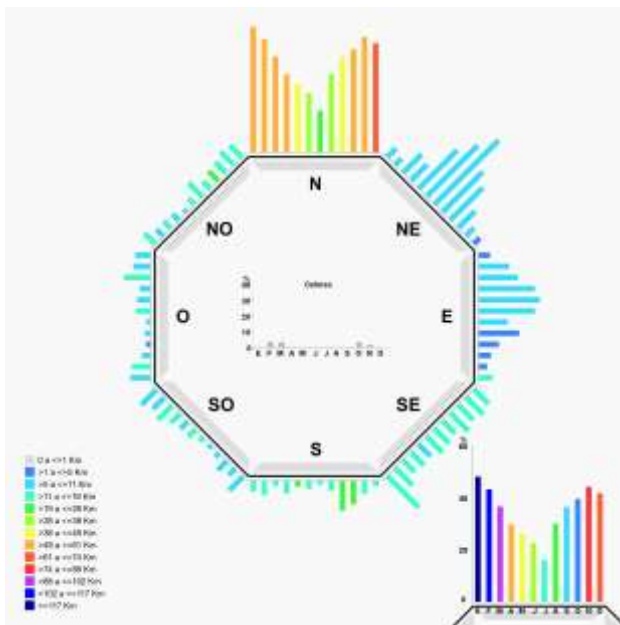
In terms of wind speed, it can be seen that the wind exceeds grade 8 on the Beaufort scale, classified as a hard wind; it is recorded in December (62.5 km/h); the months of October, November, January, February, March and April have winds of grade 7 on the Beaufort scale. Likewise, the prevailing wind direction in the last 10 years at the Sacrificios NOAA station is from the N component.

The percentages of calm winds are low and are below 3% in February, March, October and November. This buoy presents very similar data to EMA, which is located in Sacrificios Island.

Conclusions

Regarding the results obtained by studying the wind behaviour in the five stations and one buoy, it is evident to observe weak and moderate winds blowing in all directions in most months; although their percentages are very low, winds from the East and West are frequent; representing almost 50% in the stations of Boca del Río, Isla de Sacrificios, Isla de Sacrificios NOAA and Boya de la NOAA. This marked component is due to the local regime of sea breeze and continental breeze winds, which are present in synoptically stable conditions, as well as in the spring and summer seasons; which are the product of the difference in temperatures between the ocean-continent dichotomy, which cause pressure differences and consequently the wind that goes from high pressure to low pressure on surfaces.

In addition, during the months of June, July, August and September, it is observed that the easterly winds indicate a higher percentage and increase in wind speed, which means the possibility of the existence of a more accentuated sea breeze phenomenon over the area of the Port of Veracruz.

For the HENM, IOGC and Boca del Río stations, it is where the lowest wind intensities occurred, due to the fact that they are located within the urban area and the wind friction with the heterogeneities of the terrain, such as buildings, trees and small hills, causes the wind to decrease its speed or change its horizontal momentum flow to vertical.

Finally, the stations of Isla de Sacrificios, Isla de Sacrificios NOAA and the NOAA Buoy are where the wind registers the highest intensities (between 74 and 88 km/h), since these points are free of obstacles or barriers that diminish or deviate the intensity and direction of the wind, These intensities are present in the winter season with a northerly direction, which is considered the windiest season of the year, due to the air masses that move from polar areas towards the coast of the Gulf of Mexico (see figure 8).
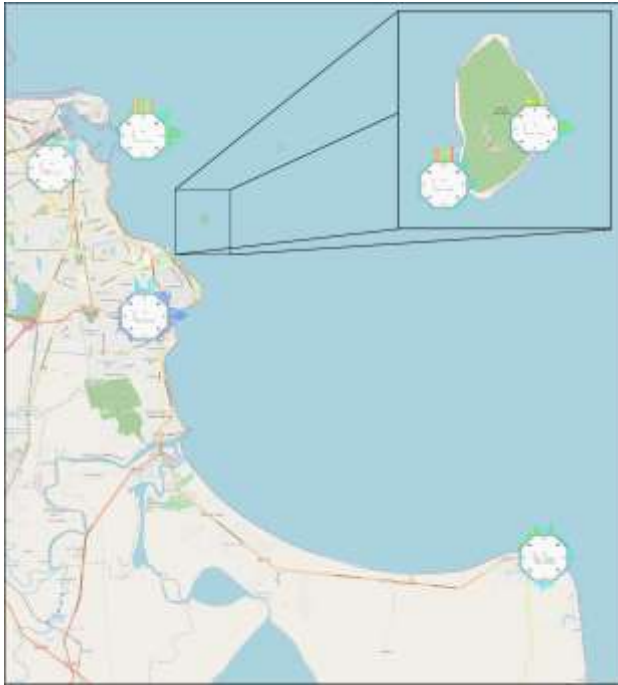
Figure 8 Octagonal roses representing the stations in the study area
Source: Google maps base map

Recommendations

The analysis and creation of wind roses for a quick and complete description of the climatic wind situation at a weather station should be put into practice in academia.

The institutions responsible for climatological data should emphasise the importance of having time series as complete as possible, since the periodic maintenance of these stations translates into good data.

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Comparative study between biological treatment and a physicochemical treatment for the removal of Butyl Acetate in industrial residual effluents

Estudio comparativo entre un tratamiento biológico y un tratamiento fisicoquímico para la remoción de Butil Acetato en efluentes residuales industriales

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Abstract

A comparison was made between a fixed aerobic biological process and a physicochemical treatment for waste effluents with butyl acetate. An acrylic tank with 100 L capacity and a support medium for PET bottles was implemented for the formation of the biofilm and thus develop the biological reactor. In the experimental phase, concentrations of 10, 20 and 30% of butyl acetate containing sample, using hydraulic retention times of: (16, 8, 5.33 and 4 days) for each concentration. After the experimentation, a removal of 99% of COD and 97% of BOD was obtained. For the physicochemical treatment, coagulant, flocculant, and adjuvants were used, by a jar test. A decrease in 74%, 53.8%, 55%, 97% and 37%, for electrical conductivity, total suspended solids, color, turbidity, COD and BOD respectively, were obtained compared to the initial sample. Both treatments were filtered through a bed packed with activated carbon, sand, and silica gravel. The aim of this work was to evaluate / quantify butyl acetate removal efficiency in each treatment for its subsequent comparison, with prospect to the reduction of similar pollutants in residual effluents is intended.

Biological treatment, Physicochemical treatment, Butyl acetate

Resumen

Se realizó una comparación entre un proceso biológico aerobio fijo y un tratamiento fisicoquímico para efluentes residuales con butil acetato. Para el desarrollo del reactor biológico se implementó un tanque de acrílico con capacidad de 100 L y un medio de soporte de botellas PET para la formación del biofilm, en la parte experimental se manejaron concentraciones de 10, 20 y 30 % de la muestra con butil acetato, empleando tiempos de retención hidráulica de: (16, 8, 5.33 y 4 días) para cada concentración. Finalizada la experimentación se obtuvo una remoción del 99% de DQO y 97 % de DBO. Para el tratamiento fisicoquímico se empleó coagulante, floculante y coadyuvantes, mediante una prueba de jarras. Obteniendo como resultados la disminución en un 74 %, 53.8 %, 55 %, 97 % y 37%, para conductividad eléctrica, solidos suspendidos totales, color, turbidez, DQO y DBO respectivamente, en comparación a la muestra inicial. Ambos tratamientos se filtraron mediante un lecho empacado con carbón activado, arena y grava sílica. El objetivo del presente trabajo fue evaluar/cuantificar la eficiencia de remoción del butil acetato en cada tratamiento para su posterior comparación, por lo cual se pretende la reducción de contaminantes similares en efluentes residuales.

Tratamiento biológico, Tratamiento fisicoquímico, Butil acetato

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Introducción

Surface water and groundwater pollution is reported at 24% and 4% respectively, which has been generated by high concentrations of various chemical species. These come from diffuse sources of pollution (use of pesticides, manure production in agriculture) and specific sources (industrial landfills, as well as in industrial mining practices).

Effluents from industrial processes contain toxic products, harmful organic compounds, and metals, of varying composition, type and concentration, depending on the processes that generate them. Natural organic compounds in the environment tend to naturally degrade slowly into less harmful components, however, volatile organic compounds (VOCs) found in effluents from industrial processes are not considered biodegradable.

VOCs are used in the manufacture of paints, varnishes, waxes and are chemical industry's main organic pollutants used as solvents, being butyl acetate (C6H12O2), most widely used, as a solvent in polyurethane resins and paints (stripping) for special applications. It is a colorless liquid with a fruity odor, soluble in organic solvents, highly flammable, and dangerous to health, affecting the central nervous system.

It has been reported in various studies that water contaminated with compounds like butyl acetate, such as ethyl tert-butyl ether ($C_6H_{14}O$), methyl tert-butyl ether ($C_5H_{12}O$), tert-amyl methyl ether (C6H14O) and diisopropyl ether (C6H14O), have been treated by using microorganisms in a biodegradation process. Because it is a slow process, the addition of specific bacteria selected for their efficiency in removing contaminants has been implemented.

Residual water

Wastewater can be classified according to its origin: industrial, commercial, and domestic sector, in some cases adequate treatments are not implemented for its reuse, which, depending on current regulations and the economic interest of each company, is the importance given to the treatment process.

