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Editorial

Español

La enseñanza de la Ingeniería en su encrucijada

Nunca antes la Ingeniería necesitó más del apoyo de la sociedad y la sociedad necesitó más de los avances de la Ingeniería que ahora. Sin embargo, hay una sensación de desmotivación por parte de los estudiantes para cursar programas de Ingeniería, por lo que otras carreras son más apetecidas como Administración, Economía, Periodismo, Derecho y Humanidades. En primer lugar, esto ocurre en parte porque la tecnología está en general al alcance de todos, es decir, todos son asiduos usuarios de ella, confundiendo su uso cotidiano (soluciones de conectar y usar) con la complejidad de fondo que existe para crearlas e implementarlas. En segundo lugar, los estudiantes potenciales de Ingeniería esperan una educación en tecnología con actividades prácticas inmediatas y con el mínimo de teoría formal, porque, en definitiva: todo es tan fácil de usar que se cree que no es necesario complicarse con comprender a fondo cómo se conciben, fabrican, operan y se realiza la disposición final de un equipo o sistema técnico. Por último, podría mencionarse el desenlace frecuente de estudiar una Ingeniería, ya que los recién graduados muchas veces no cuentan con las habilidades y conocimientos que demanda el mercado laboral y son recibidos con salarios pocos atractivos; a lo que se suma el descubrimiento de que los egresados de otras carreras con poca preparación técnica y de Ingeniería se apoyan en el uso de las tecnologías y las convierten en negocios altamente rentables.

Es un hecho palpable la disparidad existente entre el conocimiento que se enseña en la universidad y el demandado en las empresas (Becker, 2010). En general, algunas habilidades que las empresas consideran muy importantes no se están enseñando de manera suficiente por las universidades, con excepción de los conocimientos teóricos, como se puede apreciar en la Figura 1. Se requiere por tanto de cierto trabajo de acercamiento y acoplamiento de los contenidos y objetivos de formación formulados en los currículos actuales de Ingeniería, con el ámbito de actuación presente y futuro de los ingenieros.

La tecnología generada por medio de la ciencia y la Ingeniería ha mejorado de manera continua y creciente las condiciones de vida de miles de millones de personas en todo el mundo. Actualmente, los indicadores globales de expectativa de vida, servicios básicos, bienestar, seguridad y salud, entre otros, son muy superiores a, por ejemplo, los registrados hace apenas 50 años. No obstante, se debe señalar que la mejoría en la calidad de vida con el uso de mejor y más tecnología no ha alcanzado a toda la población, sobre todo por la toma de malas decisiones políticas y económicas. Peor aún, los órganos decisores han descuidado el medio ambiente y no siempre han escogido las mejores tecnologías existentes en

English

The crossroads of Engineering education

Never before has Engineering needed more from the support of society and society needed more from the advances of Engineering than now. However, there is a feeling of demotivation among the students to pursue Engineering programs, thus other careers are more desirable such as Administration, Economics, Journalism, Law and Humanities. In the first place, this occurs partially because technology is generally available to everyone, that is, everyone is a regular user of it, thus confusing its daily use (connect and use solutions) with the background complexity for creating and implementing it. In the second place, potential engineering students expect education in technology with immediate practical activities and with the minimum of formal theory, because in summary everything is so easy to use that they think it is not necessary to make things difficult with a thoroughly understanding of how to conceive, manufacture, operate and perform the final disposition of a device or technical system. Finally, the frequent outcome of studying an Engineering career could be another reason, since recent graduates often do not have the skills and knowledge demanded by the labor market and are received with unattractive salaries, in addition to the discovery that graduates of other careers with little technical and engineering preparation use technologies and turn them into highly profitable businesses.

The disparity between the knowledge taught in the university and the one required by the companies is a palpable fact (Becker, 2010). In general, some skills that companies consider highly important are not sufficiently taught by universities, with the exception of theoretical knowledge, as shown in Figure 1. Therefore, some approaching and coupling work is required in the contents and educational objectives formulated in the current Engineering curricula, considering the future and current scope of the engineers.

Technology generated through science and engineering has continuously and increasingly improved the living conditions of billions of people worldwide. Currently, the global indicators of life expectancy, basic services, welfare, safety and health, among others, are much higher than, for example, those registered just 50 years ago. However, it should be noted that improvement in the quality of life with the use of more and better technology has not reached the entire population, especially due to poor political and economic decisions. Moreover, decision-makers have neglected the environment and have not always chosen the best existing technologies based on general welfare, but those that report immediate economic benefit without considering the medium- and long-term environmental cost. For this reason, it is imperative to educate competent engineers that care for the environment and with a high ethical commitment, who

función de un bienestar integral, sino aquellas que reportan un beneficio económico inmediato sin considerar el costo ambiental a mediano y largo plazo. Por esto es imperativo formar ingenieros competentes en el cuidado del medio ambiente y con un alto compromiso ético, que puedan mitigar o eliminar por completo los impactos ambientales del uso de las diferentes tecnologías durante todo su ciclo de vida. La evaluación de los impactos ambientales y la toma de decisiones respetuosas con el medio ambiente es una de las grandes asignaturas pendientes en muchos de los currículos de Ingeniería.

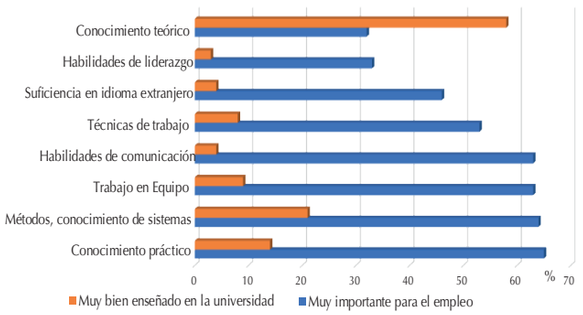

Figura 1. Disparidad entre el conocimiento enseñado en la universidad y el requerido por las empresas.
Fuente: Adaptado de Becker (2010)

Las herramientas de Ingeniería asistida por computador (CAE), las plataformas de enseñanza virtuales y las redes sociales han facilitado los procesos de enseñanza – aprendizaje de la Ingeniería, aunque en ocasiones se ha utilizado un enfoque deficiente que provoca que los estudiantes compitan por el facilismo y descuiden asuntos de fondo, que le competen y que solo pueden anticipar los ingenieros bien formados. El ingeniero debe contar con un arsenal de competencias blandas y específicas que faciliten sus funciones, así como una comunicación efectiva, pero su esencia debe consistir en la comprensión y dominio profundo de un área tecnológica, que sabe explotar a favor de la satisfacción de las necesidades reales de la sociedad.

La enseñanza de la Ingeniería se encuentra en una encrucijada: está entre aferrarse a la escuela tradicional y resistir, o lanzarse a experimentar con nuevas formas de enseñanza - aprendizaje. Muchas universidades ya han dado el gran paso de reinventar, innovar y transformar dinámicamente sus currículos en un intento por adaptarse a los tiempos de cambio. No están claros los efectos a mediano plazo de esto y surgen muchas cuestiones aún sin respuesta. ¿Los ingenieros formados bajo estos nuevos ambientes de enseñanza-aprendizaje son mejores a los formados hace tres o cuatro décadas? ¿Mejores respecto a qué? ¿Cómo anticiparnos a un futuro que no se conoce y formar al futuro ingeniero de manera efectiva? ¿Cómo sería un diseño curricular ideal para un programa de Ingeniería, si tal cosa existe? Algo evidente es que los retos y las exigencias en la práctica de la Ingeniería actual y futura no serán nunca más los mismos de hace 30 años atrás. También, se percibe que nuevas profesiones que emergen

can mitigate or completely eliminate the environmental impacts of the use of different technologies throughout their life cycle. The assessment of environmental impacts and environmentally-friendly decision-making is one of the major pending subjects in many of the Engineering curricula.

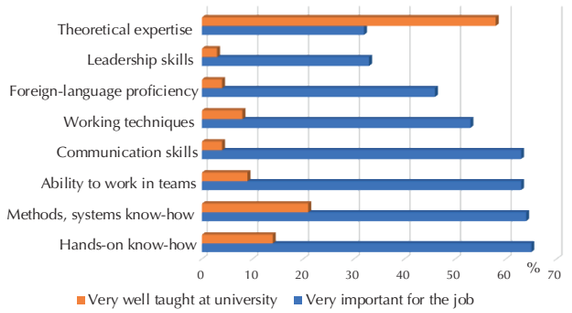

Figure 1. Disparity between knowledge taught at the universities and the one required by the companies.
Source: Adapted from Becker (2010)

The tools of Computer Aided Engineering (CAE), virtual teaching platforms and social networks have facilitated the teaching-learning processes of Engineering. However, sometimes the use of a poor approach has caused students to compete for the facileness and neglect substantive matters, which are their competence and that only well-trained engineers can anticipate. The engineer must have an arsenal of soft and specific skills that facilitate their functions, as well as effective communication, but their essence must be the understanding and deep expertise in a technological field, which can be exploited in favor of satisfying the needs of the real society.

Engineering education is at a crossroads: it is between holding on to traditional school and resisting or embarking on experimentation with new forms of teaching - learning. Many universities have already taken the great step of reinventing, innovating and dynamically transforming their curricula in an attempt to adapt to changing times. The medium-term effects of these changes are not clear, and many questions still remain unanswered. Are engineers trained under these new teaching-learning environments better than those trained three or four decades ago? If that is the case, are they better than what? How to anticipate a future that is unknown and educate the future engineer effectively? What would an ideal curriculum design be like for an Engineering program, if such a thing exists? Something obvious is that the challenges and demands in the current and future Engineering practice will never be the same as 30 years ago. It is also perceived that new emerging professions and other traditional ones, but that have been reinvented, are much more striking for young people than engineering, which is not perceived as an ideal profession in terms of a set of desired qualities, as shown in Figure 2.

There is also a paradox between the revolution regarding the availability of information and the emergence of an apparent knowledge society. The former has not necessarily led to

y otras tradicionales, pero que se han reinventado, resultan mucho más llamativas para los jóvenes que las Ingenierías. Estas últimas no se perciben como una profesión ideal en términos de un conjunto de cualidades deseadas, como se puede apreciar en la Figura 2.

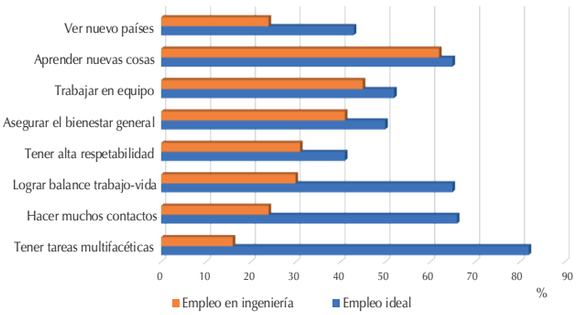

Figura 2. Comparación entre las cualidades deseadas para un empleo ideal en comparación con lo percibido para un empleo en tecnología.
Fuente: Adaptado de Acatech y VDI (2009)

También aparece una paradoja entre la revolución acontecida en cuanto a la disponibilidad de la información y el surgimiento de una aparente sociedad del conocimiento. Lo primero no ha conducido en todos los casos necesariamente a lo segundo. Una sociedad del conocimiento requiere ser capaz de hacer una apropiación crítica, por tanto, selectiva, del cúmulo de información que es generada. Contar con acceso libre y prácticamente ilimitado a la información ya no es un privilegio, hoy en día se posee abundante información en línea y de calidad en pocos milisegundos, con solo introducir un puñado de palabras clave en un buscador web. Sin embargo, la paradoja es evidente, el acceso es inconmensurablemente más fácil, pero la habilidad humana para escogerla parece deteriorarse. De modo que esta competencia general que debe poseer un ingeniero para encontrar información precisa y representativa deberá fortalecerse durante la formación profesional.

En la última reforma curricular realizada en el área curricular de Ingeniería Mecánica y Mecatrónica, se preguntó a los estudiantes sobre las actividades académicas con las cuales aprendían más y mejor (Universidad Nacional de Colombia, 2008). La respuesta indicó que las actividades mejor valoradas eran la resolución de situaciones problémicas en clase y los proyectos de diseño y construcción. En segundo puesto, con las mayores calificaciones, quedaron las visitas técnicas a la industria y las prácticas de laboratorio. Este resultado refuerza la idea que los estudiantes prefieren actividades donde se aprende haciendo y siendo (saber hacer y saber ser), y no con un único componente teórica y conceptual predominante. Esta idea también es considerada en el Plan Estratégico 2013-2020 de la ACOFI (García, 2012).

Con relación al diseño curricular de un programa de Ingeniería, este deberá contemplar espacios para el trabajo con problemas reales de Ingeniería en un ambiente de trabajo colaborativo, interdisciplinario y que genere una experiencia real para un ingeniero. Esta visión es afín con la fábrica

the latter in all cases. A knowledge society requires being able to make a critical, therefore, selective appropriation of the accumulation of information generated. The free and virtually unlimited access to information is no longer a privilege, as today there is abundant quality information online in a few milliseconds, just by entering a handful of keywords in a web browser. However, the paradox is evident: access is immeasurably easier, but the human ability to choose it seems to deteriorate. Therefore, this general competence that an engineer must have to find accurate and representative information should be strengthened during professional education.

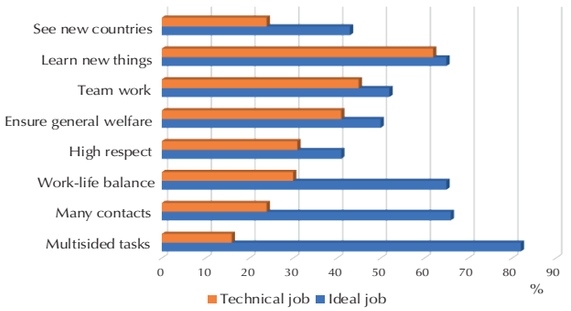

Figure 2. Comparison of the desired features for an ideal job with those perceived for a job in technology.
Source: Adapted from Acatech and VDI (2009)

In the last curricular reform of the area of Mechanical and Mechatronic Engineering, students were asked about the academic activities with which they learned more and better (National University of Colombia, 2008). Their answers indicated that the best rated activities were the resolution of problem situations in class and the design and construction of projects. In second place, with the highest qualifications, there were technical visits to the industry and laboratory practices. This result reinforces the idea that students prefer activities where they learn by doing and being (know how to do and how to be), and not with a single predominant theoretical and conceptual component. This idea is also considered in the ACOFI Strategic Plan 2013-2020 (García, 2012).

In relation to the curricular design of an Engineering program, it must contemplate spaces for working with real Engineering problems in a collaborative, interdisciplinary work environment that generates a real experience for an engineer. This vision is related to the learning factory (LF), where "multidisciplinary student teams develop Engineering leadership skills by working with industry to solve real-world problems" (Lamancusa et al., 2008). For this purpose, in our context certain aspects must be guaranteed:

- The curricular program must have a mainstay of interdisciplinary projects that serve as spaces for academic research work, integration and where the participation of two or more Engineering disciplines is required. It should also facilitate and promote the

de aprendizaje (FA), donde "equipos multidisciplinarios de estudiantes desarrollan habilidades de liderazgo en Ingeniería, trabajando con la industria, para resolver problemas del mundo real" (Lamancusa et al., 2008). Para ello, en nuestro contexto se deberán garantizar ciertos aspectos:

- El programa curricular deberá contar con una "columna vertebral" de proyectos interdisciplinarios, que sirvan de espacios de trabajo académico investigativo, integradores y donde se requiera de la participación de dos o más disciplinas de Ingeniería. Se deberá además facilitar y promover la participación de otras áreas, por ejemplo, estudiantes de administración que orienten la formulación de planes de negocios para la creación de incubadoras y pequeñas empresas.
- Existen un grupo de empresas patrocinadoras de los proyectos, comprometidas financieramente antes de iniciar el semestre, y que proporcionan otros recursos y espacios para garantizar la viabilidad del proyecto. Resulta evidente que el éxito en estos proyectos interdisciplinarios depende del grado de compromiso y participación de la empresa interesada.
- La planta docente deberá tener una cantidad significativa de profesores de excelencia identificados con el quehacer empresarial, las buenas prácticas industriales y las técnicas de diseño y manufactura más modernas, eficientes y respetuosas con el medio ambiente. Estos profesores deben mantener contacto continuo con los ingenieros de diseño, producción, mantenimiento, las gerencias y demás áreas de interés de las empresas, disponiendo de común acuerdo de un banco de proyectos cada semestre.
- La propiedad intelectual de los desarrollos obtenidos en estos tipos de proyectos deberá pertenecer a los estudiantes y a la universidad; aunque podría ser transferida a la empresa mediante un pago que iría a un fondo de fomento y desarrollo de proyectos interdisciplinarios. La universidad orienta los procedimientos de protección de las nuevas ideas materializadas, por ejemplo, las patentes de invención y modelos de utilidad, entre otros.

Un programa curricular en ingeniería moderno deberá desarrollar competencias como la capacidad para formular y solucionar problemas de manera crítica, trabajo colaborativo en un equipo interdisciplinario, liderazgo, toma de decisiones y comunicación efectiva, es decir, habilidades que otorguen a los profesionales de ingeniería las herramientas necesarias para resolver los grandes desafíos tecnológicos, sociales, económicos y ambientales, presentes y que se avecinan. Es difícil poder establecer los aspectos esenciales que conduzcan al éxito de un programa curricular en ingeniería, y estos por si solos tampoco lo garantizarán debido a la naturaleza compleja y abierta de los procesos de aprendizaje y a la gran cantidad de factores internos y externos involucrados. Sin embargo, de realizarse tal intento, incluiría con una alta probabilidad los siguientes aspectos:

participation of other areas, for example, administration students that guide the formulation of business plans for the creation of incubators and small businesses.

- There is a group of companies sponsoring the projects and financially committed even before the start of the academic semester. They also provide other resources and spaces to guarantee the viability of the project. It is evident that the success in these interdisciplinary projects depends on the degree of commitment and participation of the company concerned.
- The teaching staff must have a significant number of professors of excellence identified with business activities, good industrial practices and the most modern, efficient and environmentally friendly design and manufacturing techniques. These professors must maintain continuous contact with the engineers of design, production, maintenance, management and other areas of interest of the companies, thus creating a common agreement for a project bank every semester.
- The intellectual property of the developments obtained in these types of projects must belong to the students and the university. However, it could be transferred to the company after a payment that would go to a fund for the promotion and development of interdisciplinary projects. The university guides the procedures for protecting new materialized ideas, for example, invention patents and utility models, among others.

A modern engineering curriculum must develop competencies such as the ability to formulate and solve problems critically, collaborative work in an interdisciplinary team, leadership, decision-making and effective communication, that is, skills that give engineering professionals the tools necessary to solve the great present and coming technological, social, economic and environmental challenges. It is difficult to establish the essential aspects that lead to the success of a curriculum program in Engineering, although these changes alone will not guarantee success due to the complex and open nature of the learning processes and the large number of internal and external factors involved. If such an attempt is made, the following facts would be included with high probability:

- The first two semesters must be common for all Engineering programs. Thus, the students of the different Engineering programs know and interact with each other, and work on problems of each Engineering taking advantage of appropriate collaborative environments. This would also allow the student to provide more complete information, by immersion, on the different Engineering branches, so that at the end of the second semester, students ratify their choice of the Engineering program or make the transition to another program of their choice

- Los dos primeros semestres deben ser comunes para todas las Ingenierías. Así, los estudiantes de las distintas Ingenierías se conocen, interactúan entre sí y trabajan en problemas de cada Ingeniería aprovechando ambientes colaborativos apropiados. Esto permitiría, además, dotar al estudiante de información más completa, por inmersión, sobre las distintas Ingenierías, de manera que al finalizar el segundo semestre, el estudiante ratifique su elección del programa de Ingeniería o realice el tránsito hacia otro programa de su preferencia.

- La formación en matemáticas debe iniciar con un curso de modelamiento y simulación de fenómenos y procesos del mundo real, soportado con comprobaciones experimentales, para luego continuar con cálculo vectorial, algebra lineal, y probabilidades y estadística.

- El área de ciencias debe comprender cursos de Física, Química orgánica e inorgánica y Biología, donde no solamente se traten los aspectos teóricos de estas ciencias, sino también se establezcan relaciones hacia y con las distintas Ingenierías.

- Desde los primeros semestres se establece la formación en Humanidades y Ciencias Sociales. Esta formación permitiría preparar al estudiante para aplicar los conocimientos de Ingeniería en correspondencia con el contexto social.

- Los estudiantes deben cursar al menos una asignatura orientada hacia Negocios y Emprendimiento. La experiencia de emprendimiento puede utilizarse posteriormente en la ejecución de proyectos de Ingeniería en los que el estudiante aplica conocimientos y habilidades. La Facultad deberá proveer una unidad de incubación de negocios, donde los estudiantes sean guiados en la formulación y seguimiento de sus propios emprendimientos.

- En las actividades académicas, se utilizan metodologías activas de aprendizaje combinadas y potenciadas mediante las TICs. Entre las metodologías de aprendizaje activo que parecen funcionar bien para las Ingenierías se encuentran: aprendizaje basado en problemas (ABP); aprendizaje significativo a través de la resolución de problemas (ASARP); simulación mediante videojuegos; aprendizaje cooperativo–colaborativo y aprendizaje orientado a proyectos (AOP) (Rodríguez, Maya y Jaén, 2012). No se utiliza una única metodología de trabajo, sino que hay varias opciones que permiten personalizar el modo que en que aprende cada estudiante.

- A lo largo del plan de estudios, se implementa una estrategia transversal para el desarrollo de las habilidades de comunicación en los estudiantes, en forma escrita, hablada, visual y gráfica. El currículo debe contar además, con al menos una asignatura

- Education in Mathematics should begin with a modeling and simulation course of real-world phenomena and processes, supported by experimental tests. Then, it should continue with vector calculus, linear algebra, and probabilities and statistics.

- The science area must include courses in Physics, Organic and Inorganic Chemistry and Biology, where not only the theoretical aspects of these sciences are discussed, but also different relationships are established towards and with the different Engineering programs.

- Since the first semesters, education in Humanities and Social Sciences is established. These courses allow preparing the student to apply the knowledge of Engineering in correspondence with the social context.

- Students must take at least one course oriented towards Business and Entrepreneurship. The entrepreneurial experience can be used later in the execution of engineering projects in which the student applies knowledge and skills. The School of Engineering must provide a business incubation unit, where students are guided in the formulation and monitoring of their own projects.

- In academic activities, active learning methodologies combined and enhanced through ICTs are used. Some of the active learning methodologies that seem to work well for Engineering are: problem-based learning (ABP); significant learning through problem solving (ASARP); video game simulation; cooperative-collaborative learning and project-oriented learning (AOP) (Rodríguez, Maya and Jaén, 2012). A single work methodology is not used, but there are several options that allow you to customize the way in which each student learns.

- Throughout the curriculum, a transversal strategy is implemented for the development of communication skills in students, in written, spoken, visual and graphic form. The curriculum must also have at least one course on graphic representation and another on writing and oral presentations of a technical nature, considering the benefits that have been reported (Ramírez-Echeverry, Olarte and García-Carillo, 2016).

- The curriculum must contemplate individual and group study activities that are formally evaluated. The student prepares in this way for continuous learning (lifelong learning and unlearning) and for interaction with other professionals during this path.

- The design of systems, products and services is an integral part of the curriculum. Since the first semester, students face open design problems, in which, both technical and non-technical, knowledge and skills should be applied.

sobre representación gráfica y otra sobre la escritura y presentación oral de carácter técnico, considerando los beneficios que se han reportado (Ramírez-Echeverry, Olarte y García-Carillo, 2016).

- El plan de estudios debe contemplar actividades de estudio individual y grupal que sean formalmente evaluadas. El estudiante se prepara de esta forma para un aprendizaje continuo (aprender a aprender y a desaprender a lo largo de su vida) y para la interacción con otros profesionales durante este aprendizaje.

- El diseño de sistemas, productos y servicios forma parte integral del plan de estudios. Desde el primer semestre los estudiantes se enfrentan a problemas de diseño de naturaleza abierta, en los que se deberán aplicar conocimientos y habilidades, tanto técnicas como no técnicas.

- La naturaleza y alcance de los proyectos aumenta progresivamente su complejidad, comenzando por proyectos en ambientes académicos controlados. Luego, hacia los últimos semestres del programa, los estudiantes deberán resolver un problema real de Ingeniería en equipos multidisciplinarios, que sea de interés para una empresa.

- El programa de Ingeniería debería brindar la oportunidad a los estudiantes de seguir sus mayores motivaciones y aspiraciones de formación, en forma personalizada e independiente, bien sean tecnológicas, artísticas, humanísticas o empresariales, ofreciendo los recursos necesarios y el reconocimiento formal. Una manera de garantizar esto en el currículo es por medio de un componente de libre elección y un sistema de acompañamiento estudiantil.

- Las líneas disciplinares del programa cuentan con materias de profundización o especialización. Los estudiantes construyen las rutas curriculares de su preferencia, bajo la orientación del sistema de acompañamiento estudiantil. Los aspectos medio-ambientales y de medición de los impactos ambientales con el uso de las tecnologías deben estar siempre presentes.

- El programa de Ingeniería posibilita la articulación con el posgrado. Los estudiantes más destacados cuentan con la posibilidad de realizar el tránsito automático hacia un programa de maestría en el último semestre de su pregrado. Se cuenta con una reglamentación clara al respecto y con un programa de becas que soportan la investigación. Las becas se soportan parcialmente con las ganancias que generan los productos y resultados intangibles de las investigaciones.

- El programa de Ingeniería cuenta con un personal docente comprometido con la excelencia académica, actualizado permanentemente en el uso de herramientas pedagógicas, orientado hacia la investigación y la innovación, y con fuertes vínculos con el sector

- The nature and scope of projects progressively increases their complexity, starting with projects in controlled academic environments. Then, towards the last semesters of the program, students must solve a real problem of Engineering in multidisciplinary teams and it should be of interest to a company.

- The Engineering program should provide the opportunity for students to follow their greatest motivations and educational aspirations, in a personalized and independent way, offering the necessary resources and formal recognition, whether those aspirations are technological, artistic, humanistic or business. One way to guarantee this objective in the curriculum is through the component of free choice courses and the student support system.

- The core lines of the program have courses for in-depth study or specialization. Students build the curricular routes of their choice, under the guidance of the student support system. Environmental aspects and measurement of environmental impacts with the use of technologies must always be present.