The pollutants concentration present in wastewater varied according to the origin of the sample and industrial use, suspended solids, organic matter, oils, fats, nitrogen, and phosphorus can be found. Membrane activated carbon filtration and chemical precipitation techniques are the most used for its recovery.

Types of wastewater treatment

The treatments most used in wastewater purification processes are primary, secondary, and tertiary, the conditions, on which, the choice of a treatment is based are the flow rate to treat, the concentration of pollutants, the type of pollutants, the place weather and the continuity in the raw water supply, the treatments are described below:
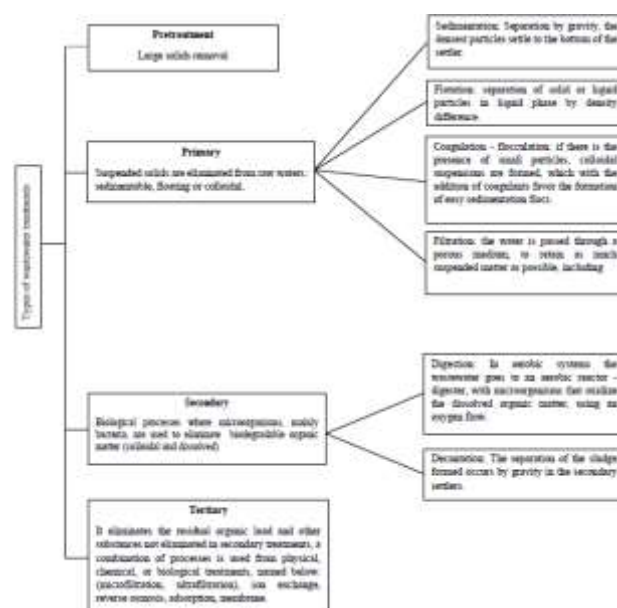
Figure 1 General water treatment diagram
Own Elaboration

Another treatment is disinfection, which consists of eliminating or inactivating pathogenic microorganisms or any other living microorganism to ensure the reuse of treated water. The main disinfection processes are chlorination, ozonation, electro-disinfection.

Methodology
Reactor development

A 100 L capacity acrylic tank was used, with the following dimensions (60 cm x 56 cm x 30 cm), which was adapted as a reactor. Two valves were placed after the feed inlet, a sphere type with a diameter of 1.5 inches, flow 3.95 L sec^{-1}, to regulate the feed flow of the affluent through the upper and lower part of the reactor.

To regulate the effluent outflow and the biomass purge, two ball valves were used as previously described. The sludge was recirculated with a MAXIMA® aeration pump for 113.6 L, which were connected to three 45 cm long porous rubber diffuser hoses, fish tank type to maintain a dissolved oxygen concentration of 3-4 mg L^{-1} arranged at the bottom of the tank.

Support medium

108 polyethylene terephthalate (PET) bottles of different capacities (2, 1 and 0.5 L) with holes were used to facilitate air flow. They were placed concentrically (they were assembled from smaller to larger capacity) and were distributed in an organized way in the bioreactor to allow the flow of the water, thus avoiding the obstruction of this, to increase the contact surface and the development of the biofilm, such as can be seen in Figure 2.

Figure 2 Fixed aerobic biological reactor prototype

Biological process development

For the formation of the biofilm in the reactor, 3 L of activated sludge inoculum from the treatment plant of the Autonomous University of Querétaro, Airport campus, were used. The sludge was fed with residual water from the same plant of the institution collected from laboratories and bathrooms, for a period of 1 to 6 months for maintenance, adaptation, and formation of biofilm in the PET support, as observed in Figure 3.

Figure 3 Biofilm formation

After establishing the biofilm and being able to guarantee the efficiency of the system in reducing nutrients, BOD / COD degradation and pH stabilization, the effluent quality analysis was carried out to verify compliance with NOM-003-ECOL-1997 and NOM-001-SEMARNAT-96.

Biokinetic coefficients

To evaluate the efficiency of the reactor and the stabilization of the biomass, the biokinetic coefficients were determined (Equation 1), which indicate the growth of the biomass, the use rate of the substrate, the food-microorganism relationship, and the mean time of cell retention. Equation to calculate the mean speed constant (Ks).

$$\frac{\theta X}{S_0 - S} = \frac{K_S}{(k)(S)} + \frac{1}{k} \tag{1}$$

Where:
θ = hydraulic retention time (h)
X = concentration of volatile suspended solids in the mixed liquor, L / h, mg VSS ML / L / h
S_0 = concentration of soluble COD in influent (mg L^{-1})
S = concentration of soluble COD in effluent (mg L^{-1})
k = maximum substrate utilization rate (h)
Ks = mean speed constant (mg L^{-1})

Equation 2 to calculate maximum cell yield (Y) and endogenous decay coefficient (kd)

$$\frac{1}{\theta_C} = Y \frac{S_0 - S}{X\theta} - k_d \tag{2}$$

Where:
Y = maximum cell yield
kd = endogenous decay coefficient, h^{-1}

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Subsequently, contaminant elimination from the test sample was sought using microorganisms adapted to the residual water in the reactor in a period of 1 to 6 months.

Calculation of the contact area of the biofilm

To calculate the contact area of the microorganisms to the PET support, the following equations were used for the truncated cone (3) and cylinder (4):

$$A = \pi\left(R_1^2 + R_2^2 + a(R_1 + R_2)\right) \qquad (3)$$
$$A_c = b \; x \; h = (2\pi \; r)\,(h) \qquad (4)$$

Adaptation of the effluent aerobic biological process (ABP) with butyl acetate

For the beginning of this adaptation stage, it was carried out by adding the effluent with butyl acetate to the biological reactor. Three concentrations were used (10, 20 and 30%) diluted in residual water, the process was carried out for four months, as shown in Figure 4 and 5.

Figure 4 Biological reactor feeding with domestic wastewater and effluent with butyl acetate mixture

Figure 5 Biological reactor adaptation to the effluent with butyl acetate

Hydraulic retention times

The different hydraulic retention times applied were 16, 8, 5.33 and 4 days for each of the concentrations used (10, 20 and 30%) of wastewater and effluent with butyl acetate.

Deveopment of the physicochemical process

For the physicochemical process, 10 experiments were carried out using the jar test for the coagulant, flocculant, and adjuvants, which were carried out on a shaker (PHIPPS & BIRD, USA), for testing 6-place jars with six 1 L beakers, the stirring time was 5 min at 150 rpm. The initial pH of the samples was 3.6.

Table 1 summarizes the methodology applied, as well as the concentrations used in the reagents to perform the jar tests.

Test	Conditions
1	pH 3.6-9, 45 ml chemical lime (20%), 5 ml metal precipitator (1%), 2 ml coagulant 90/10 (10%), 5 ml flocculant 70/24 (1%)
2	pH 3.6-2, 1.8 ml of H2SO4 (98%), 2 ml metal precipitator (1%), pH 7, 45 ml chemical lime (20%), 2.5 ml coagulant 90/10 (10%), 1.3 ml flocculant 70/24 (1%)
3	pH 3.6- 6, 30 ml chemical lime (20%), 3 ml metal precipitator (1%), 1.5 ml coagulant 90/10 (10%), 2 ml flocculant 70/24 (1%)
4	pH 3.6- 8, 40 ml chemical lime (20%), 7 ml metal precipitator (1%), 4 ml coagulant 90/10 (10%), 7 ml flocculant 70/24 (1%)
5	pH 3.6-1, 2.8 ml H2SO4 (98%), 3 ml metal precipitator (1%), pH 7, 60 ml chemical lime (20%), 2 ml coagulant 90/10 (10%), 8 ml of flocculant 70/24 (1%)

Table 1 Conditions applied at jar tests

Filtration system

A 60 cm acrylic column and a diameter of 10 cm was run. It was packed with activated carbon, sand, and silica gravel 1-1 ½ cm, using layers of 15 cm of each, the result obtained is shown in Figure 6.

Figure 6 Physicochemically treated sample before and after filtration

The samples after the biological and physicochemical treatment were subjected to a filtration process and the result is shown in Figure 7.

Figure 7 Filtered samples after biological treatment (1, 2 and 3) and physicochemical treatment (4)

Analytical techniques

The analyzes of pH, conductivity, chemical oxygen demand (COD), total dissolved solids (TDS), total solids (ST) and color (Pt-Co), were applied for both treatments.

Results

Biological treatment: Domestic wastewater characterization

Parameter	Value obtained	Maximum allowable limit
Temperature °C	25.5	40 °C
Fats and Oils	25	25 mg/L
Floating Matter	Ausente	Ausente
Settling Solids	3	2 mg/L
Total Suspended Solids	500	60 mg/L
Biochemical Oxygen Demand	600	60 mg/L
Total Nitrogen	50	25 mg/L
Total Phosphorous	20	10 mg/L
Arsenic	N.D.	0.2 mg/L
Cadmium	N.D.	0.2 mg/L
Cianide	N.D.	2.0 mg/L
Copper	N.D.	6.0 mg/L
Chromium	N.D.	1.00 mg/L
Mercury	N.D.	0.01 mg/L
Níckel	N.D.	4.0 mg/L
Lead	N.D.	0.4 mg/L
Zinc	N.D.	20 mg/L

Table 2 Characterization of NOM-001 SEMARNAT 1996

Parameter	Value obtained	Maximum allowable limit
Fecal coliforms	≥2400000 NMP	240 NMP/100 ml
Helmith eggs	< 1	< 1 (h/1)
Fats and oils	25	15 m/l
BOD $_5$	594	20 mg/l
TSS	500	20 mg/l

Table 3 Characterization of NOM-003 SEMARNAT 1997

Biokinetic constant

Obtaining the Chemical Oxygen Demand (S) and Volatile Suspended Solids (X), associated with the calculation of the biokinetic coefficients, shown in Table 4.