- The Engineering program enables articulation with postgraduate degrees. The most outstanding students have the possibility of automatic transit to a master's program in the last semester of their undergraduate program. There is a clear regulation in this regard and a scholarship program that supports research. The scholarships are partially supported by the profits generated by the products and intangible results of the research.

- The Engineering program has a teaching staff committed to academic excellence, constantly updated in the use of pedagogical tools, oriented towards research and innovation, and with strong links with the business sector. The professor must have the education needed to motivate the student towards learning of different types of knowledge, research and innovation (Carvalho et al., 2018). Regarding the organization of the teaching staff, it should not be structured by departments, but rather organized so that professors can interact as an interdisciplinary group, with mixed offices and functional and socially convergent work areas. This environment would encourage interdisciplinary work.

- The Engineering program has implemented and used a system to continuously monitor and thus measure academic quality. Indicators relevant to all levels and involving factors of importance to the program are collected in this way, which allows to have updated information and its tendency for making assertive decisions for improvement. Quality must be understood in the educational field from several perspectives: "quality based on the proximity of performance in relation to an idealized model, quality as an expression of the attachment of institutional

empresarial. El docente debe tener una formación que le permita motivar al estudiante hacia el aprendizaje de los distintos saberes, la investigación y la innovación (Carvalho et al., 2018). En cuanto a la organización del personal docente, este no debe estar estructurado por departamentos, sino más bien organizado de manera que pueda interactuar como un grupo interdisciplinario, con oficinas mezcladas y áreas de trabajo funcionales y socialmente convergentes. Este ambiente incentiva el trabajo interdisciplinario.

- El programa de Ingeniería tiene implementado y utiliza para monitorear de manera continua un sistema que le permite medir la calidad académica. Se recogen de esta manera indicadores relevantes a todos los niveles y que involucran los factores de importancia para el programa; lo cual permite tener información actualizada y su tendencia para la toma asertiva de decisiones de mejoramiento. La calidad debe entenderse en el ámbito educativo desde varias perspectivas: "calidad basada en la proximidad del desempeño con relación a un modelo idealizado, calidad como expresión del apego de las acciones institucionales a sus declaraciones misionales, y calidad como percepción del aprecio social del valor agregado a los actores del proceso educativo" (Cañón y Salazar, 2011).

La Ingeniería es un verdadero factor de cambio en la sociedad. De modo que es racional y legítimo poner en duda la certeza de los sistemas tradicionales de enseñanza de la Ingeniería a favor de su innovación y mejoramiento continuo. Si se pretende el rápido avance de la sociedad colombiana hacia una sociedad del bienestar y el conocimiento, se requiere replantear el papel que juegan los programas curriculares de Ingeniería y las universidades, en cuanto al qué, cómo y para qué, de los saberes contemplados, y la pertinencia y efectividad de los procesos de enseñanza-aprendizaje. Lo anterior debe colocar en el centro al estudiante y cómo lograr la motivación en su propia formación. Se requiere una reconceptualización sobre el aprendizaje del estudiante, sobre cómo aprende mejor y sobre cómo lograr que sea autónomo en su desarrollo intelectual para formar un pensamiento crítico. También, se debe garantizar un currículo que facilite la adquisición por parte del estudiante de habilidades para la gestión, análisis y evaluación de información significativa para su educación. Esta es una tarea de todos, muchos éxitos en tan noble y difícil propósito.

Una vez más agradecemos a los autores, revisores y lectores por sus importantes aportes e interés. La Revista *Ingeniería e Investigación* continúa realizando los mejores esfuerzos con el respaldo de la Facultad de Ingeniería de la Universidad Nacional de Colombia para divulgar el conocimiento científico y tecnológico.

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actions to their mission statements, and quality as a perception of the social appreciation of added value to the actors of the educational process "(Cañón and Salazar, 2011).

Engineering is a true factor of change in society. Therefore, it is rational and valid to question the certainty of traditional engineering education systems in favor of their innovation and continuous improvement. If the rapid advance of the Colombian society towards a society of well-being and knowledge is intended, it is necessary to rethink the role played by the curricular programs of Engineering and universities, in terms of what, how and what for of the knowledge contemplated, and the relevance and effectiveness of the teaching-learning processes. The above should place the student in the center and how they achieve motivation in their own training. A reconceptualization of student learning, how do they learn better and how do they become autonomous in its intellectual development, is required to form critical thinking. Besides, a curriculum that facilitates the acquisition of management skills by the student and the analysis and evaluation of meaningful information for their education should be guaranteed. It is everyone's task, so we wish you a lot of success in such noble and difficult purpose.

Once again, we thank the authors, reviewers and readers for their important contributions and interest. The *Ingeniería e Investigación* Journal continues to make the best efforts with the support of the Faculty of Engineering of the Universidad Nacional de Colombia to disseminate scientific and technological knowledge.

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Removal of acetylsalicylic acid (ASA) in packed microcolumns with carbon xerogel modified with TiO_2 nanoparticles

Remoción de ácido acetilsalicílico (ASA) en microcolumnas empacadas con xerogel de carbono modificado con nanopartículas de TiO_2

Viviana E. Gómez[1], Adriana P. Herrera[2], and Jorge H. Sánchez[3]

ABSTRACT

The adsorption capacity of acetylsalicylic acid was evaluated using carbon xerogel (CX) and carbon xerogel modified with TiO_2 nanoparticles (CXM). These materials were characterized by different techniques such as Scanning Electron Microscopy (SEM), X-Ray Diffraction (XRD), and Fourier Transform Infrared (FTIR) spectroscopy. BET surface area measurements found values of 762 m^2/g and 214 m^2/g for CX and CXM, respectively. Batch experiments show that the Langmuir-Freundlich model best represents the experimental adsorption isotherm, in addition to show a maximum adsorption capacity of 17,48 mg/g. In continuous experiments, the effect of the inlet concentration and flow rate on the adsorption capacity of the micro-packed bed adsorber were evaluated. Breakthrough curves agree well with the axial dispersion model. In view of their adsorption capacity, carbon xerogels provide a potential material for the removal of emergent contaminants from the pharmaceutical industry. Besides, the incorporation of TiO_2 nanoparticles allows the implementation of complementary techniques, e.g. photodegradation, as an alternative to achieve higher elimination of aqueous contaminants.

Keywords: Acetylsalicylic acid, Microcolumns, Nanoparticles, Titanium dioxide, Carbon xerogel.

RESUMEN

Se evaluo la capacidad de adsorcion de acido acetil salicılico usando xerogel de carbon (XC) y xerogel de carbon modificado con nanopartıculas de TiO_2 (XCM). Estos materiales se caracterizaron mediante tecnicas como la microscopıa electronica de barrido (SEM), difraccion de rayos X (DRX) y espectroscopia infrarroja (FTIR). Para el area superficial BET, se encontraron valores como 762 m^2/g para XC y 214 m^2/g para XCM. Los experimentos de adsorcion muestran que el modelo que mejor representa la isoterma es el de Langmuir-Freundlich, ya que mostro una capacidad de adsorcion maxima de 17,48 mg/g. En los experimentos en continuo, se evaluo el efecto de la concentracion de entrada y la velocidad del flujo sobre la capacidad de adsorcion del adsorbente en el lecho microempacado. Las curvas de ruptura concuerdan bien con el modelo de dispersion axial. En vista de su capacidad de adsorcion, los xerogeles de carbono son un posible material para la eliminacion de contaminantes emergentes de la industria farmaceutica. Ademas, la incorporacion de las nanopartıculas de TiO_2 permite la implementacion de tecnicas complementarias, por ejemplo, la fotodegradacion, como una alternativa para lograr una mayor eliminacion de contaminantes acuosos.

Palabras clave: Acido acetil salicılico, Microcolumnas, Nanopartıculas, Dioxido de titanio, Xerogeles de carbon.

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Introduction

In recent years, a lot of waste is generated from industrial and human daily activities, producing toxic compounds that pollute the environment and cannot be degraded by nature. These residues include the so-called emerging contaminants (EC), which consist in a wide variety of chemical compounds, such as pharmaceutical drugs, personal care products, surfactants, plasticizers and chemical additives from industrial processes, that are not considered in the current monitoring programs for wastewater treatment (Jiang, Xiao, Wang, Wang, and Cai, 2015). Pharmacological residues represent the highest percentage of EC, which is a big concern for public health, since the effect of chronic exposure is unknown. (Tejada, Quiñonez, and Peña, 2014) One of the most commonly used drugs is the acetylsalicylic acid (ASA),

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which serves as anti-inflammatory, analgesic, antipyretic and antiplatelet agent (Mukherjee, Ray, and Barghi, 2016). There are various methods for the removal of this type of contaminant from wastewater (Roig Bondia, 2013), but adsorption on carbonaceous materials appears to be the best and the most frequent strategy used, since it is efficient, economic, and environment-friendly (Vargas, 2013). Among these materials, there is a group called carbon xerogels, which have a mesoporous structure and are able to adsorb larger molecules, such as emerging contaminants or dyes (Álvarez, Ribeiro, Gomes, Sotelo, and García, 2015). In the literature, some studies have focused on the use of carbon xerogels as adsorbent materials. For example, Álvarez et al. (2015) studied the elimination of caffeine and diclofenac using carbon xerogels. The maximum adsorption capacity was 182,5 mg/g for caffeine and 80,0 mg/g for diclofenac. Carabineiro, Thavorn-amornsri, Pereira, Serp and Figueiredo (2012) used activated carbon, carbon nanotubes and carbon xerogel for the adsorption of ciprofloxacin, obtaining adsorption capacities from 112 to 135 mg/g. The carbon nanotube sample was the material with the highest adsorption capacity per unit area, which was attributed to its high surface area and electron-donor capacity.

The modification of the adsorbent material with TiO_2 nanoparticles offers additional advantages. Some of them are a synergistic effect with the adsorbent compound, through the increase of surface area as a function of the reduced particle size; the development of mesopores; the exposure of a more active crystalline phase; and the possibility of the subsequent photodegradation of the pollutant, avoiding the generation of residual products (Bailón-García et al., 2017; López-Muñoz, Arencibia, Cerro, Pascual, and Melgar, 2016). Authors such as Borges, García, Hernández, Ruiz-Morales and Esparza, (2015) studied the removal of paracetamol using a photoreactor, where TiO_2 was supported in glass spheres. The photocatalytic activity reached a high photodegradation between 99 % and 100 % after 4 hours of irradiation. Additionally, Bailón-García et al. (2017) studied a series of carbon xerogels-TiO_2 composites that were used as photocatalysts and adsorbents of dyes. They concluded that the adsorption of the dye is controlled by the mesopore volume, which augmented with the increasing percentage of titanium oxide present in the carbonaceous composite.

In the last two decades, related studies on the implementation of microdevices have shown that they have several advantages on conventional processes. Their small size and large surface to volume ratios leads to a lower driving force required for mass and heat transfer, thus smaller unit volumes are necessary (Kenig, Su, Lautenschleger, Chasanis, and Grünewald, 2013). Few studies about adsorption in microchannels have been reported. For instance, El-Qada, Abdelghany and Magdy (2013) studied the adsorption of dyes in a fixed-bed microcolumn using activated carbon. Their results show the effect of initial dye concentration, column diameter and particle size on the microcolumn performance. Sharma and Tiwari (2016) studied the removal of Cu^{2+} using acrylamide-co-maleic acid in a fixed-bed microcolumn. From these experiments, they observed that an increase in the flow rate and inlet concentration of the metal also increased the adsorption capacity up to a 98 % of Cu^{2+}, with the possibility of bed regeneration for a new application.

In this work, we report the removal of acetylsalicylic acid using activated carbon xerogels modified with TiO_2 nanoparticles. Batch adsorption experiments were performed to obtain the equilibrium curves and determine the effect of the adsorbent dose, pH of the solution, and initial concentration of the adsorbate. Additionally, breakthrough curves were obtained for continuous removal using packed-bed microcolumns at different operating conditions.

Experimental

Reagents

Acetyl salicylic acid (ASA) was purchased from Sigma-Aldrich in analytical grade (> 99 %). Formaldehyde (37 % in water, stabilized with 10 % methanol), resorcinol (≥ 99 %) and sodium hydroxide (98 %) were purchased from Merck. Titanium (IV) isopropoxide (95 %) and tetraethyl orthosilicate (98 %) were acquired from Alfa Aesar, while dimethylsulfoxide (99 %) was obtained from Panreac.

Synthesis of carbon xerogel

Following the experimental procedure proposed by Álvarez et al. (2015), carbon xerogel (CX) was obtained by polycondensation of resorcinol with formaldehyde (molar ratio 1:2). In a typical experiment, 9,91 g of resorcinol was dissolved in distilled water, with the addition of 13,5 mL of formaldehyde solution. In order to achieve the desired initial pH of the precursor solution (pH = 6,1), sodium hydroxide solution was added drop wise under continuous stirring and pH monitoring. Later, the resulting solution was taken to an oven at 85 °C for 3 days. The obtained gel was then dried in an oven for several days at 60 °C, with a pressure ranging between 103 Pa and 105 Pa. Finally, the gel was calcined in the presence of N_2 at 900 °C for one hour and activated with CO_2 at 840 °C for 2 hours.

Synthesis of nanoparticles and modification of the xerogel

The synthesis of titanium dioxide (TiO_2) nanoparticles was performed using the green chemistry method, where a chemical reduction of titanium tetraisopropoxide was made using an aqueous extract obtained from leaves of lemongrass. For this synthesis, 850 mL of lemongrass extract were mixed with 1,33 mL of titanium tetraisopropoxide, shaking at 175 rpm for 24 hours. Afterward, nanoparticles were precipitated by centrifugation at 5000 rpm and dried at room temperature. To obtain the desired crystal structure, the TiO_2 nanoparticles were calcined at 450 °C for 3 hours. To modify the xerogel with the nanoparticles, 1,0 g of the carbonaceous material was initially prepared and suspended in 20 mL of organic solvent dimethylsulfoxide (DMSO), which was kept under slow shaking for 24 h at 30 °C. Then, 3 mL of tetraethylorthosilicate (TEOS) were added to the mixture

and left for 48 h at room temperature. Subsequently, 0,5 g of the synthesized nanoparticles were added to the suspension, and the mixture was placed on an orbital shaker for 12 hours at 30 °C. Afterward, the modified material was precipitated using a centrifuge at 5000 rpm for 15 min and then washed with ethanol (Bitar Castro and Mejía Meza, 2015).

Characterization of nanoparticles and carbon xerogels

The physicochemical, morphological and surface properties of the carbonaceous materials and TiO_2 nanoparticles were characterized by Scanning Electron Microscopy (SEM) in a JCM-6000 Plus microscope (JEOL Ltd, Japan). BET surface area measurements were taken in an ASAP2020 Plus System (Micromeritics, USA) and X-Ray Diffraction (XRD) was performed using Empyrean Series II X-ray diffractometer (Malvern Panalytical, USA). Finally, Fourier transform infrared spectroscopy was made in a Shimadzu Model IRAffinity-1S FTIR.

Dose curve

Carbon xerogels quantities between 25 and 250 mg were taken and put in contact with 25 mL of ASA aqueous solution, with concentration of 100 mg/L. The solution pH was not adjusted. The suspensions were continuously agitated at room temperature, at 150 rpm, for 7 h until equilibrium was reached. Then, suspensions were filtered, and the ASA equilibrium concentrations were determined at λ = 280 nm, using a UV-1800 spectrophotometer (Shimadzu, Japan). The removal efficiency at equilibrium was calculated using Equation (1).

$$\% \text{ removal} = \frac{\left(C_o - C_{eq}\right)}{C_o} \times 100 \tag{1}$$

where C_o (mg/L) is the liquid-phase concentration of ASA at $t = 0$ and C_{eq} is the equilibrium concentration.

Effect of solution pH

The pH of the experimental solutions was adjusted from 2 to 11 by addition of HCl and NaOH solutions. The ASA concentration was fixed at 100 mg/L. Tests were carried out at room temperature and agitated at 150 rpm with a contact time of 7 h. Once this time was elapsed, suspensions were filtered, and the ASA concentrations were determined at λ = 280 nm, using a UV-1800 spectrophotometer (Shimadzu, Japan).

Adsorption isotherms

Batch adsorption studies allow to obtain the equilibrium data for a fixed temperature of the mixture. In this test, different ASA solutions were prepared at concentrations between 10 and 200 mg/L, at room temperature. The doses of adsorbent and pH of the solution were taken from the previous results. After a contact time equivalent to 2 h, the solutions were filtered and analyzed in a UV-1800 spectrophotometer (Shimadzu, Japan) at a wavelength of 230 nm. This determined the adsorption of ASA on the evaluated material (Gómez Rengifo, 2013). Mass of ASA adsorbed per mass of each utilized material q_e, calculated according to Equation (2), is presented as a function of the ASA concentration C_e.

$$q_e = \frac{(C_o - C_e)\, V}{m} \tag{2}$$

where C_o and C_e (mg/L) represent the initial and the equilibrium concentration of the adsorbate in the solution, respectively. $V(L)$ is the volume of the solution, and m(g) is the dry mass of the adsorbent.

Langmuir (Eq. 3), Freundlich (Eq. 4) and Langmuir-Freundlich (L-F) (Eq. 5) adsorption models were used to fit the experimental equilibrium adsorption data (Álvarez et al., 2015).

$$q_e = \frac{q_{\max} K_L C_e}{1 + K_L C_e} \tag{3}$$

$$q_e = K_F\,(C_e)^{n_F} \tag{4}$$

$$q_e = \frac{q_{\max} K_L\,(C_e)^n}{1 + K_L\,(C_e)^n} \tag{5}$$

where C_e (mg/L) represents the equilibrium concentration in the aqueous phase, q_e (mg/g) the equilibrium adsorption capacity and $q_{\max}$ (mg/g) the maximum adsorption capacity according to Langmuir and Langmuir-Freundlich models. K_L (L/mg) is a parameter related to the adsorption intensity for Langmuir and Langmuir-Freundlich equations and n is a constant associated with the heterogeneity of the adsorber in the Langmuir-Freundlich model. K_F (L/g) and n_F are parameters that define the adsorption capacity and adsorption intensity in the Freundlich model. The parameters of the models can be estimated by nonlinear regression analysis, minimizing the following objective function (Eq. 6):

$$F.O. = \sum_{i=1}^{N} \left(q_{e,i\,\exp} - q_{e,i\,\mathrm{mod}}\right)^2 \tag{6}$$

Packed-bed microcolumn experiments

A capillary glass tube of 1,0 mm internal diameter and 10 cm length was used as adsorption microcolumn. The adsorbent material was ground and sieved to obtain an average particle diameter of 300 µm, which was packed in the column with a bed length of 5 cm. Solutions of different concentrations of ASA (50, 100 and 150 mg/L) were continuously fed into the microcolumn at different flow rates (0,5, 0,75 and 1,0 mL/min) using a NE-1000 syringe pump (New Era Pumps, USA). The change in time of the ASA concentration in the column effluent was determined by continuous UV measurements at a wavelength λ = 230 nm in a UV-1800 spectrophotometer (Shimadzu, Japan). The column was kept at room temperature. The microcolumn performance was evaluated through the breakthrough curves of the continuous fixed bed system and the adsorption capacity of the adsorbent. The latter is defined as the ratio of the total adsorbed contaminant in the bed

to the total amount of the adsorbent material packed in the column (Eq. 7).

$$A.C.\,(mg/g) = \frac{Q}{m}\int_0^t (C_i - C_e)\,dt \tag{7}$$

where Q (mL/min) is the feed flow rate, m (g) is the mass of the adsorbent, C_i (mg/L) is the influent concentration, C_e (mg/L) is the effluent concentration and t(min) is the adsorption time. For comparison purposes, the breakthrough point was taken at 10 % of the initial concentration. Additionally, breakthrough curves were fitted with the axial dispersion model (Eq. 8), which assumes a dispersed plug flow through the bed characterized by an axial dispersion coefficient.

$$\frac{C_e}{C_i} = \frac{1}{2}\left\{1 + \text{erf}\left[\left(\frac{uL}{4D_L}\right)\left(\frac{V - V_{\min}}{(VV_{\min})^{1/2}}\right)\right]\right\} \tag{8}$$

where erf(x) is the error function of x, u is the interstitial velocity of the fluid, D_L is the axial dispersion coefficient, V is the volume of the fluid sent to the packed-bed in an elapsed time, $V_{\min}$ is the minimum volume required to saturate the bed and L is the bed length. The model parameters D_L and $V_{\min}$ were determined by nonlinear regression analysis (Arango Cárdenas, 2015).

Results and Discussion

Characterization of TiO2 nanoparticles and carbon xerogels

FTIR analysis was used to identify functional organic groups on the surface of carbon xerogels and TiO_2 nanoparticles. The FTIR spectra are shown in Figure 1. CX shows peaks between 3600-3200 cm^{-1} due to the O-H stretching vibrations, which is characteristic of the presence of surface hydroxylic groups and chemisorption of water. Vibrations of the ring C=C=O between 2183-2160 cm^{-1} and 1751-1581 cm^{-1} were also observed, which can be attributed to the stretching vibrations of C=O moieties in carboxylic structures. The band at 1700 cm^{-1} can be related to the stretching vibrations of C=O from an unreacted aldehyde group and/or to the carbonyl generated when formaldehyde undergoes a ring-opening reaction (Álvarez et al., 2015). The bands near 1473 and 1435 cm^{-1} were assigned to the C-H stretching vibrations in organic structures, Moreover, bands at 1300-1000 cm^{-1} and 933-920 cm^{-1} can be related to the C-O-C vibrations of methylether bridges in the resorcinol molecules and tri-substituted benzene rings, respectively (Girgis, El-Sherif, Attia, and Fathy, 2012; Rodrigues et al., 2012; Álvarez et al., 2015).

For carbon xerogel modified with TiO_2 nanoparticles, a peak at 3695 cm^{-1} was observed (Fig. 1). This band can be attributed to the Ti-COOH between the nanoparticles and carbon material. Bands between 2978 and 2870 cm^{-1} correspond to the presence of alkenes, carboxylic acids, secondary amines and phenols, whereas bands between 1188-910 and 1 581 cm^{-1} are associated with the presence of the Ti-O-C bond. Likewise, bands between 1728-1600 cm^{-1} correspond to the vibrations of stretching and flexion of hydroxyl groups bound to titanium Ti-OH atoms, whereas between 1489-1435 cm^{-1} are bands corresponding to CH_3 deformation (Bitar Castro and Mejía Meza, 2015; Fornaris Lozada, 2015; Hudlikar, Joglekar, Dhaygude, and Kodam, 2012; Santhoshkumar et al., 2014). CXM shows peaks between 2877-2401 cm^{-1} and 686 cm^{-1} corresponding to the presence of alkenes, C-N and C-H groups. Bands at 2360 cm^{-1} and 2993 cm^{-1} are related to the presence of carboxylic acids and aromatic or aliphatic C-H groups. Bands at 3780, 1589 cm^{-1}, 1481-1422 cm^{-1}, and 1094-779 cm^{-1}, are associated to hydroxyl group adsorbed in the sample, the presence of Ti-O-C group and the CH_3 deformation, respectively. These peaks demonstrate that the carbon xerogel was effectively modified with TiO_2 nanoparticles.

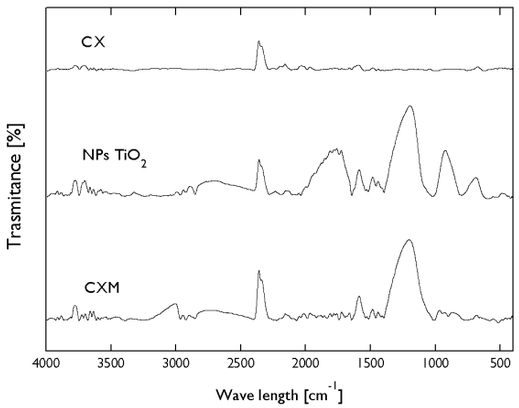

Figure 1. FTIR analysis for carbon xerogel, TiO_2 nanoparticle and carbon xerogel modified.
Source: Authors

Since carbon xerogels are mesoporous materials, Table 1 shows values about texture and porous structure of the carbonaceous materials considered in this study. Values of S_{BET} and porous parameters are higher than those obtained by Álvarez et al. (2015) for carbon xerogels, which could be due to the physical activation of the material. However, the surface area is similar to the one found for activated carbons, that is, between 824 and 1 237 m^2/g (Páez et al., 2012). Likewise, the surface area for TiO_2 nanoparticles agrees with those reported in literature of 116-586 m^2/g (Bailón-García et al., 2017; Zhou, Zhang, and Liu, 2012). Additionally, the lower S_{BET} for the modified materials is attributed to the presence of TiO_2 nanoparticles, since microporosity is mainly associated with the carbon phase (Bailón-García et al., 2017).

Table 1. Textural and porous parameters for carbon xerogel, TiO_2 nanoparticle and carbon xerogel modified with nanoparticles

	AS_{BET} (m^2/g)	$V_{mic.}$ (cm^3/g)	$d_{mic.}$ (nm)	$V_{meso.}$ (cm^3/g)	V_{Total} (cm^3/g)
CX	762	0,320	1,26	0,74	1,050
NPs- TiO_2	218	0,095	2,29	0,11	0,206
CXM	214	0,096	2,1	0,20	0,297

Source: Authors

Figure 2 shows the scanning electron micrographs (SEM) of carbon xerogel, TiO_2 nanoparticles and modified carbon xerogel. It is observed that nanoparticles are agglomerated, with a rounded structure and different sizes (Figure 2a). Activated carbon xerogel exhibits a smooth surface with a non-homogeneous particle size distribution, in addition to the formation of macropores, where TiO_2 nanoparticles can be deposited and ASA molecules adsorbed in the removal process (Figure 2b). For the modified carbon xerogel (Figure 2c), the micrographs show TiO_2 nanoparticles uniformly distributed on the surface of the material. These results agree with some previous studies, such as those by Álvarez et al. (2015), and Herrera, Reyes and Colina-Márquez (2016), where SEM images exhibit similar morphologies.

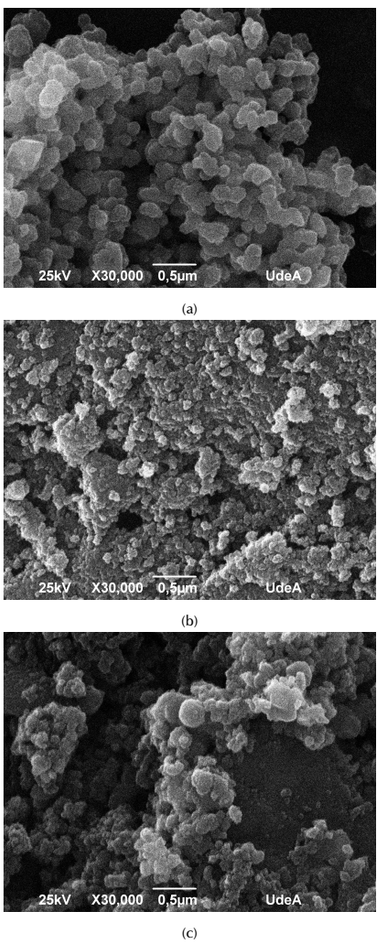

Figure 2. SEM-EDS results for a) nanoparticles of TiO_2; b) carbon xerogel; c) carbon xerogel modified with nanoparticles.
Source: Authors

The XRD technique allows the identification of the phases present in a sample and their degree of crystallinity. Figure 3 shows the results of XRD for TiO_2 nanoparticle and carbon xerogel modified. Peaks at $2\theta = 25°$, 30°, 48°, 50°, 54°, 55° and 62° correspond to the anatase phase, while peaks at 44° and 64° can be related to the rutile phase. The polymorph anatase form has a metastable characteristic, it is the most photoactive form of TiO_2, and it is widely studied due to their technological importance in various applications (Keane, 2013).

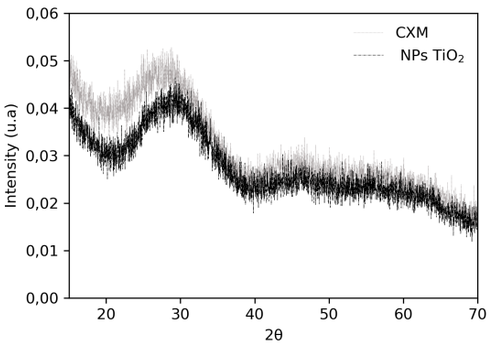

Figure 3. X-ray diffraction analysis for TiO_2 nanoparticles and carbon xerogel modified with TiO_2.
Source: Authors

Batch experiments

Dose curve and pH effect: The dose curve (Figure 4) shows an increase in ASA removal as the amount of CX increases, until reaching a maximum removal percentage of 91,82 % for an optimal dosage of 4,0 g/L.

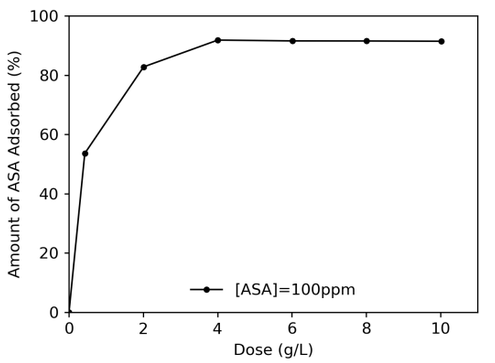

Figure 4. Effect of carbon xerogel dosage on the adsorption of ASA. Initial concentration = 100 mg/L; solution volume = 25 mL; time = 7 h; agitation speed = 150 rpm.
Source: Authors

The effect of the solution pH on the adsorption of ASA by CX is shown in Figure 5. The solution pH is a significant parameter that affects the adsorption process, as it alters the degree of ionization of the functional groups on the carbon surface. The adsorption capacity decreases with an increase in the solution pH. It has been suggested by Beninati, Semeraro, and Mastragostino (2008) that at low values of pH, the surface of the CX is positively charged, which produces an attractive force of the ASA anion, considering phenomena such as chemical bond, π-π-type interactions,

and electrostatic interactions related to the amphoteric nature of the carbons. As the pH of the ASA solution increases, a proportional decrease in adsorption takes place, probably due to the successive deprotonation of positive charged groups on the adsorbent surface and a subsequent electrostatic repulsion between ASA and the negatively charged sites on the adsorbent. There also exists a competition between OH (at high pH) and ASA for the remaining positively charged adsorption sites (Mphahlele, Onyango, and Mhlanga, 2015).

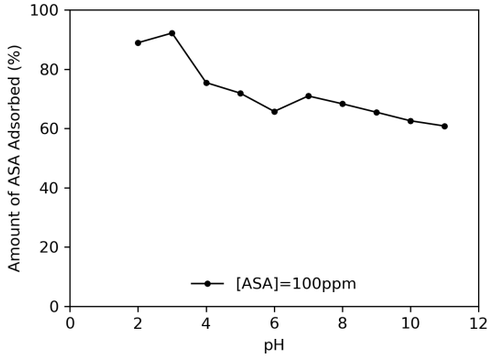

Figure 5. Effect of the solution pH on the adsorption of ASA. Initial concentration = 100 mg/L; solution volume = 25 mL; time = 7 h; agitation speed = 150 rpm.
Source: Authors

Adsorption isotherms: The adsorption isotherm describes the equilibrium relationship between bulk activity of the adsorbate in solution and adsorbed on the surface of the adsorbent at constant temperature (Pal, Deb, Deshmukh, and Verma, 2013). Figure 6 shows adsorption isotherms of ASA on carbon xerogel and carbon xerogel modified with TiO_2 nanoparticles. According to the classification system proposed by Giles, MacEwan, Nakhwa and Smith (1960), the isotherms for CX (Figure 6a) and CXM (Figure 6b) would correspond to the S class sub-group IV, given the initial slope and the shape of the upper part of the curves. This type of isotherms is typical for mesoporous materials, which indicates that adsorption becomes easier as ASA concentration raises. This also evidence that water molecules contribute negatively to adsorption, as they compete with ASA for active sites on surface. Likewise, the curve appears in sub-group IV, which is characterized by the development of a fresh surface where adsorption can occur, probably due to re-orientation of molecules already adsorbed (Álvarez et al., 2015; Giles et al., 1960).

Table 2 shows the fitting parameters of the Langmuir, Freundlich and Langmuir-Freundlich models (Equations 3-5) to experimental data. According to the correlation coefficient R^2, the adsorption of ASA onto CX and CXM is better fitted by the Langmuir-Freundlich model. This type of isotherm considers the heterogeneity of the solid surface, and is one of the models that best represents the removal of emerging contaminants (Álvarez et al., 2015).

Table 2. Parameters of Langmuir, Langmuir-Freundlich (L-F) and Freundlich models for ASA

Models	Parameters	CX	CXM
Langmuir	q_{max} (mg/g)	19,00	13,90
	K_L (L/mg)	6,56x10^{-6}	2,01x10^{-6}
	R^2	0,970	0,902
L-F	q_{max} (mg/g)	17,48	12,38
	K_L (L/mg)	4,86x10^{-3}	2,50x10^{-4}
	n	1,84	1,69
	R^2	0,991	0,972
Freundlich	n_F	1,17	1,54
	K_F (L/g)	1,09	7,88x10^{-2}
	R^2	0,990	0,972

Source: Authors

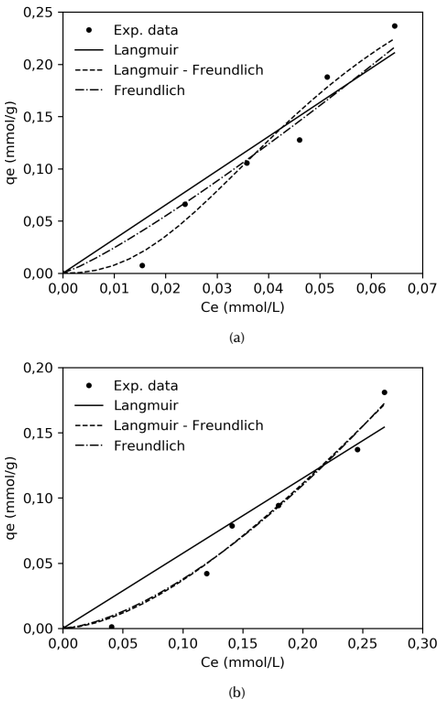

Figure 6. Adsorption isotherm of ASA onto (a) carbon xerogel and (b) modified carbon xerogel. C_o = 10-200 mg/L; xerogel dose = 4 g/L solution volume = 25 mL; pH = 3; T = 30 °C; t = 2 h.
Source: Authors

The maximum adsorption capacity (q_{max}) for CX and CXM was 17,5 mg/g and 12,4 mg/g, respectively. The lower adsorption capacity of CXM may be due to the micro- and meso-porosity blockage by TiO_2 nanoparticles, which is confirmed from results of porous parameters (Table 1). This fact denotes a preferential adsorption of ASA on the carbon surface, as found by Bailón-García et al. (2017) for the adsorption of orange G dye on TiO_2-carbon xerogel composites. Some of the functional groups of ASA that can occupy the available active sites on the surfaces of CX and CXM are aromatic

rings, through a charge transfer, and groups -OH and -OOH, by means of electron donation (Rakić, Rajić, Daković, and Auroux, 2013).

Continuous experiments

Breakthrough curve of acetylsalicylic acid: Results for the breakthrough curves at different feed conditions are shown in Figures 7 and 8. On the one hand, Figure 7 evidence that increasing the ASA feed concentration makes the bed saturation process faster. This fact may be attributed to an increase of the driving force for the mass transfer of the adsorbate from the bulk of the fluid phase to the solid phase, enhancing the adsorption rate. However, the microcolumn packed with CXM (Figure 7b) saturates sooner than the one packed with CX (Figure 7a) for the same concentration feed. This is likely due to the presence of TiO_2 nanoparticles that hinder the adsorption of ASA molecules, as was exposed in the batch experiments. Furthermore, the breakthrough curve for CXM shows a rather slow approach toward $C/C_o = 1$ asymptote, which is a well-known characteristic of particle-controlled systems. This fact is a consequence of the enhanced external mass transfer exhibited by microdevices and the low porosity of the material.

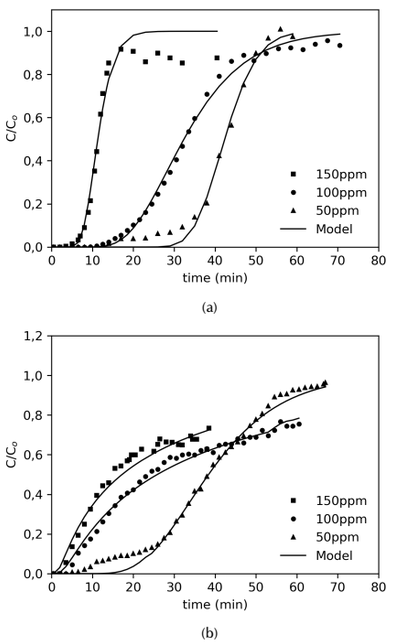

Figure 7. Breakthrough curves for ASA adsorption on (a) CX and (b) CXM for different feed concentrations. C_o = 50, 100, 150 mg/L; Q = 0,75 mL/min.
Source: Authors

On the other hand, Figure 8 shows that increasing the feed flow rate leads to a steeper breakthrough curve, since contact time between solution and solid is too short, resulting in a reduction in the breakthrough time. In this case, the solute has not enough time to interact with the surface of the adsorbent and diffuse into the pores, particularly

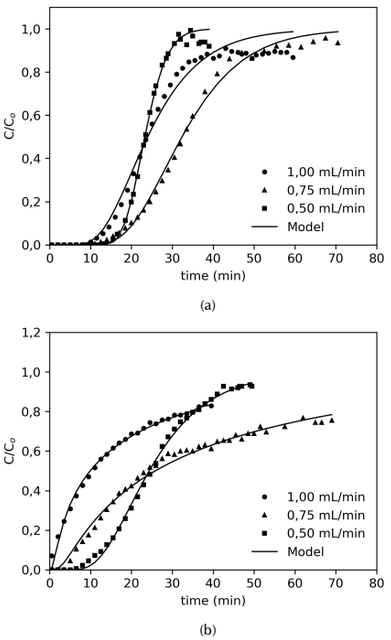

Figure 8. Breakthrough curves for adsorption of ASA on (a) CX and (b) CXM for different volumetric flows. C_o = 100 mg/L; Q = 0,5, 0,75 , 1,0 mL/min.
Source: Authors

with large molecules such as those of organic compounds, thus adsorption is limited (Cabrera-Lafaurie, Román, and Hernández-Maldonado, 2015). This behavior is more evident in the CXM sample (Figure 8b) than in the CX sample (Figure 8a), which could also be explained by the TiO_2 blocking active sites.

Table 3 summarizes the experimental results for breakthroughtime and adsorption capacity of the microcolumns, as calculated from Equation 7. The adsorption capacity was compared with the results obtained from the adsorption isotherms, $q_{\max}$. A significant decrease can be observed in $< z$ the amount of ASA retained by the xerogels. This can be explained by the fact that during the batch experiments, the CX and CXM samples had more contact time with the ASA solution, in addition to the constant stirring. This favored the interaction with the active sites and enhanced the mass transfer rate.

Equation 8 was used to fit the experimental breakthrough data. A summary of the estimated parameters, $V_{\min}$ and D_L, is presented in Table 4. It is observed that in most cases the correlation coefficient R^2 is higher than 0,99, indicating that an axial dispersion model is appropriate to describe well the breakthrough data. Furthermore, the axial dispersion coefficient increases with the volumetric flow rate in both adsorbents, obtaining in the sharpest breakthrough curves. Additionally, this indicates that there is an important contribution of the convection in flow direction. Finally, microcolumns packed with CXM exhibit higher values of D_L, which demonstrates a poor retention of ASA on this material.

Table 3. Experimental results of the continuous adsorption process

Q (ml/min)	C_I (ppm)	Breakthrough time (min) (C/Co = 0,1)	Mass of adsorbent (g)	Adsorption capacity (mg/g)
CX				
1,00	100	15,10	0,900	5,42
0,75	100	19,90	0,890	4,45
0,5	100	18,17	0,901	3,08
0,75	50	32,40	0,887	0,37
0,75	150	8,40	0,883	8,42
CXM				
1,00	100	0,92	0,901	5,28
0,75	100	6,40	0,901	3,60
0,50	100	12,88	0,901	2,87
0,75	50	19,90	0,901	0,39
0,75	150	4,40	0,904	6,69

Source: Authors

Table 4. Parameters of the axial dispersion model

Q (ml/min)	C_I (ppm)	V_{min} (mL)	D_L (cm^2/s)	R^2
CX				
1,00	100	23,97	21,06	0,983
0,75	100	24,29	13,47	0,994
0,5	100	11,64	4,60	0,996
0,75	50	31,76	5,52	0,992
0,75	150	8,49	10,37	0,924
CXM				
1,00	100	9,90	79,11	0,993
0,75	100	19,39	48,78	0,985
0,5	100	12,18	11,37	0,997
0,75	50	28,42	13,61	0,992
0,75	150	12,93	51,97	0,962

Source: Authors

Conclusions

The removal of acetylsalicylic acid (ASA) was studied using carbon xerogel and carbon xerogel modified with TiO_2 nanoparticles. It was found that low pH values favor the adsorption of ASA due to the positive charge of the carbon surface. The equilibrium experimental data for the CX and CXM were well fitted by the Langmuir-Freundlich model, where the maximum adsorption capacity of ASA was 17,48 mg/g and 12,38 mg/g for CX and CXM, respectively. Continuous experiments show that when increasing the inlet concentration and volumetric flow, breakthrough times are lower. In addition, the maximum adsorption capacities of the microcolumns were 8,42 mg/g for CX and 6,69 mg/g for CXM. Breakthrough curves agree well with the axial dispersion model. Results obtained from both equilibrium and continuous operation, demonstrate that the CXs could be used as a potential material to remove emerging contaminants such as ASA. Finally, despite experiments were not performed, the incorporation of TiO_2 nanoparticles would allow the subsequent elimination of the contaminant using a process of photodegradation, when exposed to UV or visible light, as shown by many authors in previous works such as Bailón-García et al. (2017), Zheng et al. (2018) and Ge, Zhang and Park (2019).

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Effect of the presence of CuO_x on the catalytic behavior of bimetallic Au-Cu catalyst supported on Ce-Zr mixed oxide in CO preferential oxidation

Influencia de la presencia de CuO_x sobre el comportamiento catalítico de un catalizador bimetálico Au-Cu soportado en óxido mixto Ce-Zr en la oxidación preferencial de CO

Juan David Arévalo[1], Julio César Vargas[2], and Luis Fernando Córdoba[3]

ABSTRACT

The effect of the presence of copper was evaluated on a bimetallic catalyst Au-Cu based on mixed oxide cerium-zirconium in the preferential oxidation of CO (CO-PROX). Six catalytic materials, based on mixed oxides, were prepared: (1) the support (CeZr); the monometallic catalysts, i.e. (2) gold (Au/CeZr), (3) impregnated copper oxide (CuO_x/CeZr) and (4) incorporated copper (CuCeZr); and the bimetallic catalysts, i.e. (5) impregnated copper oxide and gold (Au-CuO_x/CeZr), and (6) gold and incorporated copper (Au/CuCeZr). The catalysts were evaluated in the CO-PROX in the range 30-300 °C and atmospheric pressure, where the Au-CuO_x/CeZr showed the best catalytic behavior. The influence of CO_2 and H_2O in the feed stream was evaluated on the catalytic performance of the Au-CuO_x/CeZr. An inhibitory effect for the CO_2 was observed, while the presence of H_2O enhanced the performance. Additionally, the catalytic stability was evaluated, reaching CO conversion of 93 % and selectivity of 90 % for 118 h. The catalytic materials were characterized by XRD, showing in all cases the fluorite cubic structure. The N_2 adsorption-desorption analyses showed that synthesized materials were mesoporous and the TPR-H_2 test reveals that the presence of the active phase increases the reducibility of Ce^{4+} to Ce^{3+}. Reduction peaks of the gold catalyst were present at lower temperatures than those of the copper catalyst, which is related to a hydrogen spillover phenomenon. Finally, the samples were analyzed by SEM and TEM, which confirmed the formation of nano-particles with a diameter of about 4 nm.

Keywords: Preferential oxidation of CO, Nano-gold particles, Copper, Bimetallic Au-Cu, Mixed oxide.

RESUMEN

El efecto de la presencia de cobre en catalizadores bimetalicos Au-Cu a base de oxidos mixtos de cerio-zirconio fue evaluado en la oxidacion preferencial de CO (CO-PROX). Se prepararon seis materiales catalıticos: (1) el soporte (CeZr); los catalizadores monometalicos que fueron (2) oro (Au/CeZr), (3) cobre impregnado (CuO_x/CeZr) y (4) cobre incorporado (CuCeZr); y los catalizadores bimetalicos que fueron (5) oxido de cobre impregnado y oro (Au-CuO_x/CeZr), y (6) oro y cobre incorporado (Au/CuCeZr). Los catalizadores se evaluaron en el CO-PROX en un rango de temperaturas de 30-300 °C y presion atmosferica, donde el Au-CuO_x/CeZr mostro el mejor desempeño catalıtico. Se evaluo la influencia de CO_2 y H_2O en la mezcla de alimento sobre el desempeño del catalizador Au-CuO_x/CeZr, donde se observo un efecto inhibitorio del CO_2, mientras que la presencia del agua mejoro el desempeño. Adicionalmente, se evaluo la estabilidad catalıtica, la cual alcanzo conversiones de CO de 93 % con una selectividad de 90 %, durante 118 h. Los materiales catalıticos se caracterizaron por DRX, presentando en todos los casos la estructura fluorita cubica. Las pruebas de adsorcion y desorcion de N_2 mostraron que los materiales sintetizados eran mesoporosos. Los ensayos de TPR-H_2, mostraron que la presencia de la fase activa incremento la reducibilidad de Ce^{4+} a Ce^{3+}. Los picos de reduccion del catalizador de oro se presentaron a temperaturas mas bajas con respecto al catalizador de cobre, lo cual se relaciona con el fenomeno *spillover* para el hidrogeno. Finalmente, las muestras se analizaron por SEM y TEM, las cuales confirmaron la formacion de nanopartıculas con un diametro alrededor de 4nm.

Palabras clave: Oxidacion preferencial de CO, Nanopartıculas de oro, Cobre, Oxido mixto.

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Introduction

Proton Exchange Membrane Fuel Cells (PEMFC) are very interesting in portable applications, since they generate energy from hydrogen with high efficiency, reduced emissions and quick responses to charge changes (Salemme, Menna, Simeone and Volpicelli, 2010). The production of H_2 for PEMFC is usually accomplished by multistep processes that include catalytic reforming of hydrocarbons or oxygenated hydrocarbons followed by water–gas shift (WGS) reaction (Martínez-Arias, Hungría and Munuera, 2006). However, the gas stream obtained from these processes contains, in most cases, small amounts of CO and H_2O. The PEMFC have low tolerance to CO (10 ppm), due to the poisoning by CO adsorption on the cell Pt anode. For this reason and for the effect on the kinetic of oxidation, there is a limitation to expand their use (Cheng et al., 2007; Choudhary and Goodman, 2002; Ko et al., 2006).

Several methods have been reported for carbon monoxide removal from the steam reforming stream, such as preferential oxidation of CO (CO-PROX), selective methanation of CO, and selective diffusion through membranes (Haryanto, Fernando, Murali and Adhikari, 2005; Manzolini and Tosti, 2008; Ocampo, Louis and Roger, 2009). Among these, preferential oxidation of CO (CO-PROX) is the simplest and most direct and accessible method for removing CO (Avgouropoulos et al., 2002; Epling, Cheekatamarla and Lane, 2003).

Cerium oxide (CeO_2) has been broadly reported to be an active support and promotor for the synthesis of oxidation catalysts due to its structural properties (Fonseca, Royer, et al., 2012) and redox behavior that allows high oxygen mobility and storage, thus enhancing oxygen exchange with the reaction environment (Laguna et al., 2010; Trovalleri, 2002). Additionally, it has been found that the addition of ZrO_2 improves the thermal stability and the redox properties of CeO_2. It also improves oxygen mobility due to the formation of a mixed oxide system that promotes electronic distortions in the oxide framework, which contributes to the homogeneous dispersion of the deposited metal, long-term stability of the catalyst and an increase in the resistance to high temperatures, avoiding sintering problems (Biswas and Kunzru, 2008; Das et al., 2015).

In CO-PROX, gold supported catalysts in form of nanoparticles present better catalytic performance. Compared with other noble metals, Au catalysts are more active and selective for CO oxidation than for H_2 oxidation (Choudhary and Goodman, 2002; Haruta, 2002). Thus, the high dispersion of nano-gold particles provides a suitable catalytic activity in CO oxidation (Haruta, Kobayashi, Sano and Yamada, 1987). Gold supported on cerium oxide catalyst has been studied for the CO-PROX process due to its capacity to store and provide oxygens in the reaction of CO oxidation (Fonseca, Royer, et al., 2012). However, this catalysts can present the drawback of poor resistance to the presence of CO_2 in the reactant mixture (Trovalleri, 2002).

Recently, copper-based catalytic systems have emerged as promising substitutes for such noble metal catalysts, especially with CeO_2 as support, thanks to their low cost, high catalytic performance and high selectivity of O_2 to CO_2 (W. Liu and Flytzanistephanopoulos, 1995; Martínez-Arias et al., 2003). The excellent catalytic performance of CuO/CeO_2 catalyst is on account of the high oxygen storage/release capability of CeO_2 via the redox couple Ce^{4+}/Ce^{3+} and the strong interaction between CuO and CeO_2 (Kosmambetova et al., 2010). Mariño et al. (2008) concluded that the activity of copper and cerium oxides was lower when evaluated separately. However, the catalyst prepared with both oxides presented a high performance in the CO-PROX.

For CuO_x/CeO_2 catalysts, numerous preparation methods have been described in the literature, including co-precipitation, impregnation, inert gas condensation, and citric acid complexation–combustion (Di Benedetto, Landi and Lisi, 2018; Marbán and Fuertes, 2005; Zhu et al., 2017). In all cases, nano-sized crystals powders have been obtained.

The cooperative effect of the bimetallic gold and copper oxide has been studied to find an efficient catalyst in the CO-PROX, showing that bimetallic catalysts present better activity and selectivity than monometallic ones. Combining the catalytic properties of both metals has shown an intermediate behavior with good activity (98 % to 80 °C) and selectivity (65 % at 80 °C) (Fonseca, Ferreira, et al., 2012). Consequently, bimetallic gold–copper oxide supported catalyst has been studied in the CO-PROX reaction. Mozer, Dziuba, Vieira and Passos (2009) prepared the bimetallic Au-Cu catalyst on alumina and concluded that the addition of copper increased the selectivity to CO oxidation and reduced the H_2 consumption. Liu, Wang, Zhang, Su and Mou (2011) studied bimetallic Au-Cu catalysts over silica and reported a higher catalytic activity than in monometallic catalysts. They also observed the presence of highly disperse nanoparticles on the support with significantly lower particle size. Li et al. (2012) evaluated bimetallic catalysts of gold and copper oxide over mesoporous silica Au-CuO/SBA-15. However, this catalyst is deactivated easily due to both ambient condition and high temperatures.

Laguna et al. (2012) studied catalysts CuO_x/CeO_2 and Au-CuO_x/CeO_2 (10 % w/w copper and 1 % w/w gold), which presented a better catalytic activity than monometallic catalysts of copper. In contrast, Reina, Ivanova, Laguna, Centeno and Odriozola (2016) concluded that the addition of gold (2 % w/w) in the system Cu/CeO_2 with 15 % w/w of copper incorporated in the support do not promote the catalyst activity, due to the high load of the active phase.

Due to the complexity of some of the preparation methods above mentioned, it becomes necessary to search for simplest recipes directed to the potential mass-scale fabrication of the catalyst. The present study proposes to evaluate the cooperative effect between gold and copper oxide supported on cerium-zirconium mixed oxides in the CO-PROX reaction. Two bimetallic catalysts were prepared: one by incipient wetness impregnation to disperse copper over a previous gold supported on cerium-zirconium mixed oxide and another

using copper incorporated in cerium-zirconium oxide support, where the addition of gold was made by co-precipitation.

Materials and methods

Catalyst preparation

Six catalytic materials were prepared to be evaluated in the CO-PROX reaction: (1) cerium-zirconium mixed oxide support (CeZr), (2) gold on cerium–zirconium mixed oxide (Au/CeZr), (3) impregnated copper on cerium–zirconium mixed oxide (CuO_x/CeZr), (4) copper incorporated into cerium–zirconium mixed oxide (CuCeZr), (5) bimetallic catalyst Au-CuO_x with impregnated copper oxide (Au-CuO_x/CeZr) and (6) bimetallic catalyst Au-CuO_x with incorporated copper (Au/CuCeZr).