Cycle	S_0	S	$\theta = \theta_c$	X
	g/L COD	g/L COD	h	g VSS/L
1	0.795	--	0	5.00
2	--	0.284	1	4.86
3	--	0.176	2	4.53
4	--	0.154	4	3.5
5	--	0.138	8	2.30

Table 4 Chemical Oxygen Demand (S) and Volatile Suspended Solids (X)

To obtain the maximum substrate utilization rate (k) and the average speed constant (Ks), the data obtained from Table 5 was first plotted with calculations of the equation Y.

Xθ g VSS/h*L	1 /S (h)$^{-1}$	Xθ/(S$_0$ – S) h^{-1}
4.86	3.533	9.0005
9.06	5.6818	14.3711
14	6.4935	16.4003
18.4	7.2463	18.2825

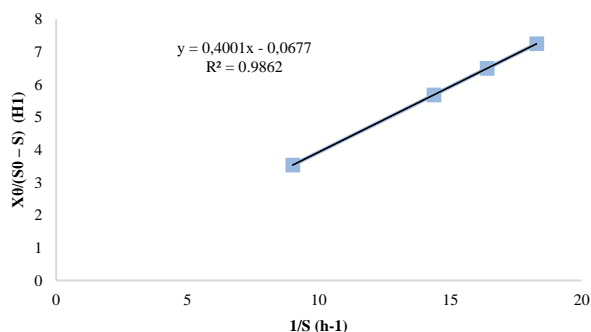**Table 5** Variables associated with the calculation of k and Ks

Figure 8 Maximum growth rate (k) and Average growth rate (Ks)

Figure 8 is the graph of Xθ / (S0 - S) according to 1 / S. In this graph the ordinate to the origin is 1 / k, and the slope is equal to Ks / k. Thus, obtaining k and Ks were 5.91 h^{-1} and 14.78 g / L respectively.

Maximum cell yield (Y) and endogenous decay coefficient (kd)

The variables 1 / θc and (S$_0$ - S) / Xθ were obtained based on the data shown in table 6. The graph of these results to obtain the biokinetic coefficients: Maximum cell yield (Y) and the endogenous decay coefficient (kd) is shown in Figure 9.

1/θc h^{-1}	(S$_0$ – S)/ Xθ h^{-1}
1	0.112
0.5	0.067
0.25	0.048
0.125	0.037

Table 6 Variables associated with the calculation of Y and Kd
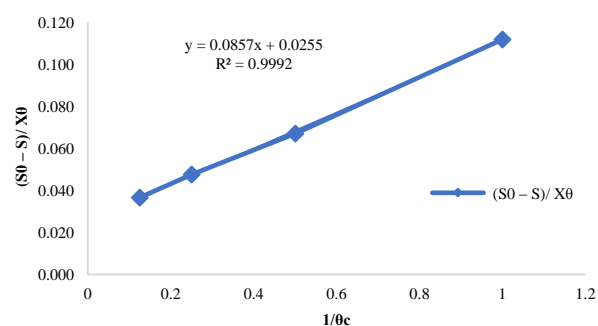

Figure 9 Maximum cell yield (Y) and endogenous decay coefficient (kd)

Coefficients	Result obtained
Substrate utilization rate (k) g CODs / gVSS	5.91
Average rate constant (Ks) mg / l CODs	14.78
Maximum cell yield (Y) mg VSS / mg CODs	0.085
Endogenous decay coefficient (kd) g SSV / g VSS	0.025

Table 7 Results obtained from the biokinetic coefficients of the biological reactor

Once 1 / θc was graphed with respect to (S0 - S) / Xθ, the ordinate to the origin kd was obtained and the slope is Y. Consequently, the values of Y and kd that were obtained were 0.085 and 0.025 h-1 respectively.

Biofilm formation

The sum of the area of the truncated cone and the cylinder resulted in 0.604262 m^2 and the total contact area of the system for the reactor was 10.272454 m^2.

Hydraulic retention

The parameters established in NOM 003 SEMARNAT 1997 were analyzed for the different hydraulic retention times in each concentration, as shown in Table 8 (a, b and c).

Holding time (days)	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	Fats and oils (mg/L)	Fecal coliforms (NMP/100 ml)	Helminth Eggs (Organismos/L)
16	16	12.90	9	<1.0	<3.0	Absent
8	14	14.32	12	<1.0	<3.0	Absent
5.33	18	17.56	15	<1.0	<3.0	Absent
4	19	18.7	14	<1.0	<3.0	Absent
Maximum allowable	N.E.	20	20	15	240	<1.0

Table 8 a 10 % concentration

Holding time (days)	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	Fats and oils (mg/L)	Fecal coliforms (NMP/100 ml)	Helminth Eggs (Organismos/L)
16	16	18.49	13	<1.0	<3.0	Absent
8	19	19.16	12	<1.0	<3.0	Absent
5.33	15.51	19.38	13	<1.0	<3.0	Absent
4	18.51	21.45	12	<1.0	<3.0	Absent
Maximum allowable	N.E.	20	20	15	240	<1.0

Table 8 b 20 % concentration

Holding time (days)	COD (mg/L)	BOD (mg/L)	TSS (mg/L)	Fats and oils (mg/L)	Fecal coliforms (NMP/100 ml)	Helminth Eggs (Organismos/L)
16	19	14.4	12	<1.0	<3.0	Absent
8	10	12.75	10	<1.0	<3.0	Absent
5.33	15	16.23	11	<1.0	<3.0	Absent
4	19	19.62	14	<1.0	<3.0	Absent
Maximum allowable	N.E.	20	20	15	240	<1.0

Tabla 8 c 30 % concentration

Physicochemical treatment

The results are shown in Table 9, of the parameters characterized before and after the physicochemical treatment.

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Parameter	Unit	Initial result	Final result
Electric conductivity	µS	13925	7298
Total suspended solids	mg/L	1390	360
Color	Pt-Co	934	432
Turbidity	NTU	756	340
COD	mg/L	35720	959
BOD	mg/L	900	300
pH	N/A	3.2	7

Table 9 Industrial wastewater characterization

Conclusions

Physicochemical treatment

The parameters analyzed after treatment were decreased by 74%, 53.8%, 55%, 97% and 67%, for electrical conductivity, total suspended solids, color, turbidity, COD and BOD respectively, compared to the initial sample.

Biological treatment

The parameters analyzed in the different hydraulic retention times in the experimental part for COD was 99%. As well as they also present the values of BOD 97%, for all the values. Regarding compliance with NOM 003 SEMARNAT 1997, all retention times comply except for the retention time of 3.2 days for the 30% concentration with wastewater and effluent with butyl acetate

In both treatments there was COD reduction, which indicates that there is a significant removal percentage for butyl acetate. The comparison of the treatments applied to the effluent showed that the biological treatment presented greater removal of the pollutant before the physicochemical treatment in 2% of COD and 30% of BOD.

Discussion

A mass coupled gas spectroscopy analysis is recommended to confirm the removal of butyl acetate in the effluent or the transformation into other chemical species.

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Article

Thermodynamic analysis of a combined gas-steam cycle without and with afterburner

Análisis termodinámico de un ciclo combinado gas-vapor sin y con Postcombustión

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Abstract

Currently in power plants what is sought are higher thermal efficiencies, which is why combined cycle plants have been chosen, since they make better use of fuel, producing greater net power, all this It has led to innovative modifications to combined cycle power plants, improving their performance. In this article the thermodynamic analysis of a combined cycle (Gas-Steam) without and with Afterburner is carried out, in said analysis adequate thermodynamic indices have been used and the calculations have been carried out taking into account the state of the art for gas turbines and the typical values for steam cycle quantities. The purpose of this study is to analyze the combined plants where the exhaust gas at the outlet of the gas turbine is used in a waste heat recovery boiler to produce steam that is expanded in a turbine and discharged in a condenser. Since the air-fuel ratio in the combustion chamber of a gas turbine is higher than the stoichiometric, fuel can be added in the boiler (Afterburner) to increase steam production or to improve the quality of the steam produced.

Combined cycle plant (Gas–Steam), Afterburner, Recovery boiler

Resumen

En la actualidad en las plantas de energía lo que se busca son eficiencias térmicas más altas, es por lo que se ha optado por las centrales de ciclo combinado, ya que en ellas se aprovecha mejor el combustible, produciendo una mayor potencia neta, todo esto ha originado modificaciones innovadoras en las centrales de ciclo combinado, mejorando el rendimiento de este. En este artículo se lleva a cabo el análisis termodinámico de un ciclo combinado (Gas-Vapor) sin y con Postcombustión, en dicho análisis han sido utilizados índices termodinámicos adecuados y los cálculos se han realizado teniendo en cuenta el estado del arte para turbinas de gas y los valores habituales para las cantidades de los ciclos de vapor. El propósito de este estudio es analizar las plantas combinadas donde el gas de escape a la salida de la turbina de gas es utilizado en una caldera de recuperación de calor residual para producir vapor que es expandido en una turbina y descargado en un condensador. Ya que la relación aire–combustible en la cámara de combustión de una turbina de gas es mayor al estequiométrico, se puede añadir combustible en la caldera (Postcombustión) para aumentar la producción de vapor o para mejorar la calidad del vapor producido.