The cerium-zirconium mixed oxide support (CeZr) and the copper incorporated into cerium-zirconium mixed oxide (CuCeZr) were prepared using the pseudo sol-gel like method (Vargas, Libs, Roger and Kiennemann, 2005), based on the thermal decomposition of propionate precursors. The starting materials were cerium (III) acetate hydrate (99,9 %, Sigma-Aldrich), zirconium (IV) acetylacetonate (98 %, Sigma-Aldrich) and copper (II) acetate monohydrate (99,5 %, Sigma-Aldrich). The salts were dissolved separately in propionic acid (99,5 %, Sigma-Aldrich) under ebullition, mixed during 1 h, and then carried to controlled evaporation under vacuum pressure. The resin obtained was calcined at 550 °C for 6 hours.

The addition of gold was made following the methodology reported by Lin and Wan (2003). A suitable amount of tetrachloroauric acid trihydrate (≥ 99,9 %, Sigma Aldrich) was dissolved in 250 ml of distillated water and then, a solution of sodium hydroxide (97,0 %, Merck) was added for adjusting the pH solution to 6. After that, the support material (CeZr or CuCeZr) was mixed with the gold solution and stirred for six hours at ambient temperature. After filtration and washing, the solid was carried-out to calcination at 350 °C for 8 hours. The samples obtained were gold on cerium–zirconium mixed oxide (Au/CeZr) and bimetallic catalyst Au-CuO_x with incorporated copper (Au/CuCeZr).

The monometallic and bimetallic catalysts impregnated with copper were prepared using incipient wetness impregnation method (Fonseca et al., 2012). Copper nitrate trihydrate (Chemi) was dissolved in distillated water, then added over the catalytic material (CeZr or Au/CeZr) with uniform mixing at ambient temperature. Finally, the mixture was carried to calcination at 350 °C for 8 hours. The samples obtained were impregnated copper oxide on cerium-zirconium mixed oxide (CuO_x/CeZr) and bimetallic catalyst Au-CuO_x over cerium-zirconium mixed oxide (Au-CuO_x/CeZr).

Catalyst characterization

The specific surface area was determined from N_2 adsorption/desorption isotherms using the BET method in an Autosorb-1 Quantachrome. The metallic composition was determined by atomic absorption spectrophotometry (GBC, AVANTA Σ) coupled to flame ionization. The Temperature Programmed Reduction (H_2-TPR) was carried out with a ChemBET Pulsar TPR/TPD equipment from Quantachrome instruments following the H_2 consumption by TCD. The textural morphology of the materials was studied by Scanning Electronic Microscopy (SEM) (JEOL, JSM-6490LV) and Transmission Electronic Microscopy (TEM) (Tecnai F20 Super Twin TMP of FEI). X-Ray Diffraction (XRD) was carried out with a PANalytical X'Pert PRO MRD equipment. Thermogravimetric Analysis (TGA) was performed using a TGA1-Mettler Toledo equipment.

Catalyst test

The catalytic tests of CO-PROX were carried out in a U-shaped reactor connected online to a gas chromatograph (Hewlett Packard 5890 Series A) with a packed molecular sieve 13X column, and a TCD at 0,76 atm pressure. The temperature was controlled using a cylindrical shape furnace with a thermocouple in the center of the system close to the catalytic fixed-bed. The samples were submitted to an oxidant atmosphere treatment for 1 h at 300 °C. The reaction gas feed consisted of 2 % vol. CO, 2 % vol. O_2, 50 % vol. H_2 with He as gas balance, and a total flow rate of 100 mL/min, through 100 mg of the catalyst with 60-80 mesh. The corresponding space velocity is 60 000 mL g^{-1} h^{-1}. The content of CO_2 and H_2O in the reaction stream was limited to 2 % vol. and 3 % vol., respectively, instead of 10-20 % vol. (real content), due to the experimental restrictions of the catalytic reaction system. However, this amount was enough to observe the kinetic inhibition effect by competitive adsorption in the CO-PROX reaction (Córdoba and Martínez-Hernández, 2015).

In this study, the catalytic test consisted of four steps. In step I, the bimetallic catalysts Au-CuO_x/CeZr and Au/CuCeZr were evaluated in the CO-PROX and the best catalytic performance, Au-CuO_x/CeZr, was compared with the monometallic catalysts Au/CeZr and CuO_x/CeZr. In step II and III, the CO_2 and H_2O effect of Au-CuO_x/CeZr bimetallic catalyst was evaluated, considering that both compounds can be produced in the reforming process for hydrogen production (Cobo et al., 2013; Tippawan and Arpornwichanop, 2014). Finally, in step IV, the catalytic stability test was performed on Au-CuO_x/CeZr bimetallic catalyst for 118 h at the temperature with the major activity, with CO_2 and water in the feed effluent.

The CO conversion (X_{CO}) and selectivity to CO_2 (S_{CO_2}) were calculated using Equation (1) and Equation (2), respectively.

$$X_{CO}(\%) = \frac{F_{CO,initial} - F_{CO,final}}{F_{CO,initial}} \times 100 \qquad (1)$$

$$S_{CO_2}(\%) = \frac{F_{CO,initial} - F_{CO,final}}{2 \times (F_{O_2,initial} - F_{O_2,final})} \times 100 \qquad (2)$$

where $F_{CO,initial}$ and $F_{O_2,initial}$ are the molar flows of CO and O_2 in the feed stream, and $F_{CO,final}$ and $F_{O_2,final}$ are the molar flows in the outlet stream.

Results and discussion

N_2 adsorption-desorption isotherms

Table 1 presents the BET specific area and the composition percentages of the metals loaded in the catalytic materials. The quantified experimental values agree with the theoretical values (2 % and 4 % w/w for gold and copper, respectively) indicating that the synthesis methods are suitable for obtaining reproducible catalytic materials.

The isotherms for the bimetallic catalytic materials, which are not shown here, were type IV, typical of mesoporous materials (Thommes et al., 2015), with a H2 hysteresis, related to the not well-defined distribution of pore shape materials (Thommes, 2007).

It is evident that incorporated copper samples showed the lowest specific area, and that mono and bimetallic samples present a lower surface area than support materials. The inclusion of copper ions in Cerium-Zirconium mixed oxides modifies the crystalline structure and the presence of Au, CuO_x and Au-CuO_x facilitates the obstruction of the smaller porous, which results in a lower surface area compared with the supports (Gurbani et al., 2009).

In the case of Au-CuO_x/CeZr bimetallic catalyst, the surface area is slightly lower than Au/CeZr sample but higher than CuO_x/CeZr. This behavior can be related to a higher dispersion of the CuO_x derived from the interaction with gold, avoiding the subsequent porous obstructions.

Table 1. Chemical composition and BET specific area of supports, bimetallic and monometallic samples

Sample	BET surface area (m^2/g)	%Au (%w/w)	%Cu (%w/w)
CeZr	28	–	–
Au/CeZr	22	2,2	–
CuO_x/CeZr	11	–	3,0
Au-CuO_x/CeZr	19	1,9	4,1
CuCeZr	3	–	3,8
Au/CuCeZr	2	1,8	3,7

Source: Authors

Temperature programmed reduction (TPR-H_2)

Figure 1 presents the TPR-H_2 patterns of the supports and the catalytic samples. Due to the limitations of the TPR test, results were only analyzed qualitatively.

The reduction profile of Cerium-Zirconium support (not shown) is characterized by a wide peak at about 563 °C, which is attributed to the strong interaction between CeO_2 and ZrO_2 and the solid solution obtained (Córdoba and Martínez-Hernández, 2015).

The Au/CeZr reduction pattern shows two hydrogen consumption peaks around 170 and 240 °C, which are related to the reduction of Au^{3+} species, promoting slightly the H_2 spillover phenomenon and therefore the cerium reduction at lower temperature (Fonseca et al., 2012; Laguna et al., 2014).

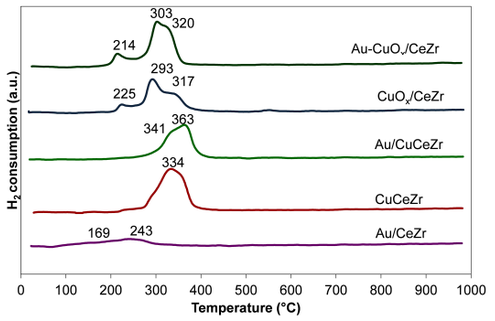


Figure 1. TPR-H_2 patterns of the bimetallic catalysts Au-CuO_x/CeZr, Au/CuCeZr; the monometallic catalysts CuO_x/CeZr, CuCeZr, Au/CeZr; and the CeZr support.
Source: Authors

The TPR profiles for CuO_x/CeZr and Au-CuO_x/CeZr are similar, showing three reduction peaks (Figure 1) at around 220, 300 and 320 °C, indicating no strong effect of gold on the cerium reduction temperatures. The first peak correspond to the reduction of copper clusters with lower oxidation, the next peak to the reduction of isolated copper species with higher oxidation state and the last peak to the simultaneous reduction of copper and surface cerium oxide (Gurbani et al., 2009; Liao, Chu, Dai and Pitchon, 2013; Martínez-Arias et al., 2009).

The samples with incorporated copper (CuCeZr, Au/CeZr) present two reduction peaks at slightly higher temperatures than CeZr based samples, indicating a more difficult reduction for copper. The reduction peaks of incorporated copper samples can be attributed to the simultaneous reduction of highly dispersed species (Cu^{2+} to Cu^{1+}) in strong interaction with the support, and the superficial Ce^{4+} reduction in the interface Cu-CeO_2 (Araújo, Bellido, Bernardi, Assaf and Assaf, 2012; Reina et al., 2016).

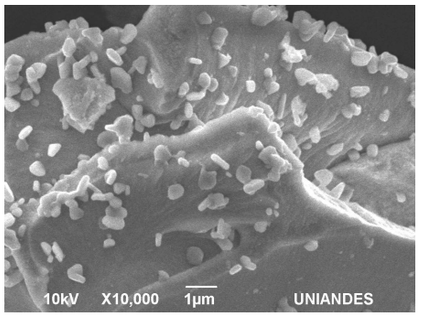
Textural morphology

The morphology of the catalytic materials was evaluated by Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). Figure 2 presents the SEM of the bimetallic catalysts.

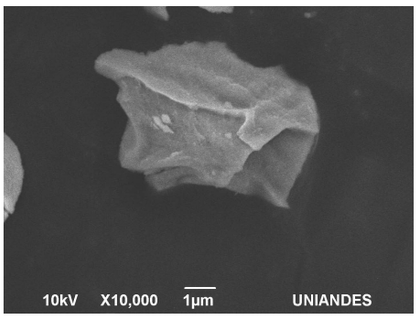
The SEM results show that the catalyst Au-CuO_x/CeZr presented smaller particles formation on the larger particles of the material, while the Au/CuCeZr did not generate this type of particle. The formation of smaller particles can be attributed to the presence of CuO_x on the bimetallic catalyst with impregnated copper (Au-CuO_x/CeZr). Figure 3 presents the TEM results of the bimetallic catalysts.

The formation of circular particles was promoted in the bimetallic catalyst with impregnated copper (Au-CuO_x/CeZr). However, the presence of well-defined nano-gold particles was not observed, possibly due to the masking effect of the copper oxide or the agglomeration of gold particles in the calcination step.

For the bimetallic catalyst with incorporated copper (Au/CuCeZr), particles of around 4 nm are observed. EDX



(a)



(b)

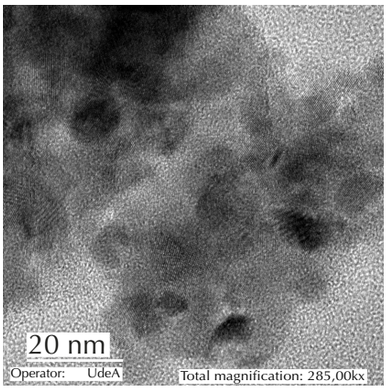
Figure 2. SEM micrographs: (a) Au-CuO_x/CeZr and (b) Au/CuCeZr.
Source: Authors

analysis and a closer micrograph are required to confirm the chemical nature of the particles, since the one presented in Figure 3 does not allow an undoubted differentiation of gold, taking into account the nature of the support.

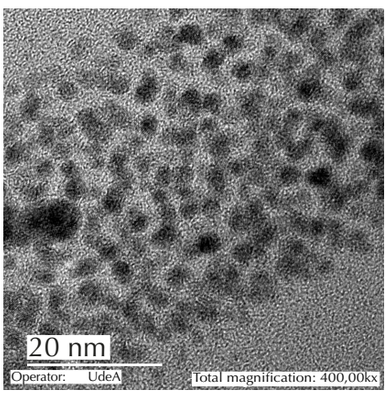
X-Ray Diffraction

Figure 4 presented the XRD patterns for the bimetallic catalysts. The materials presented diffraction peaks corresponding to the fluorite cubic structure of the mixed oxide cerium-zirconium, which is identified by the planes (1 1 1), (2 0 0), (2 2 0), (2 2 0), and (4 0 0) (JCPDS Card No. 28-0271), with an incorporation of ZrO_2 in the CeO_2 lattice forming a homogenous solid solution (Biswas and Kunzru, 2007; Córdoba and Martínez-Hernández, 2015).

Table 2 presents the average crystallite size and the lattice parameter (a) from XRD peak positions and indexation. The bimetallic catalysts did not present changes in the fluorite cubic crystalline structure when gold and copper are added. The position of peaks in both bimetallic catalysts shifted slightly toward high angles with respect to the support, which is in accordance with the decrease in the lattice parameter of bimetallic catalysts due to a possible interaction between the copper and the fluorite CeZr structure. This is not due to an insertion of copper in the crystalline structure forming a true solid solution, but to a high copper dispersion into the mixed oxides solution (Marban and Fuertes 2005).



(a)



(b)

Figure 3. TEM micrographs: (a) Au-CuO_x/CeZr and (b) Au/CuCeZr.
Source: Authors

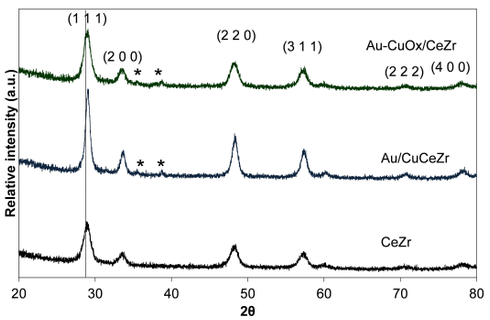


Figure 4. XRD patterns of CeZr support and the catalysts Au-CuO_x/CeZr and Au/CuCeZr *CuO.
Source: Authors

Signals corresponding to gold did not present patterns in XRD in the bimetallic catalyst (Figure 4), since gold percentage (about 2% w/w) is too low for being detected by XRD patterns. Additionally, it has been reported that gold particles below 5 nm cannot be detected by XRD (Ilieva et al., 2009; Reina, Ivanova, Centeno and Odriozola, 2014), which is in accordance with TEM results.

Table 2. Structural parameters of the catalyst materials

Sample	Average crystallite size, d(nm)*	Lattice parameter, a (Å)
CeZr	17,1	5,354
Au/CeZr	17,1	5,342
CuO_x/CeZr	15,7	5,358
Au-CuO_x/CeZr	15,9	5,316
CuCeZr	22,4	5,339
Au/CuCeZr	22,4	5,318

*Calculated with the Scherrer equation of the plane (1 1 1)

Source: Authors

However, diffraction peaks 35,5° and 38,7° correspond to the cluster of copper oxide, such as tenorite (Moretti et al., 2015). These CuO signals were present in the bimetallic catalyst with impregnated copper (Au-CuO_x/CeZr) and in the bimetallic catalyst with incorporated copper (Au/CuCeZr), discarding the formation of the solid solution Au-Cu (Laguna et al., 2014).

The TGA was done in the bimetallic catalyst with impregnated copper (Au-CuO_x/CeZr) before and after CO-PROX stability reaction test to determine coke formation (not shown). Results did not show weight loss in this temperature range, which suggests that the bimetallic catalyst used Au-CuO_x/CeZr present no carbonaceous deposits formation.

Catalytic test

- Step I

Figure 5 presents the results of the CO conversion and CO_2 selectivity of both bimetallic catalysts.

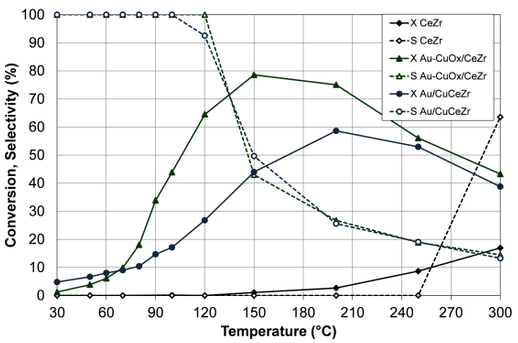


Figure 5. CO conversion (X, filled symbols) and selectivity to CO_2 (S, empty symbols) of CeZr, Au-CuO_x/CeZr and Au/CuCeZr. Feed stream: 2 % CO, 2 % O_2, 50 % H_2 and He (balance).
Source: Authors

The Au-CuO_x/CeZr presented a better behavior with respect to the Au/CuCeZr due to the possible effect of copper in the CO-PROX activity. Cu-Ce interactions in the catalyst by wet impregnation promote the formation of large interfaces Cu-Ce, where CO is absorbed to oxidation. It is believed that the reaction is catalyzed by the interfacial copper oxide–ceria centers in which ceria presents a high number of oxygen vacancies that allows high mobility of lattice oxygen (Marbán and Fuertes, 2005).

The higher catalytic activity of the Au-CuO_x/CeZr with respect to the Au/CuCeZr is in agreement with TPR-H_2 results, where the Au-CuO_x/CeZr presented a higher reducibility to lower temperatures than the Au/CuCeZr. Additionally, the Au/CuCeZr presented a lower surface area.

The catalytic behavior of the Au-CuO_x/CeZr might be related to the formation of smaller particles on the large particles of the material (SEM results), as well as to the good size distribution of particles of about 5 nm (TEM results). The Au/CuCeZr favored the formation of nanoparticles of 4 nm (TEM results). However, the gold activity was inhibited with the incorporation of copper.

Figure 6 presents the CO conversion and selectivity to CO_2 of the Au-CuO_x/CeZr with respect to the monometallic catalyst of gold (Au/CeZr) and impregnated copper (CuO_x/CeZr).

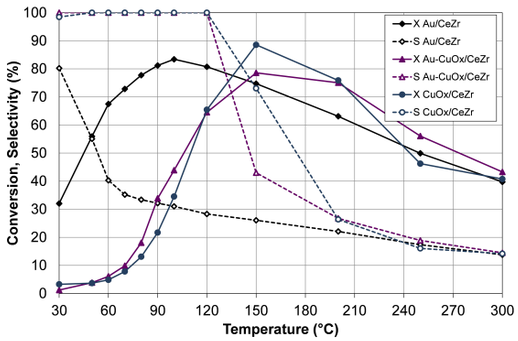


Figure 6. CO conversion (X, filled symbols) and selectivity to CO_2 (S, empty symbols) of Au-CuO_x/CeZr with respect to Au/CeZr and CuO_x/CeZr. Feed stream: 2 % CO, 2 % O_2, 50 % H_2 and He (balance).
Source: Authors

The bimetallic catalyst Au-CuO_x/CeZr (Figure 6) showed the best catalytic performance, since the CO conversion curve volcano-type was wider than in the monometallic catalyst of gold (Au/CeZr) and impregnated copper (CuO_x/CeZr). Although CuO_x/CeZr had the highest CO conversion, the bimetallic catalyst provided greater stability throughout the evaluated temperatures. The good activity can be related to the bimetallic interaction, i.e. the formation of a cooper monolayer on gold plates, which allows the adsorption/activation of O_2 and the formation of CO_2 through CO and O coadsorption. This favored the formation of alloy active sites that participate in the CO oxidation and increase the reaction speed (Hussain, 2013). The selectivity of the Au-CuO_x/CeZr was enhanced with respect to the monometallic catalyst Au/CeZr. To establish the bimetallic interaction, further experiments with techniques such as HR-TEM and XPS are needed.

The bimetallic catalyst of impregnated copper Au-CuO_x/CeZr presented a better catalytic performance than Au/CuCeZr, therefore the Au-CuO_x/CeZr was selected for the evaluation of the next step.

- Step II

Figure 7 presents the results of the CO conversion and the selectivity to CO_2 of bimetallic catalyst with incorporated copper (Au-CuO_x/CeZr), evaluating the effect of CO_2 in the CO-PROX.

The addition of CO_2 in the feed effluent affected the catalytic activity of Au-CuO_x/CeZr, since it required a higher temperature to reach the maximum conversion (Figure 7). The bimetallic catalyst presented a slightly lower activity than the same catalyst evaluated without CO_2. The selectivity was not affected by the CO_2 addition. Laguna et al. (2014) reported that the presence of CO_2 decreases CO conversion below 150 °C due to the competence in the adsorption between CO and CO_2.

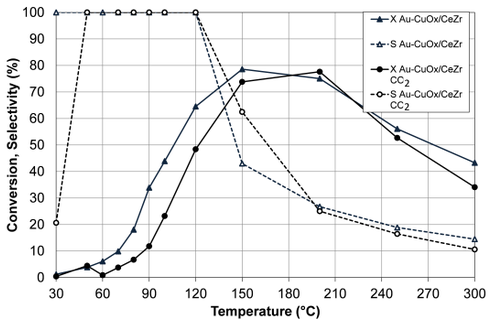


Figure 7. Effect of CO_2 on the CO conversion (X, filled symbols) and selectivity to CO_2 (S, empty symbols) of Au-CuO_x/CeZr. Feed stream: 2 % CO, 2 % O_2, 2 % CO_2, 50 % H_2 and He (balance).
Source: Authors

- Step III

Figure 8 presents the results of CO conversion and selectivity to CO_2 of Au-CuOx/CeZr, evaluating the effect of water and CO_2 addition in the feed stream.

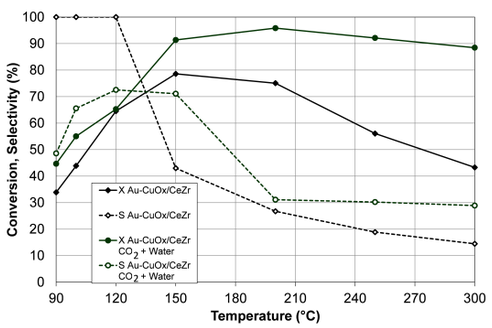


Figure 8. Effect of water and CO_2 on the CO conversion (X, filled symbols) and selectivity to CO_2 (S, empty symbols) of Au-CuOx/CeZr. Feed stream: 2 % CO, 2 % O_2, 2 % CO_2, 3 % H_2O, 50 % H_2 and He (balance).
Source: Authors

The reaction feed mixture was humidified by bubbling it through a container of deionized water at room temperature, yielding 2 % water vapor in the gas fed to the reactor. The addition of water in the feed effluent had a positive effect on the bimetallic catalyst (Figure 8), increasing CO conversion with respect to bimetallic catalyst without CO_2 and water. Au-CuO_x/CeZr presented a conversion above 90 % between 150 and 300 °C. The catalyst achieved a maximum conversion of 96 % at 200 °C. The selectivity was better with water addition, even though it was inhibited below 120 °C.

The favorable effect of water on the activity of the bimetallic catalyst can be explained by the formation of hydroxide groups in the dissociative adsorption of water on the active sites of gold (Liao et al., 2013; Mozer et al., 2009). The presence of CO_2 and H_2O can also affect the catalytic behavior of the monometallic catalyst since a competitive adsorption is expected and therefore an effect on the activity and selectivity. Further studies are needed in order to confirm this effect.

- Step IV

Figure 9 presents the results of the catalytic stability of Au-CuO_x/CeZr, evaluating CO conversion and selectivity to CO_2 with the addition of water and CO_2 in the feed effluent.

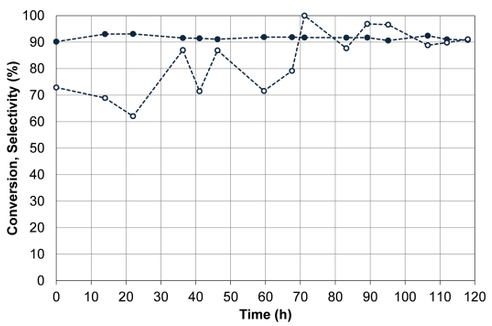


Figure 9. Catalytic stability of the Au-CuOx/CeZr. Evaluation of the CO conversion (X, filled symbols) and selectivity to CO_2 (S, empty symbols) with addition of CO_2 and water. Feed stream: 2 % CO, 2 % O_2, 2 % CO_2, 3 % H_2O, 50 % H_2 and He (balance).
Source: Authors

The bimetallic catalyst Au-CuO_x/CeZr presented a good behavior in the stability test, with was stable for 118 h, obtaining CO conversion of 92 % and selectivity of 90 %, representing an ooutstanding performance. Fonseca, Ferreira et al. (2012) evaluated a bimetallic catalyst Au-Cu over CeO_2 in the presence of 10 vol. % of CO_2 and 2 vol % of H_2O, and reached a CO conversion of 60 % and a selectivity of 85 % during 8 h without deactivation. However, since the feed compositions evaluated in this work are quite different than those tested by Fonseca, Ferreira et al., the differences in the catalytic behavior could be related to the important role of these compounds.

Conclusions

All the samples presented the crystalline fluorite-type structure, with the presence of CuO in the monometallic

and bimetallic materials with copper, enhancing the catalytic activity. It was possible to obtain nano-gold particles that promoted catalytic behavior.

The bimetallic catalyst with impregnated copper (Au-CuO_x/CeZr) and the bimetallic catalyst with copper incorporated (Au/CuCeZr) were evaluated in the CO-PROX. Results showed that the bimetallic catalyst with impregnated copper presented the best catalytic performance, since it exhibited high activity, good selectivity and good long-term stability throughout the evaluated temperatures, even in the presence of CO_2 and H_2O in the feed stream.

The Au-CuO_x/CeZr catalyst presents a cooperative effect between gold and copper, promoting higher stability in the catalytic activity, CO conversion and selectivity to CO_2 in the evaluated temperature window. Au and Cu interaction promotes the redox properties of the CeZr mixed oxide allowing the reduction of Ce^{4+} ions to lower temperatures and improving the redox behavior.

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Comparison of biogas production obtained from samples of Mitú and Sibundoy municipal solid waste

Comparación del potencial de producción de biogás obtenido a partir de residuos sólidos urbanos provenientes de Mitú y de Sibundoy

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ABSTRACT

This study compares the calorific power of biogas obtained from the municipal solid waste (MSW) of two towns in Colombia, whose populations are affected by deficiencies in the supply of electricity. The production of biogas would represent an important opportunity to meet these needs, taking advantage of the solid waste generated, in whose composition organic material predominates (45 %). For this purpose, MSW samples were taken from the municipalities of Mitú (Vaupés) and Sibundoy (Putumayo), in order to establish their relevance to produce biogas. For each sample, the organic waste was characterized in terms of its macroscopic composition, moisture content, ash, volatile and total solids. Subsequently, the composition of biogas obtained was determined from anaerobic digestion tests with biological sludge as inoculum in different proportions and the calorific value of the gas was calculated. It was found that organic waste from both municipalities is suitable to produce biogas due to the physicochemical characteristics of the samples, the high methane content generated and, therefore, the satisfactory calorific power for its use in the production of electrical energy.

Keywords: Biogas, Anaerobic digestion, Municipal solid waste, Energy potential.

RESUMEN

En este trabajo, se realiza una comparacion del poder calorıfico del biogas obtenido a partir de residuos solidos urbanos de dos municipios de Colombia, cuyas poblaciones son afectadas por deficiencias en el suministro de energıa electrica. La produccion de biogas representarıa una oportunidad importante para suplir tales necesidades, aprovechando los residuos solidos que se generan, en cuya composicion predomina el material organico (45 %). Por esto, se tomaron muestras de RSU de los municipios de Mitu (Vaupes) y Sibundoy (Putumayo), con el fin de establecer su pertinencia para la produccion de biogas. En cada muestra se caracterizaron los residuos organicos en terminos de su composicion macroscopica, contenido de humedad, cenizas, solidos volatiles y totales. Posteriormente, se determino la composicion del biogas obtenido a partir de ensayos de digestion anaerobia con lodos biologicos como inoculo en diferentes proporciones y se calculo el poder calorıfico del gas. Se encontro que los residuos organicos de ambos municipios son adecuados para la produccion de biogas por las caracterısticas fisicoquımicas de las muestras, el alto contenido de metano generado y, por tanto, un poder calorıfico satisfactorio para su aprovechamiento en la produccion de energıa electrica.

Palabras clave: Biogas, Digestion anaerobia, Residuos solidos urbanos, Potencial energetico.

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Introduction

Some studies have concluded that municipal solid waste constitutes a very important source in the generation of energy. The production of biogas is one of the simplest options that can be implemented globally at different scales (Sosnowski, Wieczorek, and Ledakowicz, 2003). Some of the main advantages are the reduction of waste generated by people sending it to a unit of final disposition and the energy use and its adaptability to more or less expensive technologies, according to the particular needs of each user (Tock and Schummer, 2017; Morgan et al., 2018).

Biogas comprises a mixture of gases including methane, carbon dioxide, low amounts of hydrogen, nitrogen, hydrogen sulfide and traces of other gases. Biogas is produced by the decomposition of organic matter under anaerobic conditions, in conjunction with the generation of energy and new biomass due to the action of various microorganisms (FNR, 2010), (Moya, Aldás, López, and Kaparaju, 2017). The main interest for its production lies in its use as a source of heat, electricity and fuel for vehicles, since its calorific value could be close to that of natural gas (MINENERGIA/PNUD/FAO/GEF, 2011).

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Municipal solid waste management is a major challenge for cities, as their characteristics should define the strategies to be adopted in each case. According to some studies, the lack of education in terms of waste management is greater in developing countries, resulting in serious pollution problems, facilitating the deterioration of ecosystems and increasing diseases among the population. It has also been shown that by providing training on the benefits of waste management and recycling, the risk of acquiring the aforementioned problems is significantly reduced, in addition to improve people's perception of paying fees related to the costs of basic sanitation (Han et al., 2018).

In Colombia, various initiatives have been developed to promote renewable energy generation. These initiatives include the implementation of cogeneration systems in specific industries, the strengthening of research in different technologies and the establishment of Law 1715 of 2014. This law promotes the development and use of unconventional sources of energy in the national energy system, through its integration into the electricity market, its participation in non-interconnected areas, other applications for a sustainable economic development, the reduction of greenhouse gas emissions from fossil fuels, and the national security of energy supply (Congreso de Colombia, 2014). Thus, it is worth evaluating the potential for energy production by using unconventional sources in municipalities with low coverage in the country, mainly in non-interconnected areas.

Mitú is the capital of the department of Vaupés, which is located in the Colombian Amazon. It has a population of 31 568 inhabitants including indigenous and settlers. They occupy almost 16 500 km^2, where 98 % are covered by tropical forest (Alcaldía de Mitú, 2016). The population is concentrated in the urban area and has an index of unsatisfied needs equivalent to 51,8 %, which include health problems related to unhealthy hygiene practices, low coverage of the aqueduct and sewerage services, in addition to the presence of an open cast dump for the disposal of residues (~8 t/day), from which 45 % corresponds to the organic fraction. A diagnosis for the 2016-2019 action plan indicated that there is a low level of civic awareness in the classification and final disposal of waste that generates risks for the population and the environment, such as unauthorized burning and direct disposal to waterways (Alcaldía de Mitú, 2016; Villamil, 2016).

Mitú is part of the 70 municipalities that are not yet within the interconnected electricity system of the country and that exceed in more than 200 % the national average of electricity consumption, besides having no natural gas supply ("U.N. promueve. . . ", 2018). Some of the reasons for this situation include the heterogeneity of their territories, the lack of management by service providers and cultural aspects of the users (Superservicios, 2018b).

In contrast, Sibundoy is within the interconnected energy system, but pays one of the most expensive electricity rates in the country (Superservicios, 2018a). The municipality of Sibundoy is located in the department of Putumayo and has approximately 14 396 inhabitants, including some indigenous reservations (22 %). Most of the people are concentrated on the urban area. In the municipality, there are paramo ecosystems and wetlands of national importance. In terms of coverage of public services, Sibundoy has 76,2 % of coverage of sewerage service and 91,5 % of electricity (DNP, 2019). This municipality has a waste separation system at the source within its territorial management model, where organic and inorganic solid waste is collected separately. Comprehensive solid waste management uses organic waste for composting and other recycling activities of nonbiodegradable materials. Unmet basic needs ratio is 20,7 % (Alcaldía de Sibundoy, 2011).

According to the foregoing, this study evaluates the potential production of biogas from the solid urban waste of the municipalities of Mitú and Sibundoy through anaerobic digestion, in order to establish if it would be suitable for the implementation of a municipal production system of biogas, which allows to formulate some strategies for the stabilization of the process, according to the environmental conditions of these municipalities.

Materials and methods

Samples of organic matter were obtained from solid waste collection centers in the municipalities of Mitú and Sibundoy. In the first municipality, samples were collected from the municipal battalion and the center for the collection of solid urban waste, while in Sibundoy samples were taken directly from the collection center of solid organic waste, whose separation is carried out directly by the community. Standardized sewage sludge from the food industry was used as inoculum.

For the samples of Mitú, a classification of the solid residues was made, conserving the organic fraction, while the inorganic components were separated for their final disposition. For the samples coming from Sibundoy, such classification was not necessary, since there is separation at the source in this municipality. The samples of interest were then subjected to a reduction stage by liquefying with a proportion of m_W: $m_{OFMSW} = 1,16\ g_W/g_{OFMSW}$ to facilitate its homogenization.

Subsequently, homogeneous samples were characterized to determine pH, moisture percentages (% M_{WB}), ash (% A_{DB}), volatile solids (% VS_{DB}) and total solids (% TS_{DB}), following the biomass characterization standards established by the National Renewable Energy Laboratory (NREL) of the United States of America. Specifically, NREL/TP-510-42621:2008 and NREL/TP-510-42622:2008 standards were used to determine the percentage of moisture and ash, respectively. According to the values obtained, the percentages of volatile and total solids were estimated (NREL, 2019). The pH of the initial sample was also determined.

For the analysis of biomethane potential (BMP), the BMP-RBP equipment of Anaero Technology was used with 1 L reactors, under constant agitation and times of hydraulic retention (THR) between 5 and 18 days. The process temperature was adjusted to 28 °C, in order to normalize it to the average ambient temperature of Mitú. For the estimation

of the production potential of biogas, the samples were subjected to digestion with and without addition of inoculum, adjusting the initial pH conditions to values between 6,7 and 7,3. The relations of volatile substrate solids to volatile inoculum solids were established in 0,5 gVS_{OFMSW}/gVS_{SS}, 0,25 gVS_{OFMSW}/gSV_{SS} and 0,17 gVS_{OFMSW}/gSV_{SS}. In addition, tests for anaerobic digestion of the organic fraction of municipal solid waste (OFMSW) were carried out without the addition of inoculum in order to evaluate the possibility of establishing a system of chimneys in sanitary landfill, since it is an economic option and would involve minor structural changes in the collection system for the capture of biogas (López, 2016; Lavagnolo, 2019).

The compositions of methane, carbon dioxide, oxygen and hydrogen sulfide were determined using the 5 000®BIOGAS equipment. The samples were collected in hermetic bags in maximum periods of one to three test days for reading.

The calorific value for each sample was weighted on the basis of the gas percentages established. The higher heating value (HHV) and lower heating value (LHV) were obtained from the literature and compared with the calorific value data generated in the combustion enthalpy formulation, according to the respective chemical reactions for each substance that comprises the biogas.

Figure 1 describes the process methodology for assessing the biogas potential of samples.

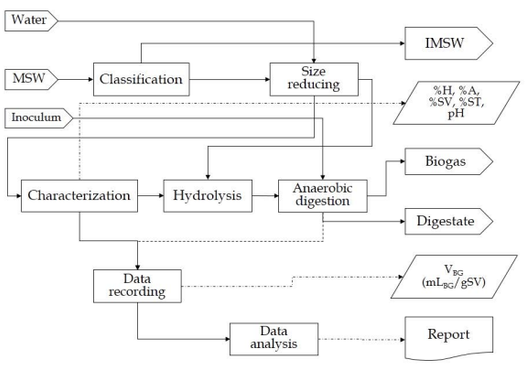

Figure 1. General process scheme for the assessment of biogas potential.
Source: Authors

Results

In samples from Mitú-Vaupés, inorganic contaminants were found, such as plastics, metals, synthetic fibers, among others, which make it difficult to carry out the tests. The organic fraction contained traces of food, such as cassava, fruits, eggshells, bananas, peas, carrots, leaves, and some meat residues. Components such as cob shells, pea pods and branches had difficult degradation during the process, also making it difficult to reduce the samples sizes.

In the case of residues from Sibundoy – Putumayo, a high content of plant residues was found, which is suitable for use as substrate in anaerobic digestion for biogas production. The low content of inorganic contaminants that inhibit production was also remarkable. Plant residues present a large quantity of fibrous material (lignocellulosic), whose degradation is less efficient than in other substrates. This condition can be improved with pretreatments such as reducing residue size and using thermal treatments or longer hydrolysis times. Table 1 describes the results of a general characterization of the selected samples of Mitú and Sibundoy.

Table 1. General characterization of the selected samples for anaerobic digestion tests (average values)

Sample	Vegetable waste (%)	Meat waste (%)	Plastics (%)	Others (%)
Mitú	94,7	4,2	1,1	0,0
Sibundoy	97,4	0,7	1,0	0,9

Source: Authors

Regarding the characterization of the homogeneous material obtained from pretreatment, Table 2 shows that Mitú samples have a moisture content between 73,97 % and 82,52 %, exceeding other values reported in the literature, where the organic fraction of a sample of OFMSW is about 70 % (Moya et al., 2017). This may be related to the humidity conditions in the municipality and the exposure of waste to the atmosphere. It is also noted that the volatile solids content of solid waste is 83,1 % on average, which is an acceptable interval with respect to other studies reported in the literature, where the percentage of volatile solids for OFMSW is between 70 % and 95 %, corresponding to the organic matter consumed by the microorganisms during the anaerobic digestion. The pH values reported for OFMSW are between 5,2 and 6,3 (Zupančič and Grilc, 2012). Low pH values could be explained by the relative high degradation of ODSs, considering both their age and contamination with possible inorganic residues.

For the municipality of Sibundoy, the characterization allowed to find a high content of minerals and inorganic material (according to the percentage of ash) that compete with the fraction of volatile solids. These values are within the same orders of magnitude reported in the literature and they represent a raw material suitable for anaerobic digestion in terms of their nutritional value. Additionally, a higher pH is observed than in the samples of Mitú and values that are within the range reported in other sources.

Table 2. Specific characterization of Mitú and Sibundoy samples

Sample	Moisture	Ash	Volatile solids	Total solids	pH
	M_{wb} (%)	A_{db} (%)	VS_{wb} (%)	TS_{wb} (%)	
Mitú	77,94 ± 3,98	16,70 ± 3,58	83,30 ± 3,58	22,06 ± 3,98	4,75 ± 0,51
Sibundoy	75,08 ± 3,36	29,39 ± 0,34	70,61 ± 0,34	24,92 ± 2,28	5,56± 0,41

Source: Authors

After subjecting the samples to digestion with and without inoculum, the composition of biogas was determined in order to compare the amount of methane in the samples and estimate its value for energy use. Tables 3 and 4 show the results of the gas composition obtained from different organic load ratios for Mitú and Sibundoy, respectively.

Table 3. Composition of biogas from Mitú samples collected. Average from 21 days of biogas production

Organic load	CH_4 (%)	CO_2 (%)	O_2 (%)	H_2S (%)	Others (%)
Digestion without inoculum	0,8	55,7	2,9	>>>	33,9
S/I = 1:2	58,7	34,9	0,9	0,06	5,5
S/I = 1:4	65,5	30,5	0,5	0,14	3,5
S/I = 1:6	58,7	34,4	1,0	0,10	5,9

Source: Authors

Samples from Sibundoy showed that the methane content is higher when the ratio of substrate to inoculum is 1:2 (volatile solids basis), while for samples from Mitú the best concentration of methane was obtained from the 1:4 substrate to inoculum ratio. Furthermore, it is estimated that digestion without addition of inoculum is not appropriate for this type of residue, as a result of the content of methane found for the samples of Mitú and Sibundoy.

Regarding the quantity of methane compared between the ratio 1:2 and 1:4 in the samples of the two municipalities, the percentages of methane obtained are good and, taking into account that the samples are raw, the quality of the OFMSW is favorable in terms of the amount of microorganisms and contaminants that could inhibit the activity of the inoculum, in this case of sludge.

Table 4. Composition of biogas from Sibundoy samples

Organic Load	CH_4 (%)	CO_2 (%)	O_2 (%)	H_2S (%)	Others (%)
Digestion without inoculum	0,1	77,5	1,4	0,98	20,4
S/I = 1:2	67,0	25,7	2,5	0,05	4,8
S/I = 1:4	58,6	35,0	1,8	0,08	4,6

Source: Authors

Tables 5 and 6 show the results of the calculation of the HHV and LHV for the biogas obtained from the samples of Mitú and Sibundoy, respectively. The obtained values are within the range of heating values reported in the literature, i.e. for biogas the LHV is between 17 and 34 MJ/m3 depending on the percentage of methane present in the mixture (Flotats, 2016), while values of HHV are reported between 15,5 and 26 MJ/m3. This shows again that the quality of biogas obtained from solid waste of Mitú is comparable to others of similar origin (IDAE, 2014).

Table 5. Higher and lower heating values of biogas obtained from Mitú samples

Organic load	HHV (MJ/m^3)	LHV (MJ/m^3)
Digestion without inoculum	0,5	0,5
S/I = 1:2	21,4	19,3
S/I = 1:4	23,8	21,5
S/I = 1:6	21,4	19,2

Source: Authors

Thus, the testing of the samples of Mitú, whose volatile solids ratio was 1:4, presented the greatest HHV, while in Sibundoy samples the best relation obtained was 1:2. This is because the estimated heating values depend directly on the concentration of methane.

Table 6. Higher and lower heating values of biogas obtained from Sibundoy samples

Organic load	HHV (MJ/m^3)	LHV (MJ/m^3)
Digestion without inoculum	4,6	4,2
S/I = 1:2	25,4	22,9
S/I = 1:4	22,3	20,1

Source: Authors

Discussion

Samples from Mitú and Sibundoy showed a similar gross composition, after removing the larger contaminants from the samples of Mitú. Differences in the pH are observed, which is related to the age of the residues of each municipality and, in the case of samples of Mitú, the influence of its predominant climate. Mitú has an average temperature of 28 °C, while Sibundoy has 16 °C. It is also noted that plant residues constitute the major part of the samples. This may be related to the diet of the population in this region. The results of physicochemical characterization, in particular the content of volatile solids, showed that the samples possess suitable properties for their use in anaerobic digestion.

The amount of methane per unit volume of biogas obtained was higher for Sibundoy samples at S/I = 1:2, whereas for Mitú samples at S/I = 1:4. Biogas was generated with a higher amount of methane. This may be related to the inoculum tolerance to the presence of contaminants and the nature of the substrate. A possible explanation of the behavior of the obtained data is that as the presence of inorganic contaminants increases in the biogas production system, the tolerance of microorganisms to high substrate loads is negatively affected and thus methane production decreases. For the ratio S/I = 1:4, the samples of Mitú generated a higher percentage of biomethane, as well as a higher amount of H2S, which is a sign that the interactions between populations of microorganisms in the reactor had greater difficulties in the chain of reactions that allow the generation of methane in the biogas.

In addition, a test was carried out to determine the production of methane from the residues, without the addition of inoculum. These tests considered the adoption of biogas recovery by chimneys, such as those implemented in some existing sanitary landfills, given their low cost and production (Lavagnolo, 2019). However, the percentage of biomethane in the mixture was found to be minimal, in contrast to a high production of H_2S, hence this option was discarded.

Finally, it was determined that the biogas obtained in the samples is suitable for applications in electric energy production, after comparing its calorific powers with reports of the literature. From an analysis of the amount of residues generated each day, in Mitú approximately 9 431 m3 BG/month could be generated, corresponding to about 77,9

kWh/h and in Sibundoy is about 5 050 BG/month and 41,7 kWh/h.

Conclusions

The analysis of samples from Mitú and Sibundoy allowed to deduce their aptitude to produce biogas through anaerobic digestion. The differences presented in their characteristics are related to the particular conditions of each municipality and the influence of each sample was observed on the percentage of methane obtained per unit of volume of biogas. Additionally, an analysis of the potential of biomethane in each municipality showed that some of the difficulties of each municipality could be overcome through the management of solid waste, the reduction of costs in energy fees and the possible supply of natural gas if required. To conclude, this type of management must be implemented, considering the advantages for non-interconnected areas and low-cost energy production.

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Nomenclature

A: ash.

BMP: biomethane potential.

DB : dry basis.

HHV : higher heating value.

HRT: hydraulic retention time.

LHV : lower heating value.

M: moisture.

MSW : municipal solid waste.

OFMSW: organic fraction of municipal solid waste.

SS : sewage sludge.

TS: total solids.

VS: volatile solids.

W : water.

WB : wet basis.

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Evaluation of internal curing effects on concrete

Evaluación de los efectos del curado interno del concreto

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ABSTRACT

The objective of the present research was the evaluation of some fresh and hardened-state properties of concretes, in which coarse aggregates were partially replaced by lightweight ones previously saturated, in percentages of 15 % and 25 %. The lightweight aggregates were calcined clays and crushed clay bricks. In parallel, the effect of an internal curing agent composed of superabsorbent polymers (SAP) was evaluated. The properties evaluated in the fresh and hardened-state of concretes with a/c of 0,30 were: slum, air content, density, compression resistance, modulus of elasticity, initial superficial absorption and chlorine resistance. Results showed the efficiency of crushed clay bricks as internal curing, as well as the need for deeper research on the use of the evaluated lightweight aggregate as internal curing aggregate in concrete. Results indicate that the crushed clay bricks and the internal curing agent fulfill the behavior expected, in terms of strength and durability. However, the evaluated lightweight aggregate produces a reduction in the resistance and durability of the concrete. The observed behavior in strength and durability is especially variable for the age of 180 days, compared with conventional concretes.

Keywords: Absorption, Chloride resistance, Contraction, Internal curing, Lightweight aggregates, Lightweight concrete, Slum, Superabsorbent polymers (SAP).

RESUMEN

La presente investigacion tuvo como objetivo la evaluacion de algunas propiedades en estado fresco y endurecido de concretos, en los cuales se realizaron reemplazos parciales de agregado grueso por agregados ligeros previamente saturados, en porcentajes de 15 % y 25 %. Los agregados ligeros fueron arcillas calcinadas y ladrillos de arcilla triturados. Paralelamente, se evaluo el efecto de un agente de curado interno compuesto por polımeros super absorbentes (SAP). Las propiedades evaluadas en estado fresco y endurecido de los concretos con una relacion a/c de 0,30 fueron: asentamiento, contenido de aire, densidad, resistencia a compresion, modulo de elasticidad, tasa de absorcion superficial inicial y resistencia a cloruros. Los resultados mostraron la eficiencia de los ladrillos de arcilla triturados y del agente curador interno, ası como tambien la necesidad de realizar investigacion mas profunda en la utilizacion del agregado ligero evaluado como agregado de curado interno en el concreto. La investigacion prueba que La mamposterıa de arcilla triturada cumple el comportamiento esperado en un agente de curado interno desde el punto de vista de durabilidad y resistencia, mientras que el agregado ligero evaluado produjo una reduccion en la resistencia y la durabilidad del concreto. El comportamiento observado en cuestion de resistencia y durabilidad es especialmente cambiante para la edad de 180 dıas, en comparacion con los concretos convencionales.

Palabras clave: Absorcion, Agregados ligeros, Asentamiento, Concreto ligero, Contraccion, Curado interno, Polımeros superabsorbentes SAP, Resistencia a cloruros.

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Introduction

The ACI 308-213 R-13 defines curing of concrete as the process through which the concrete matures and develops its hardening properties over time as a result of the continuous hydration of the cement in the presence of enough water and heat amount (ACI, 2013).

For years, the most widely used curing method has been external curing. It consists in the superficial application of water to the concrete, through a constant exposition at the surface by means of periodic irrigation of water or with the use of materials with good absorption and desorption capacities, such as sawdust and some polymers. In some cases, the elements are completely immersed in a pool of water, as in the case of test specimens and precast elements.

However, in the daily practice, immersing cast structural elements in situ is not an option. In these cases, the periodic application of water or the use of some external agent in order to conserve the moisture are implemented, as is shown in Figure 1.

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Figure 1. Concrete external curing.
Source: http://blog.360gradosenconcreto.com/

According to Neville (2010), the main problem that could occur during the external curing is call slow-flow. This effect takes place when the curing water starts circulating into the concrete and the external curing water is evaporated from the concrete. This makes that only the surface of the element and a small internal layer of little thickness and to the surface are cured and not the whole volume of the element, as expected. That is why the thicker the piece is, the higher the volume of uncured concrete will be. Therefore, in order to ensure an efficient surface curing, a permanent sheet of water must be guaranteed on the concrete surface for a long time. This condition is difficult to ensure on large surfaces, in isolated places, in hot climates and in places with water supply problems. Additionally, the lack of awareness in the construction area about the importance of an efficient external curing for the adequate behavior of the concrete makes this process hard to control.

Additionally, the ACI 308R-01 defines internal curing (IC) as the "process where the hydration of cement occurs because of the availability of additional internal water that is not part of the mixing water" (ACI, 2008). According to the Expanded Shale, Clay and Slate Institute (ESCSI), internal curing helps concrete to develop its full potential in a simple, economical and sustainable way. The IC improves hydration, reduces early cracking, reduces chloride penetration and improves durability, all of which extend the service life of the concrete.

In Figure 2, the comparison between the surface curing and the internal curing shows that the former works as a hard shell around concrete elements, while the latter makes uniform hydration of the concrete. Both, superficial and internal, could ensure homogeneous curing within the concrete mass.

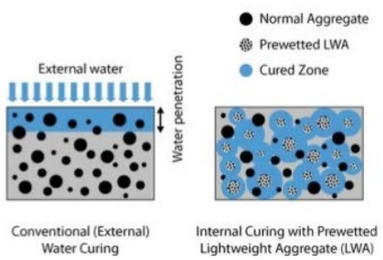


Figure 2. Internal and external curing comparison.
Source: ESCSI

According to this, a new paradigm has arisen in response to the deficient external curing practices used in infrastructure works and, especially, facing the difficulty of curing concrete with low w/c ratio. This paradigm is called internal curing of concrete and consists in storing water inside the concrete that is not available during the mixing or in the first hydration stages but is released later for curing. In order to achieve this behavior, saturated lightweight aggregates are used, since they can provide curing water from within the mixture thanks to their absorption and desorption properties.

In Colombia, according to the technical bulletin from March 15th, 2016 issued by the DANE, the use of concrete as construction material amounts to 8 500 m^3, which places it as the most widely used construction material in the country. Road infrastructure, warehouse floor slabs, concrete walls, columns and beams are, among others, the civil works with most problems in service and maintenance. The main reason is the lack of curing in the early ages of concrete, which is when the properties of strength and durability that the concrete will have during its service life are developed.

The Colombian Seismic Resistant Code (NSR-10), in its title C, defines lightweight concrete as concrete with lightweight aggregate, that has an equilibrium density between 1 440 and 1 840 kg/m^3 (AIS, 2010), as defined also by the NTC 4022 (ICONTEC, 1994) based on the ASTM C567. Likewise, the Colombian technical standard NTC 4045 provides the characteristics that a lightweight aggregate must fulfill to be part of structural concrete (ICONTEC, 1997), based on the American specification ASTM C641.

Notwithstanding the inclusion of lightweight concrete within national regulations, the use and commercialization of the lightweight aggregate for concrete are limited due to the lack of research that supports its operation, not regarding lightweight concrete but also in the practical field as internal curing agents. Possible use of lightweight aggregates nationwide could take place when a high volume of concrete is used, and it is difficult to ensure a continuous and prolonged supply of water. The use of lightweight aggregates as internal curing aggregate of concrete could be a good alternative to avoid the current wrong practices in the curing stage and as a solution to develop infrastructure in the regions where it is not possible to ensure continuous water supply.

Before using the lightweight aggregates available in the national context as internal curing agents, it is necessary to evaluate their behavior through a partial incorporation into concrete that allow the characterization of their properties in fresh state, its mechanical strength, and the influence on the durability. Subsequently, this also allows the formulation of concrete dosages with lower density than in conventional concrete with the aim to achieve similar properties.