Ciclo combinado (Gas-Vapor), Postcombustión, Caldera de recuperación

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Introduction

Man has a natural tendency to try to improve the efficiency of devices in converting thermal energy into mechanical work. Moreover, the rising costs of fossil fuels as well as the care of the environment is a stimulus for this type of research. Power plants where gas turbines, operating in open cycle, are combined with steam cycles, are of particular interest because of their high conversion efficiency. The combination of these two types of cycles is possible due to the high temperature heat in the turbine exhaust, which depends on the ratio of gas temperature and maximum pressure. For many years the focus of manufacturers and utilities has been on combined cycles (Gas-Steam). Many combinations are possible and gas turbines, in addition to generating mechanical power, can perform different tasks according to their position in the plants.

Pfenninger analysed a plant in which the maximum gas temperature was T3a = 880 °C and concluded that the gas turbine cycle must have the maximum exhaust enthalpy (i.e. the maximum product between the mass flow of the gas and its temperature). The resulting pressure ratio was intermediate between these for which the gas turbine specific work and efficiency are maximum. The afterburner was taken into consideration and the conclusions were that for a low afterburner rate the efficiency decreases slightly, then a maximum is reached in the ratio between gas turbine power and total plant power. An excess of air comprises this ratio.

The total output went up with minimal excess air in the exhaust gas. Wunsch, stated that the efficiency of a combined gas-steam plant is mostly influenced by the gas turbine parameters (T3a , β) what by the steam cycles, the parameters were set in an appropriate way. The conclusion was that the maximum efficiency of the combined Gas-Steam cycle was reached when the exhaust temperature of the gas turbine was higher than the corresponding maximum efficiency of the gas turbine. In the same study the afterburner was taken into consideration and its influence was positive when the maximum gas turbine temperature was lower than 950°C and negative for higher temperatures.

In the present study, a thermodynamic analysis of a combined Gas-Steam cycle is carried out, with one pressure level, with no regeneration drawdowns. The results of the parametric analysis of the cycle performance are given.

Nomenclature

T = Temperature
P = Pressure
V = Volume
Cp = Specific heat at constant pressure
kP = Pressure loss coefficient
h = Enthalpy
pc = Pressure in the condenser in Mpa.
q = Ratio of heat in the afterburner to heat in the combustion chamber and the heat in the combustion chamber of the combustion chamber of the gas turbine
s = Entropy
S = Mass ratio air - vapour
T6a, t6a = Temperature at discharge, °C, K
Tc, tc = Condenser temperature, °C, K
x = Steam quality at the outlet of the steam turbine steam turbine outlet steam quality
$\dot{W}$ = Work, KJ
Q = Heat, KJ
Wo = Specific work, KJ/Kg
α = Air-fuel mass ratio
α st = Stoichiometric air-fuel mass ratio
β gt = Pressure ratio of gas turbine
β st = Steam turbine pressure ratio
Γi = Net heat output KJ/Kg
Єb = Steam generator efficiency
ϒ= Fraction of compressed air for cooling of blades and accessories.
Vs = R/Cp = Ratio of gas constant to specific heat constant at constant pressure in the transformation.
Wn = Net work
Wgt = Work of the gas turbine
Wst = Work of steam turbine
CC = Combined Cycle
WCC = Net combined cycle work
QS = Heat supplied
ηgt = Thermal efficiency of the gas turbine
ηst = Thermal efficiency of steam turbine steam turbine thermal efficiency
ηCC = Thermal efficiency of combined cycle

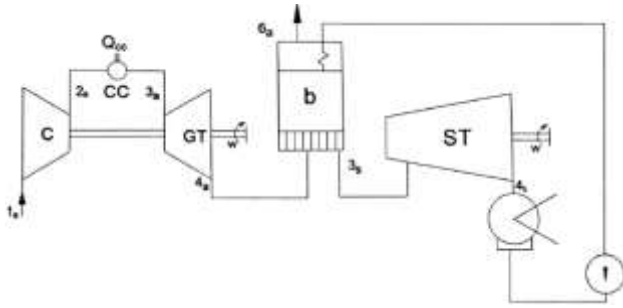The schematic diagram of the simple gas-steam combined cycle is presented below.

Figure 1 Schematic diagram of the simple combined gas-steam cycle
Source: Own Elaboration

In the following, the thermodynamic calculations of the simple combined cycle are presented, whose reference was taken from the: Cerri, G., (1987) Parametric analysis of combined gas - steam cycles. Journal of Engineering for Gas Turbines and Power, vol. 109, pag. 46 - 54.

Compression

$$T_{2a} = (T_1)(\beta^{va12/\eta pc}) \qquad (1)$$

$$T_{2a} = (305 \text{ K})(14^{0.285/0.85})$$

$T_{2a} = 738.91$ K

Taking into account the friction of the compressed air to cool the blades and accessories.

$$Y = 0.05 \quad \text{sí} \quad T_{3a} \leq 1273 \text{ K}$$
sí:

$$T_{3a} \geq 1273 \text{ K}$$

$$Y = \frac{0.05(T_{3a}-273)}{1000} \qquad (2)$$

$$Y = \frac{0.05(1536 - 273)}{1000}$$

$$Y = 0.06315$$

The work absorbed by the compressor is:

$$Wc = \frac{C_{pa1-2}}{\eta mc} (T_{2a} - T_1)(1 + \gamma) \qquad (3)$$

$$Wc = \frac{1.005}{0.98} (738.91 - 305)(1 + 0.06315)$$

$Wc = 473.08$ KJ/Kg

Gas Turbine Combustion

The energy balance of the combustion chamber is:

$$\frac{\Gamma\eta b_{gt}}{\alpha_{gt}} = (1 + \frac{1}{\alpha_{gt}}) C_{pa2-3}(T_{3a}-T_{2a}) \qquad (4)$$

The air-fuel ratio is:

$$\alpha_{gt} = \frac{\Gamma\eta b_{gt}}{C_{pa2-3}(T_{3a}-T_{2a})} - 1$$

$$\alpha_{gt} = \frac{48490\ (0.98)}{1.0838(1536 - 738.91)} - 1$$

$$\alpha_{gt} = 54.0$$

Heat Supplied

$$Qs = \frac{\Gamma\eta b_{gt}}{\alpha_{gt}} \qquad (5)$$

$$Qs = \frac{(48490)(0.98}{54.0}$$

$$Qs = 880 \text{ KJ/Kg}$$

Expansion in the gas turbine

$$\beta_{gt} = k_p\beta_c \qquad (6)$$

$$\beta_{gt} = (0.9238)(14) = 12.9332$$

$$K_p = \frac{\left(1-\frac{\Delta p_{2a}}{P_{2a}}\right)}{\left(1+\frac{\Delta p_{4a}}{P_{4a}}\right)} \qquad (7)$$

$$K_p = \frac{0.97}{1.05} = 0.9238$$

$$T_{4a} = \frac{T_3}{\beta_{gt}^{va34\eta pgt}} \qquad (8)$$

$$T_{4a} = \frac{1536}{12.9332^{((0.2366)(0.8837))}} = \frac{1536}{1.7074}$$

$$T_{4a} = 899 \text{ K}$$

$$Wgt = (1 + \frac{1}{\alpha_{gt}}) C_{pa3-4}(T_3-T_{4a}) \eta_{mgt} \qquad (9)$$

$$Wgt = \left(1 + \frac{1}{54}\right) 1.2136 (1536 - 899) 0.98$$

$$Wgt = 770.88 \text{ KJ/Kg}$$

$$\eta_{gt} = \frac{770.88 - 473.08}{800} = 0.3384 = 33.84\,\%$$

The enthalpy of steam at the boiler outlet is:

$$H_{3s} = H(T_{3s}, p_{2s}) \tag{10}$$

$$T_{3s} = 523\,°C = 796\,K$$

$$P_{2s} = 7.742\,Mpa$$

$$H_{3s} = 3457.87\,KJ/Kg$$

The enthalpy of the condenser feed water is:

$$h_c = h(p_c) \tag{11}$$

$$p_c = 8.91\,kpa$$

$$h_c = 182.46\,KJ/Kg$$

The energy balance in the generator can be expressed as:

$$\left(1 + \frac{1}{\alpha}\right) C_{pa4-6}(T_{4a} - T_{6a})\varepsilon_b = S(H_{3s} - h_c)$$

$$C_{pa4-6} = 1.12\,KJ\,Kg/K$$

$$T_{4a} = 899.61\,K$$

$$T_{6a} = 363.6\,K$$

$$\varepsilon_b = 0.96$$

By subtracting the vapour-air mass ratio (S)

$$S = \frac{\left(1 + \frac{1}{\alpha}\right) C_{pa4-6}(T_{4a} - T_{6a})\varepsilon_b}{(H_{3s} - h_c)} \tag{12}$$

$$S = 0.1878$$

The work of steam expansion

The adiabatic efficiency of the steam turbine expansion can be expressed by P_2s and P_c and the polytropic efficiency. As:

$$\beta_{st} = \frac{P_{2s}}{P_c} \tag{13}$$

$$\beta_{st} = \frac{7742\,kpa}{8.91\,kpa}$$

$$\beta_{st} = 868.91$$

$$\eta_{ast} = \frac{\beta_{st}^{Vs\eta pst} - 1}{\beta_{st}^{Vs} - 1}\,\beta_{st}^{Vs\,(1 - \eta_{pst})} \tag{14}$$