In order to evaluate the benefits of the lightweight aggregate as an internal curing agent, an experimental program was performed. Specimens with a different concrete matrix were tested using two types of lightweight aggregates. Each one was included in the concrete matrix instead of a percentage of the normal weight coarse aggregate. The first lightweight aggregate was calcined clay and the second one was recycled

crushed clay bricks (CCB) in the laboratory. An internal curing agent, commercially known as "Better Mix" and supplied by the company Toxement, was also evaluated.

The effects of internal curing were tested in six different concrete mixtures. The first mixture (M1) was a control sample, while the second (M2) and third mixtures (M3) had an addition of calcined clay with a partial replacement of the coarse aggregate in percentages of 15 % and 20 %, respectively. Likewise, the fourth (M4) and fifth (M5) mixtures contained the same percentage of replacement of the coarse aggregate, but the substitution material was the CCB aggregate. Finally, the performance of the Better Mix curing agent was assessed in the sixth mixture (M6).

Materials and Testing Procedure

Materials

The CCB aggregate was obtained from crushing 11-inch clay blocks, obtained from the external service tests of the Structures Laboratory of the Escuela Colombiana de Ingeniería Julio Garavito, as shown in Figure 3. The selection and characterization tests were carried out according to the standards presented in Table 1.

Figure 3. Crushed clay bricks aggregate.
Source: Authors

Table 1. Physical properties of aggregates

TEST	NTC	ASTM
Sieve analysis of aggregate	4045	C330
Determination of density and absorption	176	C127
Determination of unit mass and voids	92	C29

Source: Authors

The characterization of the second lightweight aggregate was carried out in the Soil and Geotechnics Laboratory of Escuela Colombiana de Ingeniería Julio Garavito, following the same characterization standards stipulated in Table 1.

The third internal curing agent was the commercially known "Better Mix" supplied by Toxement, which is a concrete additive that has the property of holding water.

Due to the used w/c ratio (w/c = 0,30), it was necessary to use a Superplasticizer additive. The additive used was "Eucon MR 500", supplied by Toxement. The dosage was calculated according to the recommendations of the manufacturer (1,5 % of cement weight).

Characterization of the materials

Results of the characterization tests of the aggregates are shown in Table 2.

Table 2. Physical properties of the aggregates

Aggregate	Ds_{bulk}	$Ds_{apparent}$ (sss):	$D_{nominal}$	Absorption
	kg/m^3	kg/m^3	kg/m^3	(%)
CCB	1 807	2 012	2 275	11,37
Calcined clay	410	870	840	29,50
Gravel	1 530	2 660	2 620	1,60

Source: Authors

Mixture design

For the design of the mixtures, the recommendations of the ACI 211.1 were followed (ACI, 1991). In common practice, the internal curing was used to obtain high strength concrete, therefore, a low w/c ratio of 0,30 was chosen.

The amount of cement and the amount of water for all the mixtures was kept fixed and partial replacements of coarse aggregate were made by the two lightweight aggregates previously described. For these replacements, the average density between the stone aggregate and the lightweight aggregate was calculated, in order to find the necessary quantities of each one. For each of the mixtures evaluated, the lightweight aggregates were pre-moistened for 24 hours prior to the preparation of the mixture. Due to this pre-moistened, the incorporated water was discounted from the calculated mix of water.

The cement used in this research was supplied by the Argos Company and characterized through the X-ray fluorescence test, in the laboratories of the Universidad Nacional de Colombia. The characterization was done in a solid cement sample in order to obtain its chemical composition, density and fineness. The characterization of the cement is presented in Table 3.

Table 3. Physical and chemical properties of the cement

Element or Compound	%
CaO	61,015
SiO_2	20,906
SO_3	5,868
Al_2O_3	4,783
Fe_2O_3	3,632
K_2O	1,047
Cement density (gr/cm^3):	3,070
Fineness S(cm^2/gr):	4 213

Source: Authors

Table 4 shows the dosage of the 6 mixtures evaluated and the dosage per m^3 of concrete.

Table 4. Dosage per m^3

Mix	Water (kg)	Cement (kg)	Sand	Coarse	Lightweight Ag.	
					CCB	Clay Calc.
M1	178,0	668	790	716		
M2	194,0	668	835	822		207,3
M3	187,0	668	817	795		107,6
M4	168,6	668	815	582	172,0	
M5	158,8	668	815	640	100,2	
M6	163,6	668	804	717		

Source: Authors

Test specimens

For the development of this research, three different types of specimens were used. Specimens type 1 were 12 slabs of 350 x 250 x 200 mm, whose dimensions were determined in order to extract 6 standard cylinders of 100 mm diameter and 200 mm high from each specimen, by means of a core extraction drill. The extraction set can be observed in Figure 4.

Figure 4. Concrete core extractions.
Source: Authors

Concrete slabs were used instead of standard cylinders based on the recommendations given in the State-of-the-Art report of RILEM 196-ICC (Klover and Jensen, 2007). The authors suggest that it is necessary to have specimens with greater area and volume than the conventional cylinders, in order to evaluate the internal curing effects. The casting process of this type of specimens consisted in placing two layers of fresh concrete, each one was tamped 20 times with a smooth steel bar of 16 mm in diameter and 600 mm in length. Then, the molds were externally compacted with a rubber mallet in order to diminish the anthills. Subsequently, the edges and the remaining material were leveled.

The compression, modulus of elasticity, ISAT, chlorides and sorptivity tests were performed on the 100 x 200 mm cores extracted from specimens type 1, according to the corresponding ASTM standards. The tests were performed after 28 and 180 days, in order to obtain a representative estimation of the concrete performance at two different ages. 12 specimens were analyzed per mixture at each test date, for a total of 144 cylinders.

In order to evaluate the performance of the concretes, it was necessary to make twin specimens of each mixture. Half of these were preserved in submerged state and the other half were conserved in a room with controlled temperature and humidity at 55 %, and constant temperature of 25 °C. These conditions were hold until the core extraction and test age.

In Figure 5, some specimens type 1 are shown, after the extraction of the cylinders.

Figure 5. Specimens type 1.
Source: Authors

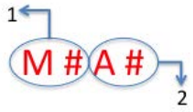
Specimens type 2 were prisms with dimensions 150 x 150 x 50 mm and elaborated following the parameters established in the NTC 3494, in order to evaluate the loss of water of the concrete and the influence of the internal curing. The specimens were preserved as specimens type 1: three per each mixture in the controlled-temperature room and three in submerged conditions until the day of the test.

Specimens type 2 were elaborated following the same process described above for specimens type 1.

Finally, specimens type 3 were standard prismatic of 75 x 75 x 250 mm, made for the volumetric variation test, according to the ASTM C157. Six specimens were made from each mixture. three of them were submerged and three were storaged in a room with controlled temperature and humidity, as well as the other specimens. A total of 36 specimens were made.

Nomenclature

For the identification of the different specimens, the nomenclature from Figure 6 was used.



1: Refers to the mixture, M1, M2, M3... M6

2: refers to the curing environment used, A means that it was preserved in the submerged state

Figure 6. Nomenclature.
Source: Authors

Results and discussion

Properties of fresh concrete

Shows the fresh-state properties recorded for the different mixtures.

Table 5. Properties of fresh concrete

Mixture	Slump(mm)	Air content(%)	Unitary mass (kg/m^3)
M1	25	2,0	2 281
M2	60	2,5	2 029
M3	55	2,0	2 123
M4	85	3,0	2 262
M5	95	3,0	2 205
M6	53	2,5	2 252

Source: Authors

As observed in Table 5, the unit mass decreased from Mixture 2 to Mixture 6 in around 1 % and 12 %, compared with Mixture 1. This is due to the lower density of the lightweight aggregates used in the mixes compared with the standard one. In large volumes of concrete, this would represent a considerable weight reduction. However, our mixes could not be considered lightweight concrete according to the definition given before. The air content has not appreciable alteration due to the use of lightweight aggregates.

The lightweight aggregates improved the manageability between 2,2 and 3,8 times compared with the standard sample. It changed from a slump of 25 mm for the standard sample to a range between 55 and 95 mm. This could be attributed to the fact that the mixing water is not absorbed by the aggregates, because these were previously saturated, thus allowing a uniform distribution of water in the mixture. This increase in the manageability for high strength concrete with low w/c ratios represents an advantage for its handling.

Mechanical properties

Compressive strength: Figure 7 shows the compressive strength for the samples cured in the controlled temperature room. Figure 8 shows the compressive strength for the pool-cured samples. Both graphics show the results of the average compression strength of the three specimens in the aforementioned test ages.

An increase of the strength resistance from the 28 days to the 180 days was observed in the standard mixture (M1) as well

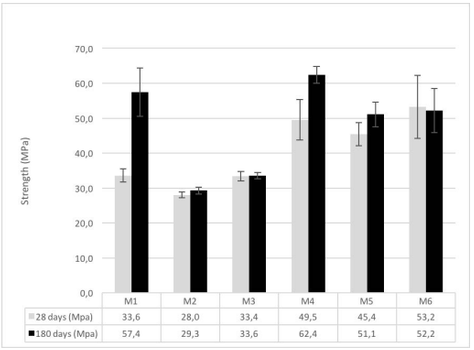


Figure 7. Compressive strength, samples in controlled temperature and humidity room.
Source: Authors

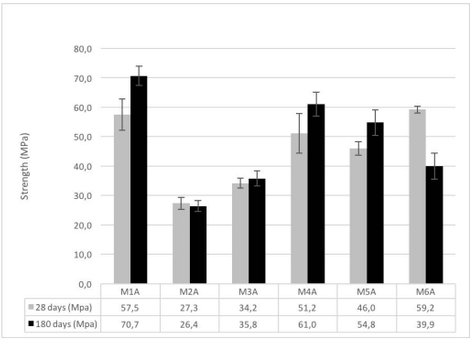


Figure 8. Compressive strength, submerged samples.
Source: Authors

as in the mixes with CCB aggregate (M4, M5), between 26 % to 70 %, suggesting an increase of the strength at long ages. Mixes with the calcined clay presented just a slight variation smaller at the 4 %, which induced the maximal strength resistance in these mixes within 28 days. The mixture with the superplasticizer (M6) presented a bigger reduction in the strength resistance for the submerged samples, however, it is necessary to increase the number of specimens in this mixture before concluding this behavior. Among all the specimens, the maximal strength at 180 days was for the Mixture 1 in submerged state, as expected, with 71 MPa. The closest strength to this maximal value was observed in the Mixture M4 in the controlled temperature room, only with a reduction of the 11,7 %, which suggests the effectiveness of the internal curing. Additionally, comparing this mixture in submerged and non-submerged state did not show a representative variation in the strength, which then allows to infer that the internal curing in this mixture is optimum.

Meanwhile the standard mixture M1 has a strength reduction of almost 20 % between the specimens submerged and non-submerged. The specimens cured internally have just a difference between 3 % and 10 %, therefore it could be said that the internal curing really occurred, and that its success depends on the dosage and kind of the aggregate.

Figure 9 shows the percentage difference between the resistance obtained in the standard mixture in the submerged state and the mixtures conserved in the room with controlled humidity and temperature.

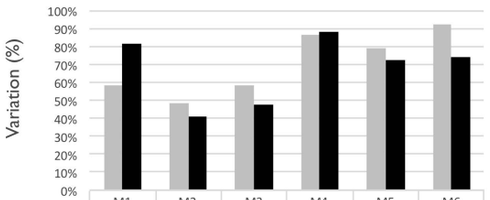


Figure 9. Variation of the compressive strength in mixtures conserved in the room compared with the standard mixture in submerged state after 28 and 180 days.
Source: Authors

It is observed that the samples with crushed clay bricks (M2 and M3) achieved a compression resistance equivalent to 88 % of the externally cured standard mixture after 180 days. In addition, M2 and M3 presented a similar strength in the cylinders conserved in the room with controlled humidity and temperature to those preserved in the submerged state, thus proving the properties of crushed clay bricks as curating agent.

The mixes with calcined clay, M2 and M3, obtained the greatest reduction in compressive strength. The internally cured samples achieved only 41 % of the resistance achieved by the standard sample.

From the foregoing, it could be observed that the compressive strength of mixtures with lightweight aggregates depended fundamentally on two factors: the percentage of coarse aggregate substituted by lightweight aggregate and the type of lightweight aggregate used. Comparing the behavior obtained for the concretes with lightweight aggregate of calcined clay against concrete with CCB aggregate in equal replacement percentages, a variation of the resistance is observed up to 49 %, where the CCB mixes obtained the higher strength. In addition, all mixtures with lightweight aggregates, the ones in the room as well as the ones in the submerged state, had lower compressive strength than the standard mix. This result agrees with the conclusions of Shafigh, Jumaat, Mahmud and Hamid (2012) regarding the reduction of resistance in mixtures with lightweight aggregates.

Modulus of elasticity: The procedure followed to evaluate this property was as specified in the ASTM C469 standard (2014). Figure 10 shows the average moduli of elasticity for the samples preserved in the room with controlled humidity and temperature.

Figure 11 shows the average modulus of elasticity for the samples in submerged state. It shows that the standard mixture obtained the largest modulus of elasticity (27 375 MPa), after 180 days. The modulus of the mixture with the curative agent preserved in the room with controlled humidity and temperature was the closest to the standard sample after 180 days (25 565 MPa), while the sample with the lowest elasticity modulus corresponded to the mixture with 15 % replacement of the coarse aggregate with calcined clay after 180 days (19 889 MPa).

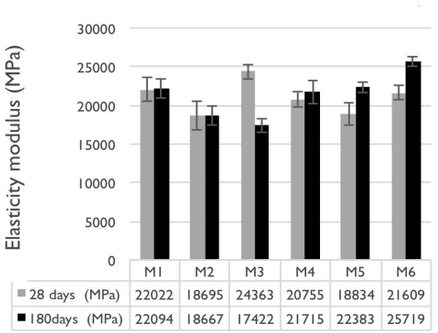


Figure 10. Moduli of elasticity, samples preserved in the room.
Source: Authors

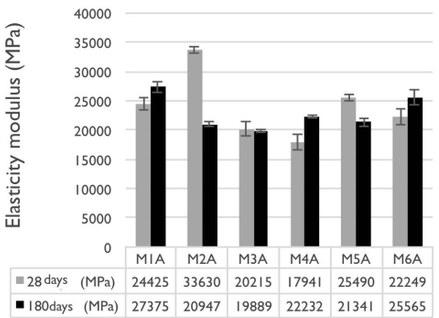


Figure 11. Modulus of elasticity, samples in submerged state.
Source: Authors

The variation of the elasticity modulus was different for all mixtures. In the case of the standard mixture in submerged state, and the samples with 25 %, replacement of the coarse aggregate by CCB in the room (M4), there was no variation in the modulus of elasticity after 180 days regarding the modulus obtained after 28 days. Meanwhile, all the other samples showed a variation between 10 % and 40 %, which is attributed to the difference in the composition of each mixture.

The only mixture with a decreasing modulus of elasticity was mixture M3 with a decrease of 29 %, which suggests the need of additional tests to determine the reason for this decrease.

Figure 12 and Figure 13 show the relation between the compressive strength and the modulus of elasticity, according to the following equation:

$$E = K\sqrt{f'c} \tag{1}$$

As observed in the figures, the relation constant between the modulus of elasticity and the $f'c$ is different for every mixture and curing environment. The M2A had a K value

of 4 080, whereas the other mixtures had a K value lower than 3 500. Compared with the values defined by the NSR-10 for concretes with a unit mass between 1 440 and 2 460 kg/m^3, the closer constant corresponds to the one defined for sedimentary aggregates with a K value of 3 600 (AIS, 2010).

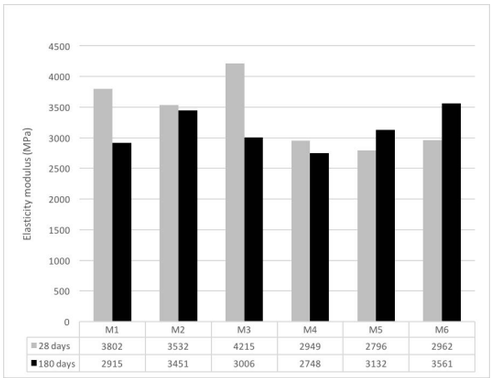


Figure 12. Relation of the modulus of elasticity and the $f'c$ in the samples preserved in the room.
Source: Authors

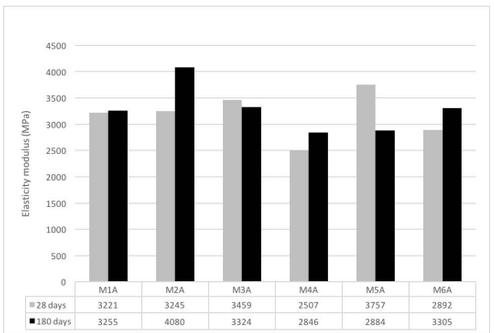


Figure 13. Relation of the modulus of elasticity and the $f'c$ in the samples preserved in submerged state.
Source: Authors

Durability properties of the concrete compressive strength

ISAT – Initial surface absorption test: this test was carried out following the guidelines described in the English standard BS-1881 part 5: Testing concrete.

For the ISAT, data were taken after 10, 30 and 60 minutes per sample, according to the aforementioned standard. Results are presented after 10 minutes, because the trend observed at that time was constant for the rest of the measurement. However, for the following reading time values, the absorption values were lower due to the corresponding pore saturation.

Figure 14 and Figure 15 show the results obtained from water absorption for each of the concrete samples, measured at 10 minutes.

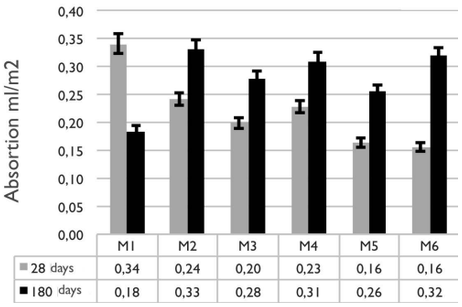


Figure 14. ISAT after 10 minutes for samples preserved in the room.
Source: Authors

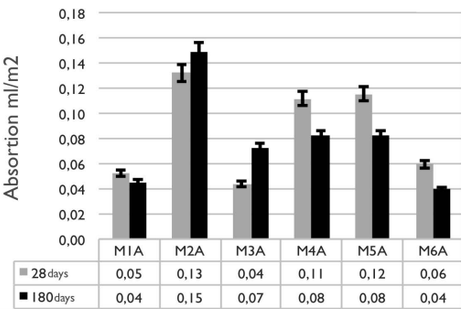


Figure 15. ISAT after 10 minutes for samples preserved in submerged state.
Source: Authors

Mixtures with light internal curing aggregates had an increase in the initial water absorption rate between 26 % and 36 % after 180 days. This can be attributed to the porous nature of the lightweight aggregates. The samples of the standard specimen preserved in the room with controlled humidity and temperature achieved an absorption decrease of 84 %.

It is concluded that concretes with lightweight aggregates obtained a greater absorption than the externally cured standard sample, which confirms the conclusions made by Castro, Keiser, Golias and Weiss (2011). However, it is worth clarifying that external curing was performed under ideal laboratory conditions where the samples were saturated until the day of the test and that those conditions are not reproducible in practical cases.

Chloride penetration: this test, as defined by the ASTM C1202-12 standard (2012), allows the determination of the electrical conductivity of the concrete to provide a quick indication of its resistance to chloride ion penetration. Figure 16 and Figure 17 show the current flowing through the test specimens for each of the mixtures after 28 and 180 days. In summary, a lower penetration of chlorides was obtained in the mixtures conserved in the room, which achieved a reduction of 34 % after 180 days, regarding the penetration obtained after 28 days.

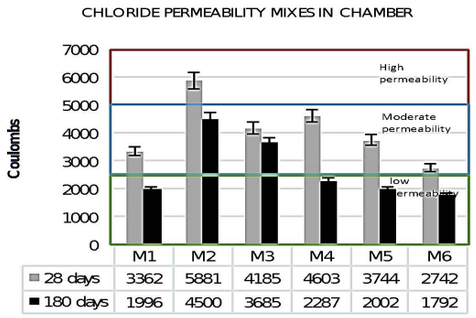


Figure 16. Permeability of chloride ions in samples preserved in the room.
Source: Authors

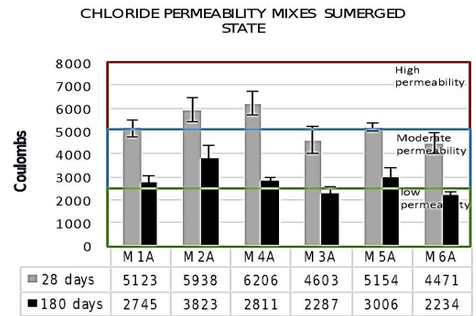


Figure 17. Permeability of chloride ions in samples preserved in submerged state.
Source: Authors

Samples with internally cured calcined clay recorded a greater passage of Coulombs ranging from 34 % to 64 % at 180 days compared with the mixture preserved in the room. The mixtures with CCB registered a reduction in the passage of Coulombs between 17 % and 27 % after 180 days, compared with the sample preserved in the camera. The mixture with the curing agent recorded the smallest Coulombs passage among all the samples evaluated and it had a 35 % lower step at 180 days than the externally cured standard sample.

Except for the internally cured sample 2 (M2), all the mixtures recorded a moderate and low passage, thus indicating an acceptable chloride migration. At the age of 180 days, a transcendental reduction occurred in the passage of Coulombs, changing the categorization of moderate to low in all the evaluated mixtures, which agrees with what was found by Dayalan and Buellah (2014).

Microscopy: the main objective of this test was to observe the interaction between the aggregates and the cement paste within the concrete matrix. The microscopy test was performed in mixtures M3 and M6.

In Figure 18 and Figure 19, the interaction between the aggregate and the cement paste can be observed. There is a noticeable change of tone between the cement paste and the lightweight aggregate. It can be concluded that the darkest shade is the superficial part of the lightweight aggregate and the clear part corresponds to the cement paste, where there are signs of perimeter humidity, which indicates the expulsion of the internal curing water.

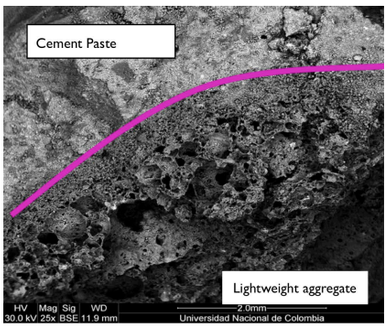


Figure 18. Microscopy of mixture M3 (25x).
Source: Authors

Figure 19, which belongs to sample 6, shows small elongated spots distributed around the entire cement paste, which correspond to the curing compound from Toxement.

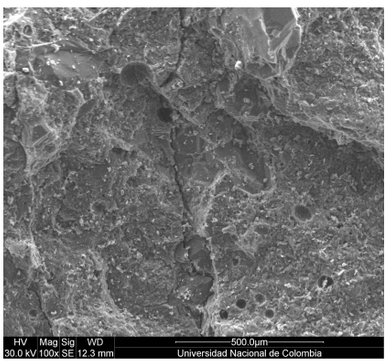


Figure 19. Microscopy of M6 (50x).
Source: Authors

Conclusions

The crushed clay bricks in partial replacement of 25 % of coarse aggregate, presented the best behavior in the different tests carried out and surpassed the sustainability point of view. This can represent a benefit, given that waste of the clay units is generated in buildings, due to its fragility, and it can become an economic option when used as a lightweight aggregate for the internal curing of the concrete; thus, decreasing the environmental impact. Nevertheless, the optimal replacement percentage should be proved for each concrete mix, through probe mixes.

Calcined clay does not have good behavior in the tested conditions, the mechanical and durability characteristics were always reduced compared with the standard mix. The authors suggest additional research with different densifications and different aggregate granulometry in order to obtain further conclusions.

In all the internally cured mixtures, there was a reduction in the strength resistance. This is contrary to the conclusion given by Saffar, Saad and Tayeh (2019), where the authors state that the internal curing should increase the strength resistance. However, their conclusion is based on experimentation with fine aggregates.

The Better Mix curing agent had a good behavior in all the tests evaluated, but also had a reduction in the strength of 32 % in submerged conditions. This suggests a limitation in its use for external members. It is also recommended further research with different humidity conditions.

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Strategic portfolio of IT projects at universities: A systematic and non-conventional literature review

La cartera estratégica de proyectos de TI en las universidades: una revisión de literatura sistemática y no convencional

Francisco Valverde-Alulema[1] and Faraón Llorens-Largo[2]

ABSTRACT

One of the most accepted review methods in the scientific community is the Systematic Literature Review (SLR). A SLR process allows determining the interest of the scientific community in the subject matter of the preliminary research, the type of research and the areas of knowledge to which the topic is more related, among other aspects. For our research, we need to determine the scientific basis of the portfolio of information technology (IT) project, as initial good practice for the implementation of an IT governance culture. Universities have been specifically selected as the type of organization in the communities that have developed formal processes and good practices for the implementation of IT governance. In addition to the SLR, a review was carried out based on non-conventional literature from repositories of prestigious professional organizations and universities. It is concluded that the portfolio of IT projects is a good practice of IT governance and that there is an interest from the scientific community. From this analysis, it is clear that there are works in both the area of Computer Science and the Administration of Organizations.

Keywords: Information technology, IT governance, Portfolio of IT projects, Best practices, Universities.

RESUMEN

Uno de los metodos de revision mas aceptados en la comunidad cientıfica es la *Systematic Literature Review* (SLR). Un proceso de SLR permite determinar el interes de la comunidad cientıfica en el tema objeto de la investigacion preliminar, encontrar publicaciones existentes y establecer las areas del conocimiento con las que el tema a investigar se encuentra mas relacionado, entre otros aspectos. Para nuestra investigacion necesitamos determinar la trascendencia cientıfica de la cartera de proyectos de tecnologıas de la informacion (TI), como una buena practica inicial para la implantacion de una cultura de gobernanza de las TI. Se eligen las universidades en las cuales se han desarrollado procesos formales y de buenas practicas de implantacion de gobernanza de las TI. Adicionalmente al SLR, se realiza una revision sustentada en la literatura no convencional de repositorios de organizaciones profesionales de prestigio y de universidades. Se concluye que la cartera de proyectos de TI es una buena practica de la gobernanza de las TI y que existe interes en la comunidad cientıfica. Del analisis se desprende que hay trabajos procedentes tanto del area de las Ciencias de la Computacion como de la Administracion de las Organizaciones.

Palabras clave: Tecnologıas de la informacion, Gobernanza de TI, Cartera de proyectos de TI, Buenas practicas, Universidades.