$$\boldsymbol{\eta_{ast} = 0.9365}$$

The entropy of the steam at the turbine inlet is:

$$S_{3s} = s(T_{3s}, p_{2s}) \tag{15}$$

$$S_{3s} = 6.8149\,KJ\,Kg/K$$

Quality at the turbine outlet:

$$x = \frac{6.8149 - 0.61515}{7.5821} = 0.8176$$

$$H_{cs} = H(S_{3s}, p_c) \tag{16}$$

$$H_{cs} = H_f + x\,H_{fg}$$

$$H_{cs} = 2143.88\,KJ/Kg$$

$$\eta_{tv} = \frac{H_{3s} - h_{4s}}{H_{3s} - H_{cs}} \tag{17}$$

$$h_{4s} = 2227.32\,KJ/Kg$$

Steam turbine work:

$$W_{st} = s(H_{3s} - h_{4s})\eta_{ast}\eta_{mst} \tag{18}$$

$$W_{st} = 212.09\,KJ/Kg$$

Heat supplied:

$$Q_s = s(H_{3s} - h_c) \tag{19}$$

$$Q_s = 615.12\,KJ/Kg$$

Thermal efficiency of the steam turbine:

$$\eta_{st} = \frac{W_{st}}{Q_s} \tag{20}$$

$$\eta_{st} = 0.3448 = 34.48\,\%$$

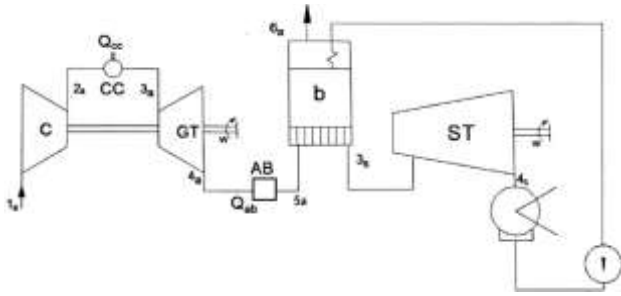The schematic diagram of the combined gas-steam cycle with afterburner is shown below.

Figure 2 Schematic diagram of the combined gas-steam cycle with afterburner
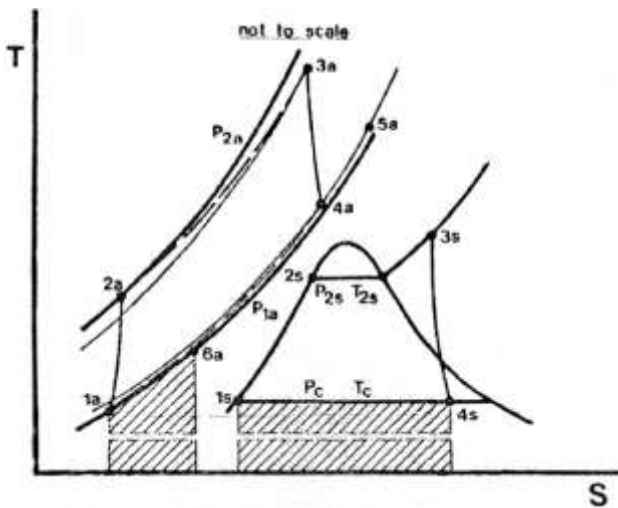*Source: Cerri*

Figure 3 T-S diagram of the combined gas-steam cycle with afterburner
Source: Cerri

The T-S diagram of the combined gas - vapour cycle with afterburner, starts with the compressor drive by admitting air at atmospheric conditions (1a), increases the pressure and temperature up to (2a), this air is supplied to the combustion chamber, in which the fuel is also injected. Combustion takes place, resulting in high-temperature combustion gases (3a). After combustion, the gases go to the turbine where the transformation of thermal energy to mechanical energy takes place, leaving in conditions (4a), it continues to the afterburner chamber where the thermal energy is increased leaving in (5a), it continues to the heat recuperator where the gases transfer heat to the water, being discharged to the atmosphere (6a).

The liquid that is supplied to the heat recovery unit comes out as superheated steam to enter the steam turbine (3s), after the transformation it comes out as a steam with quality (4s), in the condenser the condensation of this steam is carried out (1s), finally this liquid is propelled towards the heat recovery unit to start the cycle again.

The thermodynamic calculations for this cycle are presented below:

The work and thermal efficiency of the gas turbine is the same as for the combined cycle without post-combustion, therefore, the calculations will no longer be carried out.

Heat recovery steam generator

We define α_ab as the ratio of compressed air to fuel used in the afterburner, the final air - fuel mass ratio is:

$$\alpha = \frac{\alpha_{gt}\,\alpha_{ab}}{\alpha_{gt}+\alpha_{ab}} \quad (21)$$

Which, expressed in stoichiometric ratio and with excess air, is:

$$\alpha = \alpha_{gt}\,(1+e) \quad (22)$$

$$\alpha = 14\,(1+0.06) = 14.84$$

Therefore, the ratio of the afterburner fuel to the fuel in the combustor of the gas turbine is:

$$q = \frac{\alpha_{gt}}{\alpha_{st}\,(1+e)} - 1 \quad (23)$$

$$q = \frac{54}{14.84} - 1$$

$$q = 2.6388$$

$$q = \frac{\alpha_{gt}}{\alpha_{ab}} \quad (24)$$

$$\alpha_{ab} = \frac{\alpha_{gt}}{q}$$

$$\alpha_{ab} = 20.46$$

The heat balance in the afterburner can be expressed as:

$$\left(1+\frac{1}{\alpha}\right) C_{pa5}T_{5a} = \left(1+\frac{1}{\alpha_{gt}}\right)C_{pa4}T_{4a} + \frac{\Gamma \eta_{bgt}}{\alpha_{gt}}$$

$$T_{5a} = \frac{\left(1+\frac{1}{\alpha_{gt}}\right)C_{pa4}T_{4a}+\frac{\Gamma \eta_{bgt}}{\alpha_{gt}}}{\left(1+\frac{1}{\alpha}\right) C_{pa5}} \quad (25)$$

$$T_{5a} = \frac{\left(1+\frac{1}{54}\right)(1.1204)(899.61)+\frac{48490(0.98)}{74.46}}{\left(1+\frac{1}{14.84}\right)(1.1204)}$$

$$T_{5a} = 1392.06\,K$$

CASADOS-LÓPEZ, Edzel Jair, CASADOS-SÁNCHEZ, Alvaro, ESCAMILLA-RODRÍGUEZ, Frumencio and CORTÉZ-DOMÍNGUEZ, Cristóbal. Thermodynamic analysis of a combined gas-steam cycle without and with afterburner. Journal of Experimental Systems. 2021

The enthalpy of the steam at the boiler outlet is:

$$H_{3s} = H\,(T_{3s}\,,p_{2s})$$

$T_{3s} = 523\ °C$
$p_{2s} = 7.742\ Mpa$

$$H_{3s} = 3457.87\ KJ/Kg$$

The enthalpy of the feed water in the condenser is:

$$H_c = h\,(p_c)$$

$p_c = 0.00891\ Mpa$

$$\mathbf{H_c = 182.46\ KJ/Kg}$$

The energy balance in the steam generator can be expressed as:

$$(1+\tfrac{1}{\alpha})\,C_{pa5-6}(T_{5a}-T_{6a})\epsilon_b = S(h_{3s}-h_c)$$
$$(1+\tfrac{1}{14.84})\,(1.198)(1392.06 - 363.60)(0.96) = S(3457.87 - 182.46)$$

$$S = \frac{1262.41}{3275.41}$$
$$S = 0.3854$$

With the

$p = 7.742$ You get $H_{2s} = 1304.53$

Steam expansion work

The adiabatic efficiency of the steam turbine expansion can be expressed by p_2s ,p_c and the polytropic efficiency. As β_st= p_2s/p_c the adiabatic efficiency is:

$$\eta_{ast} = \frac{\beta_{st}^{Vs\,\eta_{pst}} - 1}{\beta_{st}^{Vs} - 1}\,\beta_{st}^{Vs\,(1-\eta_{pst})}$$

$$\beta_{st} = \frac{P_{2s}}{P_c} = \frac{7742}{8.91} = 868.91$$

$$V_s = \frac{R}{C_p} = \frac{0.4615}{2.1465} = 0.2150$$

$$\eta_{ast} = [\frac{868.91^{0.2150(0.86)} - 1}{868.91^{0.2150} - 1}]\,868.91^{0.2150(1-0.86)}$$

$$\eta_{ast} = 0.9312$$

The entropy of the steam at the turbine inlet is:

$$\begin{matrix} T = 523°\ C \\ P = 7.742\ Kpa \end{matrix} \Big\{ \quad S_{3s} = 6.8149\ KJ/Kg\ K$$

The final state of the isentropic expansion is:

$$H_{cs} = H\,(S_{3s}\,,p_c)$$

$$x = \frac{6.8149 - 0.61515}{7.5821} = 0.8176$$

$$H_{cs} = H_f + x\,H_{fg}$$

$$H_{cs} = 2143.88\ KJ/Kg$$

$$h_{4a} = 3457.87 - (3457.87 - 2143.88)0.93$$

$$h_{4a} = 2227.32\ KJ/Kg$$

Steam turbine work

$$W_{st} = S\,(H_{3s} - h_{4s})\eta_{ast}\eta_{mst}$$

$$W_{st} = 0.3854\,(3457.87 - 2227.32)(0.9312)(0.98)$$

$$W_{st} = 432.79\ KJ/Kg$$

Heat supplied

$$Q_S = S\,(H_{3s} - h_c)$$

$$Q_S = 0.3854\,(3257.87 - 182.46)$$

$$Q_S = 1262.34\ KJ/Kg$$

Steam and gas turbine thermal efficiency:

$$\eta_{gt} = \frac{W_{tg} - W_c}{Q_s}$$

$$\eta_{gt} = \frac{297.80}{880}$$

$$\eta_{gt} = 0.3384\ = 33.84\ \%$$

$$\eta_{st} = \frac{W_{st}}{Q_s}$$

$$\eta_{st} = \frac{432.79}{1262.34}$$

$$\eta_{st} = 0.3428\ = 34.28\ \%$$

Thermal efficiency of the combined cycle:

$\eta_{cc} = (\eta_{tg} + \eta_{ts}) - \eta_{tg}\,\eta_{ts}$
$\eta_{cc} = (0.3384 + 0.3428) - (0.3384)(0.3428)$
$\eta_{cc} = 0.5652 = \textbf{56.52 \%}$

The following table compares the combined gas-steam cycles without and with afterburners.