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Introduction

Universities have adopted Information Technology (IT) within administrative and academic processes. The question at this time is whether its use is adequate, that is, if IT has been acquired under an analysis of needs, if studies have been carried out to observe its benefits and possible risks when implemented, and especially if they have generated institutional value. The question of whether the technologies are aligned with the objectives of the organization and whether they are prioritized by top university management are aspects that have almost never been analyzed. Specific indicators are needed to confirm that IT is being used properly. A culture of IT governance can answer these questions.

IT Governance and Portfolio of IT Projects

Incorporating properly the IT in the University will dynamize its processes and allow them to fulfill its mission (González, Arango, Vásquez and Ospina, 2015). If universities do not get IT to create value, they will lose competitive advantage. Universities carry out studies to assess this issue, such as the UniversiTIC reports (Analysis of IT in Spanish Universities) (Gómez, Jiménez, Gumbau and Llorens, 2016), which evolved so that, in addition to being a catalog of available technologies

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in universities, they collect characteristics of IT governance models. As a complement to the detailed inventory of IT deployed in Spanish universities, good practices in IT management are analyzed, addressing the optimization of IT resources, portfolio of IT projects, IT services, IT management, quality, regulations and IT standards and collaboration (Fernández, Llorens and Hontoria, 2015). In a dynamic and unpredictable environment, organizations, and therefore universities, are threatened by major changes, especially technological ones (Sierra, 2012). The use of technology and the management of IT projects become a key aspect for them. To develop a strategic role in the business, the IT organization needs to move from being an order-taker to becoming a business partner integrated with the rest of the company's activities, thus ceasing to be a set of tangible and intangible elements to become the strategic ally of the organization.

One of the most difficult questions to answer is how an organization can implement a governance culture of IT in a practical way. Management teams are adopting principles of IT governance. According to Delgado, Marcilla, Calvo-Manzano and Fernández-Vicente (2012), "IT governance encompasses a set of good practices that facilitate new opportunities for improvement in organizations". One of the best practices that can be applied in relation to the acquisition principle is the implementation of a portfolio of IT projects (Fernández, Hontoria and Llorens, 2014). The portfolio of technological projects is the concrete expression of the company's technological strategy. In what and how resources are spent tells us a lot about the strategic priorities of a company, no matter they are explicit or not. Organizations must use IT portfolio management techniques to ensure that programs (a set of related IT projects) are aligned with strategic objectives (ISACA, 2013). The need to govern IT is a consequence of two strategic factors: the needs of the business and the maturity of the company (Juiz and Toomey, 2015). As shown in Toomey (2009), in addition to technology, we must consider people, processes and structure to understand the IT governance. According to Laita and Belaissaoui (2017), the IT governance aims to ensure that IT expectations and achievements are aligned with organizational objectives and that the associated risks are under control. There must be a strategic alignment between the use of IT and the achievement of business goals, both from the public or private sectors. Governing IT today is not a choice, and the Strategic Portfolio of IT Projects is a good practice that can help us with its implementation.

Systematic Literature Review

It is important to determine what previous studies have been developed on the subject, what areas of knowledge are relevant to the subject under research, what is the scientific interest on the subject, what is the group of documents that give scientific support to the research and what is the proper process to search for related documents. Finally, after the selection of articles, one must have the capacity to answer questions such as: what topics are being addressed? What are the different theories or approaches? What do the different authors think? What work or research lines do they propose? What problems do they address? What solutions have they found? And what gaps remain to be filled or research to be made? The Systematic Literature Review (SLR) is an important contribution as a mechanism to collect, organize, evaluate and synthesize all the available evidence regarding a topic of interest, either to improve the current practice or to suggest new research directions. A systematic literature review aims to exhaustively identify all the relevant studies, to answer a question or several research questions, and assess the validity or solidity of each study, keeping this in mind when drawing conclusions (Ferreras, 2016; Sánchez-Meca, 2010; Brettle, 2003). A systematic review is the selection of documents whose origin is the databases of scientific research, such as Scopus and Web of Science (WoS), among others. The individual studies that contribute to the SLR are called primary studies. In this paper, we will base on the group of SLR activities proposed by Kitchenham, Mendes and Travassos (2007), which is the most used in Software Engineering and Information Systems (Chai, Liu and Ngai, 2013).

Non-conventional literature

The results of a research are published in journals, conference proceedings, monographs, theses and reports. The type of publication is very diverse and the access to publications in many cases is not simple or public. Ferreras (2016) affirms that the Internet and the Web have managed to solve these problems under the new scheme of digital journals that have become popular due to their characteristics and versatility. But this new scenario also opens a new way of dissemination to other types of research literature, such as doctoral theses, that is fundamental in scientific research and, therefore, essential in its communication. For this reason, any type of content or publication on the web can be, in theory, open access and can be digitized and put online without economic barriers or permits for reuse. PhD theses are a fundamental element in the development of research and represent an important milestone in the academic career of those who perform this work. In addition, as the objective is to find out if there is research on good governance practices of IT in Universities, due to the nature of the topic we cannot ignore the sources from professional associations (Cesare, Luzi and Ruggieri, 2008; Sondergaard, Andersen and Hjorland, 2003).

Methodology

According to Genero, Cruz-Lemus and Piattini (2014), and Kitchenham et al. (2007), the need for a SLR arises from carefully summarizing all the relevant information on a specific topic of interest. Based on Kitchenham et al. (2007), we structure our systematic review in three phases: plan, do and report (Table 1).

Plan the SLR

Planning is considered a relevant activity, since the correct development of the SLR will depend on the decisions taken in this activity. Table 1 shows the activities of this first

phase. In our work, this planning applies not only to the search of scientific databases, but also to the search of non-conventional literature. Activity 2 consists in formulating the research questions. As stated by Genero et al. (2014), the specification of research questions is the most important aspect of any systematic review, since the questions will direct the entire process. Subsequently, the definition of the protocol of the review is addressed (activity 3). According to Kitchenham et al. (2007), a SLR protocol is a formal plan to carry out the systematic review, which should reduce the possibility of bias. In this activity, the search and data extraction strategy is created. The elements to consider are: justify the relevance of the need to carry out the review; include research questions previously defined; and establish the search strategy, defining the search string, period and sources (Genero et al., 2014).

Table 1. Phases and activities of the SLR

ACTIVITY	Plan the SLR
1	Identify the need for the review
2	Ask the research questions
3	Define the protocol of the review
4	Validate the protocol of the review
	Do the SLR
5	Identify relevant research
6	Select primary studies
7	Evaluate the quality of primary studies
8	Extract the relevant data
9	Synthesize the extracted data
	Report the SLR
10	Write the review report
11	Validate the review report

Source: Authors

Genero et al. (2014) also state that it is advisable to define initial search strings and apply them in some source to detect in the titles or summaries if in fact they are contributing to the objectives of the SLR. Regarding the sources to search, they must include articles from journals indexed in scientific databases or international conferences, books indexed in scientific libraries and non-conventional literature (reports of prestigious associations, scientific reports of experts in the area, doctoral theses, master's theses, norms and standards of recognized organizations). In addition, it is convenient in turn to review the bibliography of the articles found. The inclusion and exclusion criteria of the primary studies will help to reduce the number of publications to analyze. Researchers should also define the aspects to be taken into account for the qualification of each article. As affirmed by Genero et al. (2014), since the protocol is a critical element for the realization of the SLR, it is advisable that it is validated by experts (activity 4). The experts can be those who validate the final report of the SLR.

Do the SLR

In this phase, we put into practice what was previously planned in the protocol and we obtain the final results that will answer the research questions. Table 1 shows the tasks that must be executed in this phase. The set of relevant research (activity 5) is found following the search strategy defined in the review protocol. In this activity, it is necessary to refine the search strings, include new sources or change the period. It is important to document the changes and record the results through reference management systems. In addition to the basic data (title, authors, year, etc.) it is necessary to save the summary. The selection process should locate the primary studies (activity 6) that show evidences related to the research questions.

After selecting the primary studies, they will undergo a quality evaluation process (activity 7), following a checklist defined in the review protocol. All articles that do not exceed the minimum threshold established to be considered adequate for the research must be excluded. Subsequently, a data extraction list must be made, as defined in the protocol. As a result, the data extraction forms will be obtained filled with the information corresponding to each primary study that has been selected (activity 8). Once all the publications considered relevant have been collected, they will be synthesized using the methods established in the review protocol, which will answer the questions asked. The synthesis is accompanied by tables and graphs to illustrate the results (activity 9).

Report the SLR

The activities of this phase are detailed in Table 1. According to Kitchenham et al. (2007), to finalize the systematic review, a report must be written that reflects the entire review process (activity 10), considering the means of disclosure selected when defining the protocol. It is necessary to collect the information with the detail of documentary quality and relevance of results. Finally, reports of validity threats, limitations of the SLR and lessons learned can be attached, which compile the experiences of the SLR carried out and can serve as reference for future researchers. The more information about the study, the more transparency of the validity will have the SLR performed. Finally, the report should be sent to experts for validation (activity 11).

Selection criteria

Our research work requires evaluating the effect of the portfolio of IT project as an initial good practice for the implementation of IT governance in Universities. A systematic review of the scientific and non-conventional literature is initially proposed in order to identify the relevant studies to the following question: In a university with an IT governance that is not explicit, is the portfolio of IT project an initial good practice for the proper implementation of an IT governance framework?

To formulate the research question (activity 2), it has been considered that the general problem to be solved is the lack

of an adequate implementation of a specific IT governance framework in universities. The population in which evidence is collected belongs to universities with an IT governance that is not explicit. The intervention group is the portfolio of IT projects as a good practice that deals in a cross-cutting way with all the IT governance principles. The results should be related to the portfolio of IT projects, as a good practice for the adequate implementation of a specific IT Governance framework for the universities.

We addressed the definition of the review protocol (activity 3). Four terms are proposed as key words of the search: "IT Governance", "Project Portfolio", "Good Practices" and "Universities", with its different terminological variants and considering the search both in English and Spanish. The databases consulted are WoS, Scopus and Google Scholar. In addition, due to the particularity of the research topic, the study is complemented with non-conventional databases of universities and recognized international associations. The inclusion criteria for the search in scientific databases and repositories of non-conventional literature are shown in Table 2.

Table 2. Inclusion criteria for scientific databases and non-conventional literature

	Inclusion criteria for scientific databases
Language	English, Spanish
Year of publication	2000 onwards
Document type	Articles, conference articles (congresses), books
	Inclusion criteria for non-conventional literature
Language	English, Spanish
Year of publication	2000 onwards
Document type	Articles, conference articles (congresses), books, reports, master's thesis, doctoral thesis, standards

Source: Authors

To determine the relevance of each publication in relation to the specific research topic, the five evaluation criteria that appear in Table 3 are used. Each criterion is rated with a value between 0 and 2, where 0 indicates a minimum contribution of the selected publication to the criterion, 1 a medium contribution and 2 a high contribution. After evaluating all the selected primary studies (activity 7), we proceed to select publications with a high level of contribution (which have obtained between 9 and 10 points) and read them completely. With these publications, the state of the art of the research will be written (activity 10).

Results

In this section, the final results obtained in the systematic review are presented. The set of publications is cleared out, eliminating the redundant documents. We found 242 primary publications. It is observed that 147 of those publications come from scientific databases and 95 from non-conventional databases. From the publications found in the scientific databases, the highest percentage (46,94 %) come from Scopus, followed by 38,10 % from Google Scholar and 14,97 % from WoS. Regarding non-conventional literature, 33,68 % of the publications found come from repositories of universities and 66,32 % from prestigious professional associations and expert recommendations. Considering the total number of publications, it is observed that 60,74 % come from scientific databases, which allows to guarantee the scientific quality of the works found in the review. However, the remainder of works that correspond to non-conventional publications is important, because it comes from recognized institutions in the academic and professional field and complements the research work. The publications are classified by area of knowledge. This analysis is only carried out in the publications coming from the scientific databases, since they contain this field. There are 38 documents belonging to Computer Science, 40 to Engineering, 28 to Business Administration, 7 to Economics and Finance, 3 to Decision Sciences and 31 to Information Technologies. Engineering, Computer Science and Information Technology are the most frequent fields. In the classification according to the year of publication, restricted to the period 2000-2017 defined in the protocol, 242 publications have been found. The growing interest of the scientific community in the topic of IT governance is evident in universities, specifically in relation to the portfolio of IT projects and its good practices: from only 3 publications in 2000, it has risen to 26, 32 and 23 in 2014, 2015 and 2016, respectively. The number of works found in 2017 is not comparable with those of the other years, since the search was done before the end of the period.

Table 3. Criteria to evaluate the relevance of publications

Criteria	Points	Description
Origin	2	Prestige of the journal/organization that supports it
Coherence	2	Consistency of the summary
Adequacy	2	Adequacy of the study to the objectives of the research
Results	2	Assessment of the results of the study
Transferability	2	Transferability to the research context
Total possible	10	

Source: Authors

Regarding the language in which the papers are written, 173 out of 242 publications (71,49 %) are in English and 69 (28,51 %) in Spanish. As expected, the number of publications found in the scientific databases and written in English is significantly higher than those in Spanish (130 versus 17). In those from associations, the number of publications per language is balanced (34 and 29), while in those from university repositories, there is a greater number in Spanish (23 compared to 9) due to the bias of origin of the authors of this work. Table 4 classifies documents by type. From the 242 selected papers, 143 are journal articles, followed by 36 articles from conferences and congresses. There is a considerable contribution of reports (22) and books (20). The

scientific databases have contributed more articles indexed in journals (113), while non-conventional literature provides mostly books (17) and reports (22). The doctoral theses (13) and master's theses (5), important for the present research work, come exclusively from the institutional repositories.

Table 4. Results by type of document

Document type	Scientific DB	Universities	Associations Experts	Total
Articles	113	7	23	143
Articles conference	31	2	3	36
Books	3	0	17	20
Reports	0	5	17	22
Rules	0	0	3	3
Doctoral theses	0	13	0	13
Master's theses	0	5	0	5
Total	147	32	63	242

Source: Authors

Final assessment

Each summary, title and keywords are read and the document is qualified (Table 5). Each publication had a rating of a maximum of 10 points, obtained according to the five evaluation criteria in Table 3. Finally, a contribution level has been assigned to each publication according to the points obtained: dismissible (0-3 points), low (4-6 points), medium (7-8 points) and high contribution (9-10 points). As final result, 51 publications are considered high contribution to answer the research question proposed at the beginning of the SLR. Looking more closely at the origin of the 51 high-contribution publications, we can see that 23 come from scientific databases, 8 from non-conventional literature in universities and 20 from prestigious associations. From the 23 high contribution publications from scientific databases, 12 were found in Scopus, 2 in WoS and 9 in Google Scholar. In the non-conventional literature, 8 belong to repositories of universities, 12 belong to professional associations and 8 are recommendations made by experts in the field. Thus, from the total of 242 publications selected at the beginning, the number of publications to be considered in the qualitative analysis of the research has been reduced to 21,07 %. The rest of the publications (191) will probably not be taken into account in the qualitative analysis during the writing of the state of the art, but they are identified and may be accessed at some point during the research.

For the final report, only selected publications with a high contribution are considered and the entire evaluation process is reported. The details of the selected publications from scientific databases (23 publications) are presented in Appendix 1. We have read completely the 51 selected publications.

Table 5. Contribution percentage of the publications

Level of contribution	Scientific DB	Universities	Associations	Total	Percentage
DISCARD	50	12	13	75	30,99 %
LOW	32	5	9	46	19,01 %
MEDIAN	42	7	21	70	28,93 %
HIGH	23	8	20	51	21,07 %
Total	147	32	63	242	100 %

Source: Authors

Scientific and professional interest

To determine the scientific interest we proceeded to analyze the 147 primary studies from scientific databases. From these documents, 31 come from conferences and 113 from scientific journals (Table 4). We can see the conferences from which the selected works come from. The Hawaii International Conference on System Sciences (HICSS) has contributed 4 publications. The indexed journal in which more articles have been published on the subject of study is JISTEM (*Journal of Information System and Technology Management*) with 6 publications, followed by the *Journal of Theoretical and Applied Information Technology* with 5 publications.

Due to the nature of the research topic, framed within the IT governance, it is also convenient to analyze the professional interest. From the 63 publications found in the non-conventional professional literature (Table 4), 45 come from prestigious associations and 18 are direct recommendations made by experts. There are 9 associations that concentrate 38 of these publications. The Association with more selected documents is the Crue-TIC (ICT Sectoral Commission of the Conference of Rectors of Spanish Universities) with 13 publications. This concentration is due to the strong implication of the authors with this association. It is followed by other associations with fewer publications related to the portfolio of IT projects in universities but equally concerned with the subject: the ISACA (Information Systems Audit and Control Association), EUNIS (European University Information Systems) and ITGI (IT Governance Institute), among others. It must be borne in mind that the search for research works in associations has not followed a systematic method. It has been based fundamentally on the experience of the authors and on references provided by experts in the field.

Discussion of results

The ultimate goal of a systematic literature review is to carefully summarize all the relevant information about a specific topic of interest. It is important to extract from the selected publications the answer to various questions, so that it allows us to successfully address our future research. The first step for our research has been to look for answers on the IT governance and the portfolio of IT projects issues. In the review conducted, different approaches to how to use

IT properly can be found. This new approach allows us to determine methods, good practices, standards, frameworks and procedures, which attempt to analyze how to use IT appropriately as service providers, and their relationship with users and customers. The IT governance can be seen as the set of mechanisms, structures, procedures and relationships defined by the senior management to evaluate, direct and monitor actions and the correct use and management of IT (Santos and Santos, 2017). The key element in IT governance is the alignment of IT to the business and, thereby, generating business value. IT services are increasingly integrated into business operations. According to Fernández et al. (2015), the alignment of IT with the business allows to verify the impact of IT infrastructure and IT projects and services on the organization itself. We must move the focus of IT from cost efficiency to operational effectiveness and thus improve business processes. In relation to the project portfolio, numerous works have been found with different models (PMI, 2013). Some of them are even specifically designed for universities (Correa and Benavides, 2013). The strategic priorities of a company are reflected on what and how resources are spent. The portfolio of IT projects is a powerful tool for IT governance. It requires close connections between principles, processes, people and performance. Next, how the different selected works address different aspects is presented, that is, basic approaches, research lines, problems detected and proposed solutions.

Basic approaches

With respect to the IT Governance, several authors describe related theories, models and procedures. Reynolds and Yetton (2013) propose a new model of IT governance that re-conceptualizes business and IT alignment, contributing with detailed explanations of how IT creates value at the corporate level and at the level of strategic business units. Toomey (2009) states that companies have evolved to demonstrate how IT (personnel and technology) helps them to meet their business objectives. IT governance must deal with IT demand and provision (Delgado et al., 2012). Highly aligned organizations take advantage of more mature IT governance practices compared to poorly aligned organizations (ISACA, 2013; Montaña, 2013). Regarding the portfolio of IT projects, IT project management alone does not guarantee that the organization is spending its resources in the right areas and doing the right projects. A prioritized set of well-defined IT projects that can be successfully executed in the short term should be generated. In the portfolio of IT projects, it is fundamental in the business strategy that the combination of projects reflects the strategic priorities. Furthermore, Jairak and Praneetpolgrang (2013) propose the establishment of a procedure to prioritize the projects and involve IT and business managers from the beginning of the project. The portfolio of IT projects is successful if the steering committee assumes the responsibility of supervising large projects and managing the priorities, costs and allocation of IT resources. Tu, Shaw and Subramanyam (2015) believe that all the no financial impact would result in the financial value of the investment portfolio of IT projects in a company. In the case of universities, according to Fernández et al. (2014), every university should have some economic and human resources, so that their IT is centralized and sufficient to achieve the objectives established by its own strategy. Fernández et al. (2014) believe that IT planning should be obtained from the university global strategy and include a portfolio of IT projects that implement the proposed strategies. Franco Reboreda (2017) analyzes the current state of governance of IT in the Universities and Institutions of Higher Education in Mexico, where route maps can be drawn towards the consolidation of IT governance initiatives. Ponce (2016) affirms that the life cycle of the portfolio of IT projects must conclude with the evaluation of the success achieved by each project and the decision by the board of directors on its continuity, modification or cancellation.

Research lines

IT Governance brings together five research areas: strategic alignment, resource management, risk management, performance and value generation for the organization (Delgado et al., 2012). Prediction models and decision support systems are new areas in IT governance research (Jairak and Praneetpolgrang, 2013). Laita and Belaissaoui (2017) recommend to carry out studies on the contribution of IT governance to the provision of services in the public sector. Additionally, it is proposed for the public sector to research the threat posed by the decrease in IT budget and the lack of mechanisms for the adequate implementation of IT governance. The management of the portfolio of IT projects, the information economy, the strategic IT planning, the methodologies of project management, the return on investment based on well-being (ROI and ROIW), IT quality, prediction models, decision support systems and datamining are lines for research that can be explored and exploited. Current research on IT portfolio management is very limited, therefore, it presents great opportunities for researchers on information systems to advance in the knowledge of this good practice.

Detected problems

From the detailed reading of the selected articles, different obstacles are detected and related to both the governance and the portfolio of IT projects. One of these obstacles is to propose and implement in the organizations a new business model and IT alignment that provides results to explain how IT creates value (Rahimi, Moller and Hvam, 2016). Another problem, according to Fernández et al. (2014), is that there are obvious differences between IT management and IT governance and consequently their differences must be clearly established. It is necessary to find procedures that demonstrate that IT is not a commercial expense, but an investment with not only economic but also social benefits. According to Jairak and Praneetpolgrang (2013), the companies from developing countries without an adequate industrial infrastructure are not at the same level as those from developed countries. The implementation of an IT governance culture requires not only good intentions

but also IT investment, trend analysis and technological prospection, which makes it more feasible to implement an IT governance in developed countries. Lima, Fernandes and Machado (2016) state that there is still limited knowledge regarding the management of the portfolio of IT projects. Quantifying the benefits of a portfolio of IT projects can be difficult.

Stated solutions

Rahimi et al. (2016) propose a new business and IT alignment model in organizations, providing results that explain how IT creates organizational value. Additionally, Ghorfi, Oudau, Aboutajdine and Aroussi (2014) determine a model that allows the people in charge of IT to have a decision tool regarding their future strategic choices. Santos and Santos (2017) affirm that the effectiveness of IT governance in public or private companies will be achieved if the results of decision-making and related processes for the management and control of IT operations reach IT objectives. The findings can be used to improve the current IT governance frameworks, enabling companies to focus on IT concerns with a strong impact on the performance of IT governance. Project management is the institutional memory of governance. Simon, Fischbach and Schoder (2013) establish closer relations between the business architecture and the management of the IT portfolio through their integration not only in the process but also in the strategy, the meta-model, the organization and the level of the software tool. With regard to the selection process of IT projects, several solutions are proposed. Zhijie (2012) suggests that IT governance plays an important role in the selection of IT projects and the prioritization of the portfolio. Regarding solutions found in universities, Fernández et al. (2015) state that one of the best practices that can be applied in relation to the acquisition principle is the implementation of a portfolio of IT projects. An IT investment portfolio should be designed based on a prioritized set of well-defined IT projects, that is, a portfolio of IT projects must be executed. One of the bases of good IT governance consists in developing a portfolio of projects aligned with the objectives of the University (Fernández, Gumbau and Llorens, 2012; Fernández et al., 2014; Gómez et al., 2016; Fernández et al., 2015).

Conclusions

A systematic review of the literature has been applied, both in scientific databases and in university repositories and professional associations, to initiate the research that leads us to answer the question of whether the portfolio of IT projects can be an initial good practice for the implementation of an IT governance framework in a university with a non-explicit one. Throughout this document the methodology followed has been explained. The figure of Appendix 2 summarizes the process followed. We can consider it as a sequential filtering that leads us to select, from all the existing documentation on the Internet, a small number of works related to the subject that allow us to determine the research situation in that area. The first filter applied is related to the sources in which the information has been sought: the scientific databases (Scopus and WoS), non-conventional sources (Google Scholar), professional associations and institutional repositories of universities. Once the sources have been determined, the search has been carried out. For scientific and non-conventional databases, a second filter has been applied, consisting in searching the terms (IT governance, portfolio of IT projects, good practices and universities) and the inclusion criteria. We have obtained 242 primary publications (Valverde-Alulema, 2019), which have been evaluated and labeled as high contribution for research (51), medium, (70), low (46) and dismissible (75). For the final selection of the works for writing the state of the art, a last filter has been applied, keeping only the 51 high-contribution publications.

According to the analysis of the selected final documents, the portfolio of IT projects is a good practice for IT governance and there are researches on this regard. In the period taken for the search (from 2000 to 2017), an increasing trend in the number of publications has been found. The scientific community has a real and progressive interest in the line of research of the IT Governance in general, and in particular in the Universities, where there is still a long path for research. The portfolio of IT projects is a very useful practice and has been implemented in many institutions. The greatest number of publications are from the technological areas, although there is also an interest in the business areas. This leads us to propose that a multidisciplinary research must be carried out to coordinate research from the technological and business areas. This would benefit the alignment of IT with the strategy of organizations for better Corporate Governance.

At a general level, the creation of a research line related to the IT Governance is of great relevance and its insertion within university postgraduate and research plans is justified. For the purpose of the present investigation, the study of good practices that give strength to IT governance is also justified. The portfolio of IT projects is a proven practice and could be an initial good practice, prior to the adoption of a culture of IT governance, in organizations. Specifically in the universities, some initiatives have been developed through the application of good practices, as a result of the contribution of the scientific community and prestigious international associations that have been working on issues related to the IT Governance. In this way, the review of the literature will help us answer the research question proposed at the beginning and justify the future work of implementing a Strategic Portfolio of IT Projects specific to universities, with analysis of characteristics and established standards. This demonstrates that it is the first step to implement and ensure a good start in the adoption of a specific IT governance framework for Universities, which is the purpose and future objective of our research.