Combined Cycle	Wc	Wgt	Wst	Wcc	η_{cc}
Without Post Combustion	473.08	770.88	212.09	509.89	54.6
With afterburner	473.08	770.88	435.25	773.05	54.6

Table 1 Comparative table of work in (KJ/Kg) and thermal efficiency in (%) for the combined cycles with and without afterburner
Source: Own Elaboration

Conclusions and Results

Combined gas-steam cycles for power generation are of great interest, due to the high efficiency that can be obtained. In this research work, a comparison of a combined gas-steam cycle without and with post-combustion was carried out, where the advantage of adding a complementary combustion system before the heat recovery system was determined, obtaining the following results:

For the case of the cycle without post-combustion:

Wc = 473.08 KJ/Kg

Wgt = 770.88 KJ/Kg

Wst = 212.09 KJ/Kg

Wcc = 509.89 KJ/Kg

$\eta_{cc} = 0.5465 = 54.65 \%$

For the case of the afterburner cycle:

Wc = 473.08 KJ/Kg

Wgt = 770.88 KJ/Kg

Wst = 435.25 KJ/Kg

Wcc = 773.05 KJ/Kg

$\eta_{cc} = 0.5465 = 54.65 \%$

These results indicate that when using post-combustion in a combined gas-steam cycle as in this case study, the only variation that exists is in the steam turbine due to the difference in the steam-air mass ratios.

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Rupture voltage in mineral oil using the megger OTS 60pb equipment to determine its quality and use in transformers

Tensión de ruptura en aceite mineral empleando el equipo megger OTS 60pb para determinar su calidad y utilizarse en transformadores

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Abstract

In this project some practices of mineral oil were made to determine the quality for its application in the electrical industry. Then the practices were developed in the laboratory of the Faculty of Mechanical and Electrical Engineering at Universidad Veracruzana using the Megger OTS 60 PB equipment, according to the current IEC 60156 and ASTM D1816 standards, new oil was used in a first analysis which proved to be of correct quality according to the standard, In the second case, oil polluted by the environment was used and it was of less quality since it did not pass the test according to the standard, and finally, degraded oil was used, which was less quality (15°C) and heat was supplied up to 40°C, taking readings at 40°C, 35°C, 30°C and 25°C, giving favorable results due to the influence of the temperature on the mineral oil. In conclusion, according to the results of the test and the comparison with the parameters of the standards, the OTS60PB equipment operates correctly and the results of the equipment are reliable and it can be recommended that mineral oil can be used in transformers.

Quality, Mineral oil, Rupture Voltage

Resumen

En este trabajo se realizaron algunas prácticas de aceite mineral para determinar su calidad para su aplicación en la industria eléctrica. Las practicas se desarrollaron en el laboratorio de la Facultad de Ingeniería Mecánica y Eléctrica de la Universidad Veracruzana utilizando el Equipo Megger OTS 60 PB, de acuerdo a lo establecido con la normatividad vigente IEC 60156 y la ASTM D1816, se empleó aceite nuevo en un primer análisis que resulto ser de calidad correcta de acuerdo a la norma, en segundo caso se utilizó aceite contaminado por el medio ambiente y fue de mala calidad puesto que no paso la prueba de acuerdo a la norma y por último se utilizó aceite degradado el cual fue de mala calidad (15°C) y se le suministro calor hasta los 40°C, tomando lecturas en 40°C, 35°C, 30°C y 25°C, dando resultados favorables por la influencia de la temperatura en el aceite mineral. En conclusión, de acuerdo a los resultados de las prácticas y a la confrontación con los parámetros de las normas, el equipo OTS60PB opera correctamente y los resultados del equipo son confiables y se puede recomendar que el aceite mineral puede ser empleado en transformadores.

Calidad, Aceite mineral, Tensión de ruptura

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†Researcher contributing as first Author.

Introduction

One of the problems faced by energy transformation equipment, as is the case of transformers used in CFE, is the cooling or insulation medium by means of gas or oil. In the case of oil, it is necessary to characterize it and verify its quality in order to use it in transformers, considering its physical and chemical properties and thus conclude whether it is possible to use this oil, as well as to use equipment to measure its dielectric strength. The oil is used as a cooling medium and when it comes into contact with solid elements such as the transformer core, it degrades and it is not possible to maintain the insulation oil in optimal conditions for the proper operation of power transformers.

This has led to the development of different physical, chemical and electrical tests that set the parameters of the oil characteristics and as a whole offer a diagnosis of the oil quality for the proper operation of the transformer. Taking into account this background, the research will allow verifying the quality of the oil with the parameters obtained when performing dielectric strength tests.

Justification

The insulating fluid that has the greatest use in electrical equipment is mineral oil, it fulfills the function of electrical insulation and cooling, this is due to its slow degradation period. It is important to know in time the quality of the fluid (mineral oil) to protect the electrical equipment in a power system.

The realization of this work is due to the scarce information on the dielectric strength test in the books that refer to the analysis of power systems. Most of them deal with electrical equipment testing in a general way and not with all the elements that make up an electrical equipment. This work will be of great support to the students of electrical engineering since the results of the practices of dielectric strength of mineral oil developed in the laboratory of FIME Poza Rica, Veracruz, are presented.

Scope

The evaluation of new mineral oil, in service and contaminated by the environment or degraded by means of the dielectric strength test with the Megger OTS60PB equipment of the FIME Poza Rica Laboratory of the Universidad Veracruzana is proposed, presenting the results of the tests developed as laboratory practices. Therefore, the design and construction of transformers is not considered, only the quality of the insulating fluid (oil) is evaluated, giving a recommendation according to the results.

Considerations of IEC 60156 and ASTM D1816 standards for testing

IEC 60156 recommends using a separate test cup for each type of insulating fluid to be tested. Fill them cover them then store them in a dry place. ASTM offers an alternative option of storing the empty beakers in a dust-free cabinet. Immediately prior to testing, those stored full should be emptied and then all surfaces, including the electrodes, should be rinsed with fluid taken from the same sample to be tested. The beaker should then be emptied again and carefully filled with the test sample, taking particular care to avoid the formation of bubbles. If the beaker was stored empty, or if it is to be used for a different fluid than that used for filling during storage, it should be cleaned with a suitable solvent prior to the rinsing and filling procedures described above.

ASTM D1816 specifies the use of a dry hydrocarbon solvent such as kerosene. Do not use solvents with a low boiling point, as they evaporate quickly, cooling the vessel and creating the risk of condensation. Commonly used solvents include acetone. Use clean, lint-free rags to clean the vessel. Avoid touching the electrodes inside during cleaning, and check that they are free of pits or scratches that can cause breakdown voltage values to be reduced.

Methodology for the development of the mineral oil practices

Pour the oil sample. The cleaning methods detailed in the national specifications for oil testing must be followed. Rinse the container with part of the oil sample.

The sample should be poured into the container, avoiding the formation of air bubbles, up to the 500 ml level mark. (Cover the test container when transferring the oil from the filling area to the oil test assembly to avoid contamination).

1. Clean the electrodes and all surrounding parts that come in contact with the oil sample to be tested.

It is recommended to flush with a portion of the oil sample prior to final filling with the oil to be tested. This may be convenient to allow the oil to stop dripping from the electrodes before removing the oil container after opening the door. This will reduce the need to clean the floor of the test chamber.

2. Set the spacing between the electrodes according to the requirement of the test specification undertaken.

The OTS 60PB is a 0 - 60 kV portable dielectric oil tester. Its size and weight make it suitable for on-site evaluation of insulating oil quality.

Figure 1 Schematic of an OTS60PB 70°C dielectric strength meter with a measurement range of 60 kV and a scale division of 1 kV

The dielectric strength test is performed to determine the quality of the mineral oil and a chemical property pH or degree of acidity of the oil. In this study only the dielectric strength test will be carried out with the OTS 60PB equipment.

This equipment is user friendly and shows on screen the type of test to be selected according to the standard as shown in Table 1.

VDE 0370	AS 1767
BS 148	ASTM D877
BS 5730ª	ASTM D1816
BS 5730a LEPLC	CEI 10-1
BS 5874	ГOCT 6581
IEC 60156	IP 295
IEC 156	NFC 27-221
WITHSTAND	SABS 555
5-minute test	UNE 21
Self-check	

Table 1 Table of standards available for the equipment
Source: Prepared by the team

3. Select the desired option and proceed as indicated in the following instructions on the screen fig. 2.

OPTIONS	
BS 148: 1984	
BS 5730 a: 1979	
BA 5874: 1980	
IEC 156: 1973	
▲ ▼	SELECT

Figure 2 Sample menu screen

Dielectric strength of oil

The dielectric strength of the oil is defined by the breakdown voltage or dielectric strength test. The exact method of performing the test is defined by the standard being used. The standard generally defines parameters such as the voltage value, the shape and size of the electrodes, the electrode spacing, the rate of rise of the test voltage, the number of times the test is repeated and whether the oil is agitated during the test.

Standards for breakdown voltage values in insulating oil testing

From the "Megger's Guide to Dielectric Breakdown Testing of Insulating Oils" we can take the following:

ASTM D877 standard the IEEE recommends it only for acceptance testing of new oil received from a supplier, either in bulk loads or containers, to ensure that the oil was properly stored and transported.

In these cases, a breakdown voltage value of 30 kV or more is generally considered acceptable, while values below 25 kV are considered unacceptable. Values between 25 and 30 kV are considered questionable. For new oil, a minimum value of 30 kV.

Use of disk-shaped electrodes with 25.4 mm (1 in.) diameter and at least 3.18 mm (0.125 in.) thickness. These electrodes are made of polished bronze and are mounted so as to have their faces parallel and horizontally in line on the test vessel. It is specified that the edges should be sharp, with a radius of not more than 0.010 in (0.254 mm).

ASTM D1816 is more sensitive than D877 to moisture, aging and oxidation of the oil, and is more affected by the presence of particles in the oil.

Specifies the use of 36 mm diameter mushroom-shaped electrodes. The electrodes are made of bronze and must be polished and free of pickling, scratches, pitting or carbon build-up. The oil is agitated during the test sequence by a motor-driven two-vane impeller. The standard prescribes the impeller dimensions and pitch, as well as the operating speed, which must be between 200 rpm and 300 rpm.

This method is very sensitive to dissolved gases. Excessive amounts of gas in the oil can lower the test results to the point that suitable oil samples with low moisture and particulate content will fail this test. It is important to keep this in mind when testing small insulated transformer oils in gas atmospheres and, in some cases, free-breathing transformers.

IEC 60156 is an international standard that appears in various forms, as IEC national member committees in several countries have adopted it.

Standard test	IEC156, EN60156, AS 1767, BS 5730, IP 295, NFC 27, SABS 555 y UNE 21
Electrode shape	
Electrode spacing	2.5 mm

Table 2 Comparative table of European standards

The IEC standard differs in several points from D1816, but the main difference is that the IEC standard allows the optional use of an impeller for agitation, the use of a magnetic ball stirrer or no agitation. The standard specifies that no statistically significant differences have been found between tests with or without shaking. The use of a magnetic stirrer is allowed only when there is no risk of removing magnetic particles from the oil sample under test.

When the oil is used as a coolant and therefore when circulating it, it will be agitated during the test. For example, oil from a transformer is normally circulated if it is used as a coolant, so an oil sample taken in this case will normally be agitated to ensure the best chance of detecting particulate contamination.

Circuit breaker oil is normally used statically so particles will naturally fall to the bottom where they are unlikely to cause problems. So in static applications an oil sample will not be agitated. The dielectric breakdown values of the IEC 60156 method are usually higher than those of the ASTM methods.

Possibly this is due in part to differences in ramp-up rate and electrode spacing when compared to D1816, and electrode shape when compared to D877. (The IEC electrode shape provides a more uniform electric field). The result is that for well-maintained transformers the breakdown voltages may be higher than the 60 kV that the test instrument can reach. This may not be a problem when evaluating new oil from a supplier, or even oil in use, but often an actual breakdown voltage value is required. When testing with IEC 60156, therefore, it is advisable to use an instrument capable of applying a higher voltage. As with D1816, dissolved gas in the oil sample can reduce breakdown values, but the effect is much less pronounced than with IEC 60156.

Using the IEC 60156 test method 30 kV or more. Oil that has been vacuum filtered in a laboratory must have a minimum dielectric breakdown voltage of 70 kV.

Dielectric strength test of mineral oil

A series of new oil practices were carried out to determine its quality under the following protocol:

a. Take oil temperature and ambient humidity.
b. Wash the cup with part of the sample. Fill the cup with another portion of the sample up to the 500 ml mark. Place it in the test equipment.
c. Press the power button on the test equipment, let it stand for 2 min.
d. Select the test standard on the screen, once selected press the start button.

e. Take data of each rupture and at the end of the test take data of the mean and standard deviation if required by the standard.
f. Remove the cup from the equipment
g. Verify the results according to the standard.
h. Give diagnosis according to the standard
i. See sequence of standards

First practice with the UNE 21- 309- 89 standard

New mineral oil was considered as the first case. Two practices were carried out under the UNE 21 standard, where the humidity and temperature conditions are shown in tables, as well as the results of the breakdown voltage readings. The practice starts according to the protocol for the beginning of the test, the sequence is as follows**.**

Temp	Humidity		Date	
28 °C	80%		16/10/2019	
	kV	LS	LI	Media	Ds
1	54				
2	60				
3	60	65	53	59	2%
4	57				
5	58				
6	60				

Table 3 Results of practice No. 1 UNE 21 standard
Source: Own Elaboration

Temp	Humidity		Date	
28 °C	80%		16/10/2019	
	Kv	Ls	Li	Media	Ds
1	58				
2	54				
3	60	633	51	577	4%
4	56				
5	57				
6	59				

Table 4 Results of practice No. 2. UNE 21 Standard
Source: Own Elaboration

Practices 3 and 4 were performed under BS 148, where humidity and temperature conditions are shown in tables, as well as the results of the breakdown voltage readings. A sample of the same transformer is used and the practice is carried out according to the test start protocol. This standard has a "pass/fail" option and displays the six results, the average and indicates whether the oil is of the correct quality.

Temp	Humidity	Date
26°C	67%	18/10/2019
	kV	Media
1	47	
2	60	
3	60	56
4	51	
5	60	
6	55	

Table 5 Results of practice No. 3. BS 148 Standard
Source: Own Elaboration

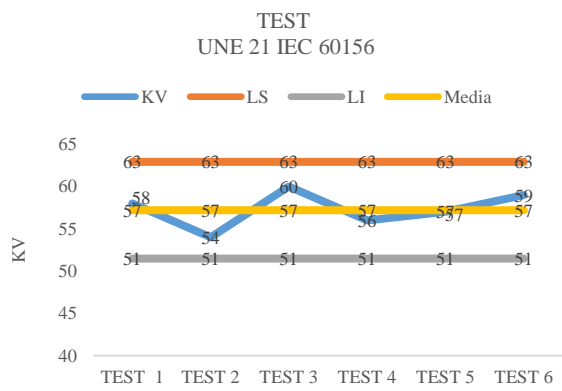| Temp	Humidity	Date
26 °C	67%	18/10/2019
	kV	Media
1	47	53
2	59	
3	60	
4	60	
5	57	
6	31	

Table 6 Results of practice No. 4. BS 148 Standard
Source: Own Elaboration

Results

The results obtained are compared below. First, the results of the practices are validated and then compared with the parameters established by the regulations in order to verify if the oil complies with the established stress ranges. Graphs 1 and 2 show the results of the UNE 21 test.
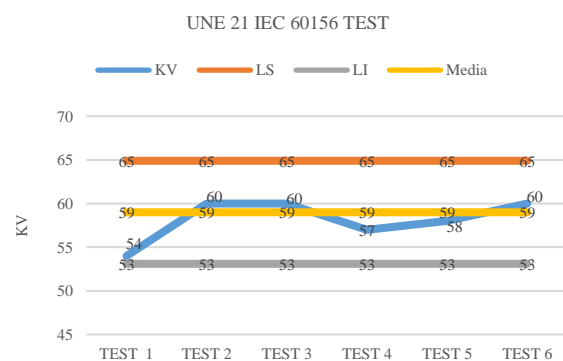

Graph 1 UNE 21 Practice 1. This test is within the parameters of the IEC 60156 standard, because the standard deviation does not exceed 4% of the upper and lower limits
Source: Own Elaboration

ESCAMILLA-RODRÍGUEZ, Frumencio, LAGUNA-CAMACHO, Juan Rodrigo, RÍOS-HERNÁNDEZ, Sara Anahí and JIMÉNEZ-CRISTÓBAL, Juan Daniel. Rupture voltage in mineral oil using the megger OTS 60pb equipment to determine its quality and use in transformers. Journal of Experimental Systems. 2021

Article

TEST
UNE 21 IEC 60156

Graph 2 UNE 21 Práctica 2**.** Esta prueba está dentro de los parámetros de la norma IEC 60156, porque la desviación estándar no pasa del 3% del límite superior e inferior
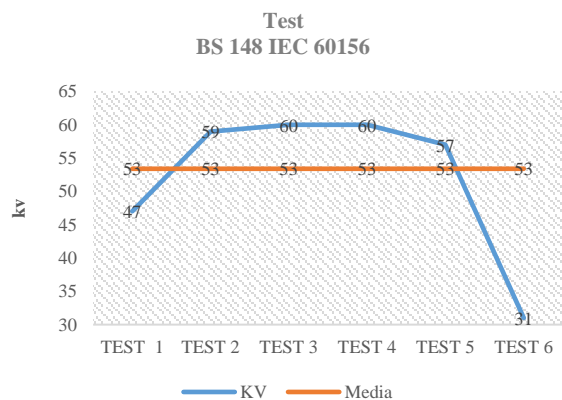*Source: Own Elaboration*

Graphs 3 and 4 show the results of practices 3 and 4 BS 148

TEST
BS 148 IEC 60156
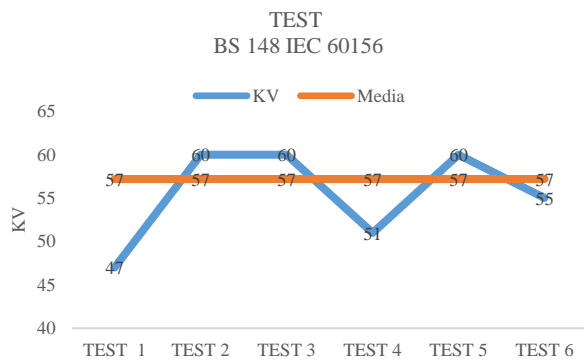
Graph 3 BS 148 Practice 3. Result of oil in service that also complies with the parameters of the standard
Source: Own Elaboration

Test
BS 148 IEC 60156

Graph 4 BS 148 practice 4. Result of oil in service that also complies with the parameters of the standard
Source: Own Elaboration

In this second case, four tests were carried out and all were found to be of incorrect quality. This was under BS 148, where the humidity and temperature conditions are shown in tables, as well as the results of the breakdown voltage readings.

A few samples of contaminated oil are used and the practice is carried out according to the protocol. This standard has a "pass/fail" option and shows the 6 results, the mean and the result of the mineral oil condition.

Temperature	26 °C
Humidity	66%
Wind	11 km/hr
Deviation standard deviation	S= 1.366 $s/\bar{x} = 0.132$
Dielectric Capacity	
1	9 kV
2	12 kV
3	9 kV
4	12 kV
5	10 kV
6	10 kV
Average voltage: 10 Kv	

Table 7 Results of practice No. 5. BS 148 Standard
Source: Own Elaboration

The four practices were then analyzed as a whole using a comparative matrix and the results were plotted.

	Practice 5	Practice 6	Practice 7	Practice 8
1	9	11	21	12
2	12	14	17	13
3	9	13	24	9
4	12	10	17	13
5	10	10	15	9
6	10	17	15	13
Average voltage	10 kV	13 kV	18 kV	12 kV

Table 8 Dielectric strength results
Source: Own Elaboration

Dielectric Stiffness Test
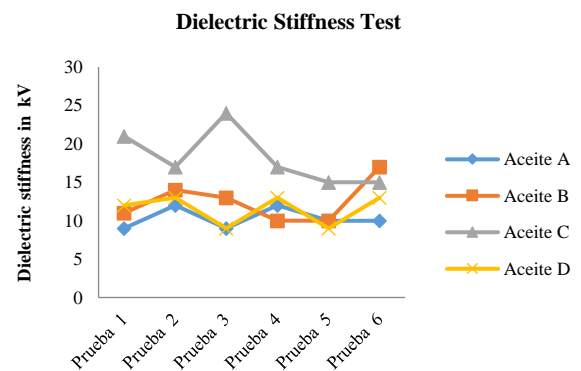
Graph 5 Dielectric strength
Source: Own Elaboration

Graph 5 shows the variation of the dielectric strength of practices 5, 6, 7 and 8 considered oil A, oil B, oil C and oil D respectively of which oil C test can be considered of adequate quality due to its breakdown voltage.

ESCAMILLA-RODRÍGUEZ, Frumencio, LAGUNA-CAMACHO, Juan Rodrigo, RÍOS-HERNÁNDEZ, Sara Anahí and JIMÉNEZ-CRISTÓBAL, Juan Daniel. Rupture voltage in mineral oil using the megger OTS 60pb equipment to determine its quality and use in transformers. Journal of Experimental Systems. 2021

Finally, a practice 9 was performed on another degraded mineral oil to observe its behavior with or without heat supply. This oil did not pass the UNE 21 test (5 minutes) under normal conditions (15°C) and it was decided to supply it with heat, performing the practice again. This was done by increasing its temperature by 5 degrees, therefore, the following temperature readings were considered, 25°C, 30°C, 35°C and 40°C. As the oil cooled very quickly, the first reading was 40°C and subsequently 35°C, 30°C and 25°C, giving results that we can observe in the following table, to a certain extent expected, because the amount of humidity was decreased.

	Oil 15°C	Oil 25°C	Oil 30°C	Oil 35°C	Oil 40°C
1	10	42	54	39	41
2	10	50	52	60	48
3	9	35	50	50	40
1	10	42	54	39	41
Average voltage	10kV	42 kV	52 kV	50kV	43kV

Table 9 Results of practice 9 of mineral oil at different temperatures
Source: Own Elaboration

Annexes

Standard test	EN60156 AS 1767 BS 5730 IEC156 IP 295 NFC 27 SABS 555 UNE 21	CEI 10-1 TOCT 6581 VDE 0370 SATS 286 AS1767	ASTM D1816
Electrode shape			
Electrode spacing	2.5 mm		2.0 mm

Annex 1 Test specification and different types of electrodes

Valid test conditions	
ASTM D 877	
Procedure A	Procedure A
Tests should be repeated if the range of recorded breakdown voltages is more than 92% of the mean. If the range of 10 breakdown voltages is more than 151% the cause should be investigated.	
ASTM 1816	
If the rupture does not occur at 2 mm, reduce the distance to 1 mm. distance to 1 mm. Tests must be repeated if the range of breakdown voltages recorded is more than 120% of average at 1 mm electrode spacing and 92% of the average with 2 mm electrode spacing. electrode spacing of 2 mm.	
IEC 60156	
Expected range of the standard deviation to mean ratio as a function of the mean is provided as a graph. standard deviation to mean as a function of the mean is provided as a graph.	

Annex 2 Validation of the test in the different standards

Oil in service	Dielectric breakdown voltage		
Equipment voltage	Well	Acceptable	Poor
≥ 72.5 kV	> 40kV	30-40 kV	> 30 kV
≥ 72.5 kV ≥ 170kV	> 50 kV	40-50 kV	> 30 kV
> 270 kV	> 60 kV	50 - 60 kV	> 50 kV

Annex 3 Breakdown voltage for oil in service IEC 60156

ASTM D 877 Method		
Acceptable	Dudoso	Unacceptable
≥ 30 kV	< 32 a 28 ≥ 25 kV	< 25 kV

Annex 4 Voltage range per ASTM D 877 standard

Acknowledgements

Conclusions

After analyzing the results of the mineral oil breaking strain, we can conclude the following: The practices carried out under the UNE 21 standard, are within the parameters of the standard. No result exceeds 10% of the mean value, therefore the result is valid. According to the parameters of the standard, the oil is in good condition for use. When applying BS 148, which gives the pass/fail option in practices 3 and 4, where oil in service was used, it was found that the two samples comply with the standard, since the screen of the equipment shows the result when applying this standard (pass/fail). For practice 5, contaminated oil was used under BS 148, the result fails, as well as practices 6, 7 and 8.

For practice 9, the oil used in practices 5, 6, 7 and 8 was used again and when heat was supplied to it, the breaking strain of the oil improved considerably. According to the results of the practices and the confrontation of results with the parameters of the standards, the OTS60PB equipment operates correctly and it was concluded that all results of the operation of the equipment are reliable, that the instructions for handling the oil samples must be followed, since any contamination, no matter how small, can negatively affect the test results, thus generating an erroneous diagnosis of the oil conditions.

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Norma IEC 60156 (por sus siglas en ingles International Electrotechnical Commission)

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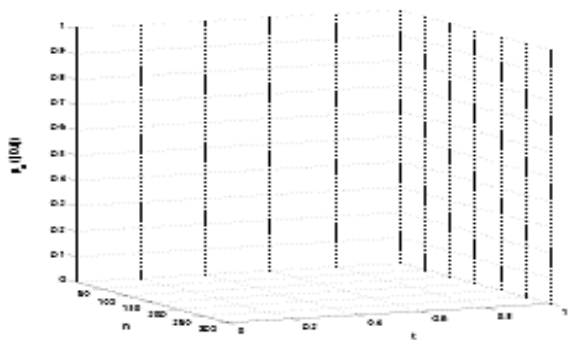
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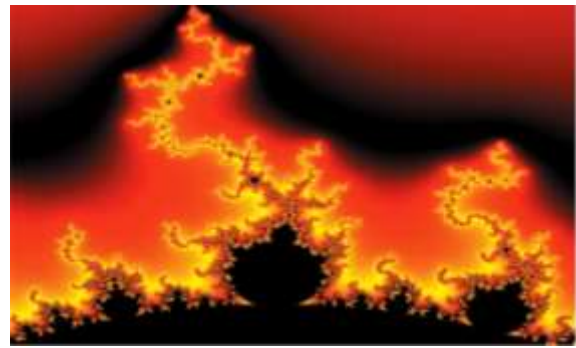
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