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Appendix 1. Detail of the 23 studies from scientific databases selected for the review

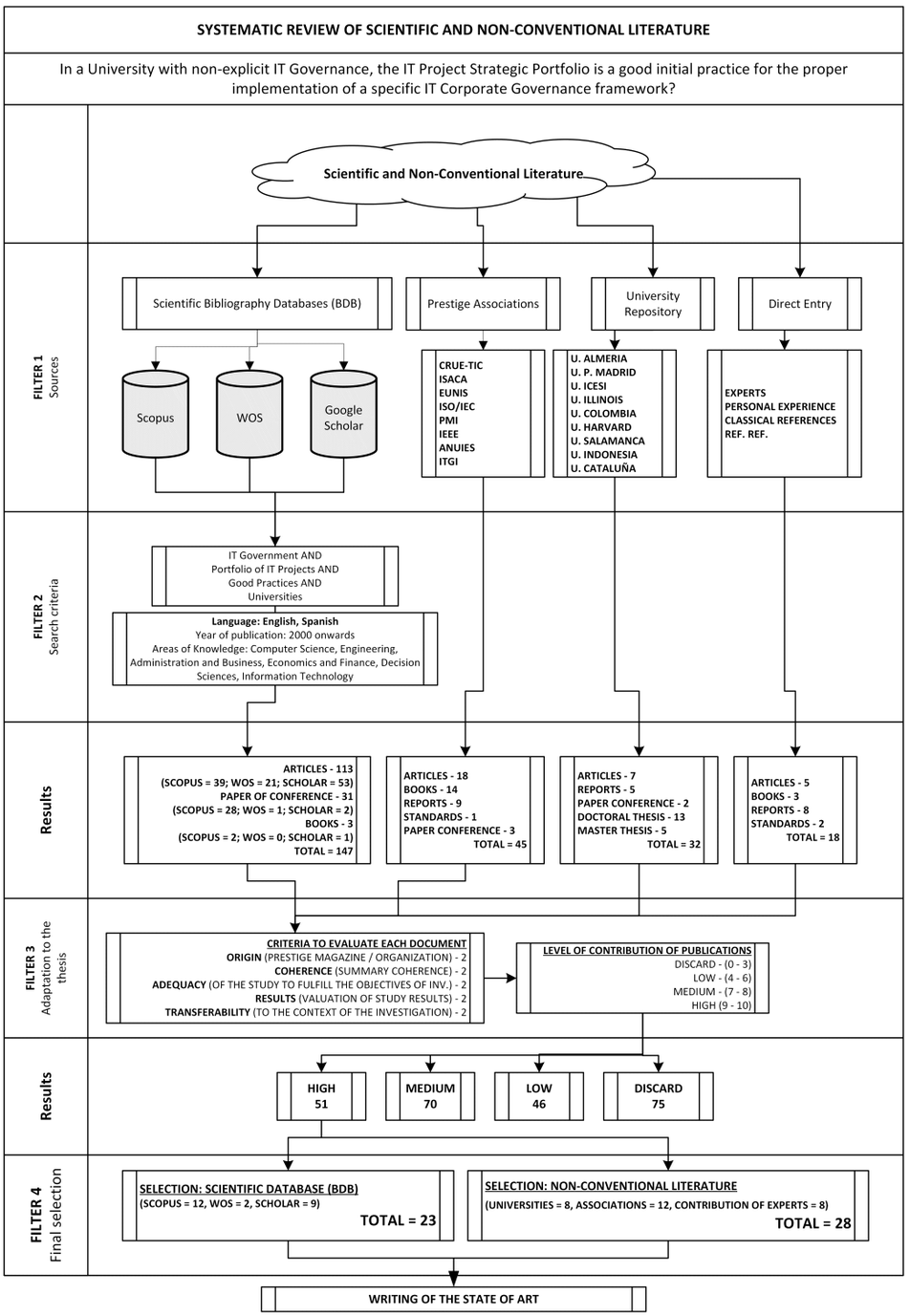
Author	Title	Year	Journal/Conference	Method	Results
Cameron, B. H.	IT portfolio management: Implications for IT Strategic Alignment.	2005	AMCIS Human Scale 4, pp. 1662-1669	Current techniques and best practices for managing the portfolio of IT projects.	Alternative corporate strategy and IT investments.
Chiang, I. R., y Nunez, M. A.	Strategic planning and project selection for IT portfolio management.	2009	International Research Workshop on IT Project Management 2009. 10.	Analysis of characteristics, dependencies of projects and team experience.	Optimization procedure of the portfolio of IT projects.
Cubeles-Márquez A.	IT Project Portfolio Management: The Strategic Vision of IT Projects.	2008	NOVÁTICA	Analysis of individual and group management of IT projects.	Good practices to implement the strategy through IT projects.
Delgado, M. de la C., Marcilla, F. J. S., Calvo-Manzano, J. A. and Fernández-Vicente, E.	Project management and IT governance. Integrating PRINCE2 and ISO 38500.	2012	CISTI - 6263172	Study of PRINCE2 and ISO 38500.	Integration of ISO 38500 principles with PRINCE2 processes and roles.
De Haes, S. and Van Grembergen, W.	IT governance and its mechanisms.	2006	HICSS 8,1579683, pp. 193	Analysis of IT strategies and IT governance.	Good practices of IT governance.
De Haes, S. and Van Grembergen, W.	An Exploratory Study into IT Governance Implementations and its Impact on Business/IT Alignment.	2009	Information Systems Management 26(2), pp. 123-137	Triangulation of multiple strategies for the implementation of IT governance in companies.	Mature IT governance practices for business alignment maturity.
Ghorfi, R. El, Ouadou, M., Aboutajdine, D., and Aroussi, M. El.	A Modeling Approach for IT Governance Basics Application on IT Projects and IT Goals.	2014	Artificial Intelligence, Modelling, and Simulation 7102462, pp. 211-216	Analysis of IT governance models. Model of Monte Carlo.	Knowledge model of IT governance with IT governance activities.
Jairak, K. and Praneetpolgrang, P.	Applying IT governance balanced scorecard and importance-performance analysis for providing IT governance strategy in university.	2013	Information Management and Computer Security 21(4), pp. 228-249	Analysis of CIOs perception of the performance of IT governance, BSC and surveys to universities.	Current status of IT governance and IT controls in developing countries.
Karhade, P., and Shaw, M.	Rejection and selection decisions in the IT portfolio composition process: An enterprise risk management based perspective.	2007	AMCIS Reaching New Heights 4, pp. 2838-2848	Analysis of the portfolio of IT projects (risks, technological factor, time and financial)	Model of the composition process of the portfolio of IT projects for IT investments
Karhade, P. P., Shaw, M. J., and Subramanyam, R.	Evolution of decision rules used for IT portfolio management: an inductive approach.	2009	Lecture Notes in Business Information Processing 36 LNBIP, pp. 307-320	Inductive learning, data analysis of business decisions.	Decision rules for the planning of the portfolio of IT projects.
Laita, A., and Belaissaoui, M.	Information technology governance in public sector organizations.	2017	Advances in Intelligent Systems and Computing 520, pp. 331-340	Comparison COBIT, ITIL, ISO 17799, Val IT.	Management and government differences, public sector model.
Lima, A., Fernandes, G., and Machado, R. J.	Project and Program Management Implications in the Portfolio Management of IT Projects in Applied R&D Organizations.	2016	QUATIC 7814553, pp. 224-229	Study of PMI, OGC and IT project management models.	New method for the management of the portfolio of IT projects.
Neville Holmes, W.	Strategic Alignment and IT Project Portfolio Management.	2009	The Credit Crunch and the Digital Bite. IEEE Computer.	Development of a support system for the distribution of IT projects according to performance.	Redesign of the process management of dysfunctional IT projects.

Continúa

Author	Title	Year	Journal/Conference	Method	Results
Oh, L., Ng, B., and Teo, H. H.	IT portfolio management: A framework for making strategic IT investment decisions.	2007	ECIS ISBN10: 1599046873	Maturity index, structural model, analysis of results with business performance.	How to allocate IT resources and obtain value in IT investments.
Rahimi, F., Moller, C. and Hvam, L.	Business process management and IT management: The missing integration.	2016	International Journal of Information Management 36(1), pp. 142-154	Analysis of literature, business processes, GTI frameworks and case studies.	Horizontal integration between aligned business processes and IT
Reynolds, P., and Yetton, P.	Aligning business and IT strategies in multi-business organizations.	2013	Journal of Information Technology 30(2), pp. 101-118	Review of strategy literature, revision of IS theory.	Business model and IT alignment.
Simon, D., Fischbach, K., and Schoder, D.	Integrating IT portfolio management with enterprise architecture management.	2013	International Journal of Conceptual Modeling. ISSN: 1866-3621	Analysis of the characteristics of the portfolio of IT projects, surveys.	Integrated process design management of the portfolio of IT projects.
Simonsson, M., Johnson, P., Ekstedt, M.	The Effect of IT Governance Maturity on IT Governance Performance	2010	Information Systems Management 27(1), pp. 10-24	Statistical methods for correlation force analysis applied to data collected.	Maturity correlation of IT governance and the performance of IT governance.
Thiadens, T. J. G., and Steenbackers, C. G. A.	Deciding about IT: IT Portfolio management in 19 major Organizations in the Netherlands.	2010	MCIS 2010 Proceedings	Analysis of portfolio management, governance and organization, mapping.	Procedure to measure the level of control of the portfolios of IT projects.
Tu, T. Y., Shaw, M. J., and Subramanyam, R.	IT Governance and Portfolio Management: An Exploration of the Superior IT Project Investment Portfolios.	2015	PACIS 2015 - Proceedings	Exploration of IT investment characteristics, computational modeling.	Practices to improve selectivity, scalability of investments of IT projects.
Verhoef, C.	Quantifying the effects of IT-governance rules.	2007	Science of Computer Programming 67(2-3), pp. 247-277	Quantitative analysis and database patterns of portfolios of IT projects.	Lessons learned to recognize unwanted effects.
Wee, A., and Theodorou, P.	Strategic Information Technology and Portfolio Management.	2009	ISBN13: 9781599046877	Analysis of management principles and portfolio implementation.	How to implement an IT portfolio management framework.
Zhijie, X.	A Method of IT Investment Portfolio Optimization in the Government Sector Integrated with IT Governance.	2012	BCGIN 6382450, pp. 6-9	Development of multi-object non-linear programming, matrix of stakeholders in IT investment and decision process.	Portfolio management framework integrated with IT governance (risk, technology, benefit and capital)

Source: Authors

Appendix 2. Summary of the systematic review of the scientific and non-conventional literature



Source: Authors

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The why of adaptive protections in modern electrical networks

El porqué de las protecciones adaptativas en las redes eléctricas modernas

Juan M. Guardiola[1], Eduardo Gómez-Luna[2], Eduardo Marlés-Sáenz[3], and Jorge de la Cruz[4]

ABSTRACT

Electrical networks are evolving and taking on more challenges as the inclusion of renewable energy and distributed generation units increase, specially at distribution levels. Big trends of generating electricity with alternative and renewable resources has promoted the formation of distribution networks subsystems or micro grids, capable of supplying their own electric demand and to export energy to the interconnected system, if necessary. However, the effects of these generation units into the network and into the microgrid as well are many, as harmonic distortion, voltage flickers and especially in electrical protections.

This paper provides an overview about implementation of renewable energy and distributed generation worldwide, as well as an introduction to microgrids concept and its main impacts and challenges into the electric systems. Finally, the main impacts of microgrid on protection equipments are presented at a distribution level, being adaptive protections one of the solutions to the dynamic changes of the electric system.

Keywords: Distributed generation, Distributed energy resources, Smart grids, Microgrids, Adaptive protections.

RESUMEN

Las redes electricas estan evolucionando y asumiendo mas retos conforme incrementa la inclusion de energıas renovables y unidades de generacion distribuida, especialmente a niveles de distribucion. La gran tendencia a generar electricidad con fuentes alternas y renovables ha impulsado la formacion de subsistemas de distribucion o micro redes, capaces de suplir su propia demanda electrica y exportar energıa al sistema interconectado de ser necesario. Sin embargo, los efectos de la inclusion de estas unidades de generacion sobre la red electrica y la misma micro red son varios, como distorsion armonica, oscilaciones de tension y sobre todo, sobre las protecciones electricas.

Este artıculo brinda un panorama actual de la implementacion de energıas renovables y generacion distribuida a nivel mundial, ası como una introduccion al concepto de micro redes y sus principales impactos y desafıos en el sistema electrico. Finalmente, se presentan los principales impactos de las micro redes sobre los equipos de proteccion a nivel de distribucion, siendo las protecciones electricas adaptativas una de las soluciones a los cambios dinamicos del sistema electrico.

Palabras clave: Generacion distribuida, Recursos de energıa distribuidos, Redes inteligentes, Micro redes, Protecciones adaptativas.

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Introduction

Nowadays global energy is based on fossil fuels in approximately a 79,5 %, while nuclear energy and renewables contribute with 2,3 % and 18,2 % respectively. Within electricity generation with renewable sources without traditional biomass (10,4 % of the previous 18,2 %), contributions are considerably low, only 3,7 % corresponds to a hydraulic source, while solar, wind and geothermal represent the 1,7 %, biofuels 0,9 % and the remaining 4,1 % represents biomass and geothermal heat. Data estimate at the end of 2016 (Renewable Energy Policy Network for the 21st Century (REN21), 2018).

Figure 1 illustrates the global consumption based in primary energies such as oil and coal between 1965 and 2017, reaffirming the predominance of fossil fuels as the energetic foundation worldwide. The generation of electricity with renewable and alternative sources has increased gradually in the world, for example, from 2 017 GW of the global capacity in 2016 to 2 195 GW in 2017, data that includes hydroelectric

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generation, without this type of source the global increased has been from 922 GW to 1 081 GW (Renewable Energy Policy Network for the 21st Century (REN21), 2018).

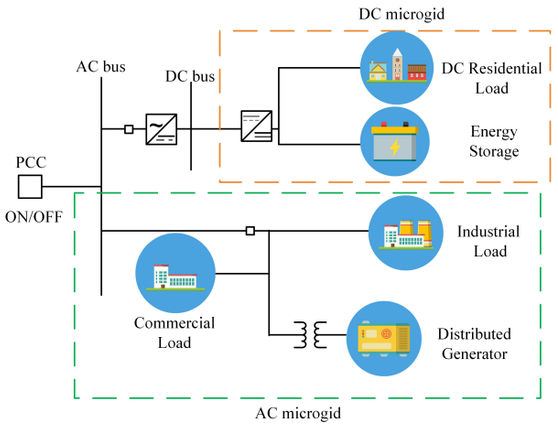

Figure 1. Shares of global primary energy consumption by fuel. Percentage.
Source: (BP, 2018)

Implementation of units based in renewable and alternative energies of low power capacity, and usually connected to a feeder, substation or near to the user, are known as "distributed generation units" (DG's) or "distributed energy resources" (DER's), because they are often distributed along the transmission and distribution system (Gers & Viggiano, 2016; J. P. Nascimento, Brito, & De Souza, 2016; Yang & Wang, 2015). In Colombia, for example, activities as generation of electricity can be done for supplying users own demand or near consumption centers by being connected to the local distribution system or SLD by the Spanish words (Comisión de Regulación de Energía y Gas. CREG, 2018).

The main distributed energy technologies implemented worldwide are: solar photovoltaics (PV), wind energy, small hydroelectric plants, combined heat and power (CHP), solar thermal, gas turbines and diesel generators. Distributed generation units are characterized by having synchronous or asynchronous generators, usually with rated capacities below 50 MW and voltages in the range of 240 V and 34,5 kV; also, DG's can be inverter based generators or IBDG's applied for PV systems, for example (Gers & Viggiano, 2016; Gönen, 2014; Horowitz & Phadke, 2014; Muda & Jena, 2017a; Singh, 2013). A review of characteristics of energy storage systems for microgrids like batteries, supercapacitors, fuel cells, superconducting magnetic energy storage and others are also discussed in (Guacaneme, Velasco, & Trujillo, 2014).

This paper is divided as follows. An introduction to the concept of microgrids and their integration into power systems is presented; the main impacts and challenges of microgrids in distribution systems; impacts of microgrids in electrical protections and finally, and introduction to the adaptive protections concept in microgrids.

Microgrids integration in electrical power systems

According to (Gupta, Varshney, Swathika, & Hemamalini, 2016), the need for an alternative power generation system presents an opportunity for the on-site energy generation, in vicinity to the place of consumption, which aims to administrate and/or control the associated loads and generation in a better way. In this way, the integration of generation units has led to the integration of energy storage units like batteries and control systems, connected to the main grid through a point of common coupling or PCC. This combination of small units or distributed generation, energy storage and control systems at distribution level, form a distribution network subsystem, also known as a microgrid (MG) (L. L. Do Nascimento & Rolim, 2013; Gupta et al., 2016; Khederzadeh, 2012; Tello-maita & Marulanda-guerra, 2017; Tummasit, Premrudeepreechacharn, & Tantichayakorn, 2016).

MG's are low and medium voltage systems in AC, DC or both, single or three-phase, which operates connected to the main grid, usually referred to as a macrogrid; or disconnected from it (island mode). The last mode of operation can be presented due to a system disturbance in the main grid or by a controlled action. The MG is then disconnected through the PCC (see Figure 2) (Monadi, Gavriluta, Luna, Candela, & Rodriguez, 2017),(Hosseini, Abyaneh, Sadeghi, Razavi, & Nasiri, 2016). Under a MG steady state condition and connected to the main grid, both, the main grind and MG supply all the system loads by burden sharing, especially in peak demand (Kroposki et al., 2008), (Che, Khodayar, & Shahidehpour, 2014; Hosseini et al., 2016; Ustun, Ozansoy, & Zayegh, 2012). On the other side, while working on island mode, MG loads are totally supplied by the DG units and energy storage systems until the MG is reconnected to the main network, otherwise, these units must have the power capacity to maintain the generation-demand balance (L. L. Do Nascimento & Rolim, 2013),(Laaksonen, Hannu; Ishchenko, Dmitry; Oudalov, 2014).

Additionally of being a distribution level network of low or medium voltage, MG's have different characteristics and properties according to their main feeders (Hooshyar & Iravani, 2017):

Urban MG's: feeders are located in a populated or concentrated industrial area and generally densely loaded. Imbalance level is very low and the short circuit ratio at the PCC is approximately 25 (ratio of the short circuit capacity by the main grid to the total generation capacity of the MG). As a consequence, during it grid-connected mode, voltage and frequency are dictated by the macrogrid.

Rural MG's: feeders are placed in low populated areas, where laterals are long from the main trunk, thus, have very low load density. MG imbalance can be significant, with high impact on voltage by the DG's.

Off-grid MG's: are located in remote areas with no possibility of connection to the macrogrid and transmission lines due to geographical conditions. This type of MG always operates in island mode. Despite not having a PCC, they are considered a MG because they fulfill the basic requirements mentioned above and other characteristics like such as voltage regulation, voltage flickers and harmonic distortion, also met in common MG's.

At this moment, several MG's have been implemented worldwide in distribution systems, as an example, consider the MG installed in the biggest island of Finland, Hailuoto Island. A pilot medium voltage MG was installed to operate in islanding mode, which includes a portion of 20 kV overhead feeder, with a wind turbine of 0,5 MW and a diesel generator of 1,5 MW (Laaksonen, Hannu; Ishchenko, Dmitry; Oudalov, 2014). In Thailand, a 22 kV distribution feeder supplies electric power to the remote area of Mae-Sariang city, where a MG is located from the main grid in approximately 106 km. Several loads of 1 MW, 0,9 MW and 1,3 MW are supplied by a hydro generator of 1,5 MVA, a solar system of 4 MW, a diesel generator of 7,5 MVA and battery storage of 3 MW (Tummasit et al., 2016). Other case of an implementation of a MG was reported by (Mahat, Chen, Bak-Jensen, & Bak, 2011), where the distribution network is located in Aalborg, Denmark and is formed by three wind turbines of 630 kW, a CHP and three gas turbines.

In a more regional approach, in Latin America an isolated MG, Huatacondo microgrid located in Atacama Desert, Chile. The microgrid consists on a 150 kW diesel generator, 22 kW tracking solar PV systems, a 3 kW wind turbine, a 170 kWh battery and a energy management system, which minimize the operation costs by providing the set-point for the generation units. In (Palma-Behnke, Ortiz, Reyes, Jiménez-Estévez, & Garrido, 2011) a social SCADA approach was proposed to guarantee an optimal energy consumption based on the community requirements. Also in (Bonilla-Gámez, 2017) a microgrid design was proposed in the community of Santa Elena, Costa Rica. Other microgrid projects around the world are summarized and their main characteristics, such as size, type of generation unit, energy storage devices, load and control are provided in (Mina, 2017).

Design methodologies for off-grid microgrids in Colombia, and power systems optimization models considering integration of distributed energy resources are exposed by (Correa-Henao & Rojas-Zerpa, 2017; Garzón-Hidalgo & Saavedra-Montes, 2015; Meneses, 2011; Tello-maita & Marulanda-guerra, 2017)

Several MG's have been modeled through simulation software's, which is a widely used tool for power systems analysis and for the MG itself, due to its integration in distribution networks. As evidenced by (J. P. Nascimento et al., 2016), two DG's were connected to the IEEE 13-node network for a protection analysis by real-time simulation (RTS). Similarly, PSCAD (Power System Computer-Aided Design) was used to simulate transient events in a 20 kV MG with two 1,5 MVA generators at 10 km and 11 km

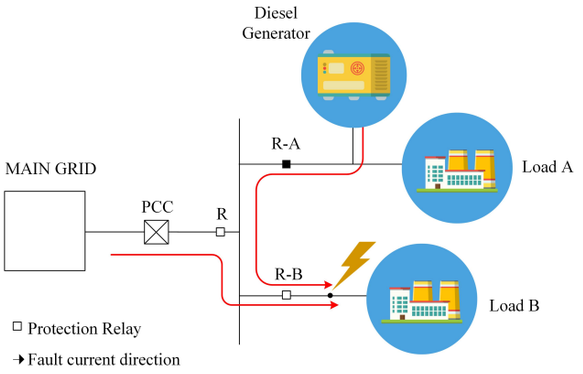

Figure 2. AC/DC microgrid with connected and island mode of operation.
Source: Authors

from the main feeder, DG's converters were simulated as well. A three-phase fault was analyzed in islanded and grid-connected mode of operation, connected to a 110 kV system (S. Voima, Laaksonen, & Kauhaniemi, 2014). Hereon, the term "fault" is going to be refers to a three-phase short circuit fault specifically.

One of the main reasons of studying MG's, besides its great application potential, is to improve its behavior, reliability and reducing impacts for both, the power system and the users. As mentioned before, MG's are formed by generation and storage units, that is why, is important to establish an adequate control system in each element in the MG. In addition, with a trend to growth in DC MG's, there is more implementation of electronic converters or VSC's (Voltage Source Converters) and other power electronic devices, which are one of the main challenges that DG's and MG's have to deal with to become a more reliable and promising distribution network subsystem. Challenges that increase with new technologies and new ways of generating electricity (Hosseini et al., 2016; Monadi et al., 2017).

MG's Impacts and challenges in distribution systems

The traditional concept of a power system and more specifically, a distribution system is conceived to have radial operation with passive nature elements, i.e., a system that is characterized for generating electricity with some high power generators and are the only sources of power in all the network to supply the loads or customers, harnessing and consuming the energy (Ishchenko, Oudalov, & Stoupis, 2012).

In accordance with this perspective, power flow is always unidirectional, from the generation units to feeders and then, the loads (Che et al., 2014). Integration of DG's at the same level as users implies a change of scheme with respect to

the conventional power flow, which becomes bidirectional. Is important to notice that power systems had not been designed to considered generation units along distribution networks (Gupta et al., 2016; Luna & Parra, 2011). As a consequence, technical changes in the network due to the DG's characteristics have been presented, as the dependency of the resource and time variable availability of the energy sources (Gers & Viggiano, 2016). Being reflected in dynamic and intense changes of the grid topology, as a way to satisfy generation-demand balance (Shih & Enriquez, 2014). It is understood by topology as the operational mode of the system (islanded mode or grid-connected mode), with different grid configurations (radial, looped, meshed or a combination) (Hosseini et al., 2016).

The benefits achieved with DG's at a distribution level are many, as technical, economic and environmental, which are not the main focus of this paper. However, reaching optimal conditions to obtain those benefits is a hard task as it strongly depends on the DG reliability, the energy source variability, size and total power capacity of the DG and being at the proper location. Also, some standard control, installation and maintenance conditions have to be met, on the contrary, the minimal operative criterion won't be achieved and the integration of the DG's will impact the electrical system negatively (Barker & De Mello, 2000).

An important aspect is the behavior of the MG in the presence of any disturbance, which depending on their impact, can be reflected in small signal stability, transient or voltage stability in the MG as well. Some of the main reasons of instability or security issues are the occurrence of frequent faults, load/generation variations, load dynamics and insufficient control schemes in the DG's as explained by(Teimourzadeh, Aminifar, & Davarpanah, 2017). If any kind of faults occurred inside the MG or in the main grind are not cleared in a short time, it le that the MG presents frequency or voltage instability and then, a blackout may take place while operating in islanding mode, being unable to supply all the loads present in the MG (Li, Li, & Zhou, 2015). Therefore, microgrid stability must be assessed in the post-contingency period, nonetheless, due to the great complexity of power systems and variety of components, high computational resources are required (Schweickardt, Manuel, & Alvarez, 2013).

Contrary with conventional networks where synchronous generators have a fundamental role and their stability can be studied from the rotor-angle, frequency and voltage point of view, MG's implement a widely number of IBDG's, being the characteristics and dynamics of the MG different with respect to conventional networks. This is why, MG's are not fully compatible with traditional analysis methods, being a case of study nowadays (Shuai et al., 2016). In this way, factors as the load dynamics, low inertia constant in generators, fault frequency and many others are the reasons of security issues in MG's (Teimourzadeh et al., 2017).

According to (Barker & De Mello, 2000; Bhise, Kankale, & Jadhao, 2017; Mozina, 2010), impacts and challenges of DG's and MG's in the electrical system can be reflected in six fundamental topics, as is described as follows:

Voltage regulation

Voltage regulation is made to maintain adequate voltage levels for the users, by using tap changers in power transformers at substations; line regulators and capacitors bank at feeders.

The criterion for voltage regulation is based on radial systems with passive elements, therefore, integration of DG's may affect stability and efficiency of such action by modifying the conventional power flow characteristics mentioned above. Nonetheless, in some cases, DG's may contribute to a continuous voltage regulation by the contribution of reactive power to the grid, improving voltage at its own and neighboring busbars. Also defined as a localized or regional control of voltage output (Arango, Carvajal, & Arango, 2011).

With aims to reduce or to determine the impacts of DG's integration, is important to consider dimensions and location of the generation unit, characteristics of the regulation element and associated transmission line. For example, by not considering the location point of the DG's, if they are located in a system with a common transformer, is possible to have a voltage increased or drop in the secondary-side of the transformer and the regulator device might not be able to detect such event if the DG is located downstream the regulator. Then, electrical devices may be damaged due to modification in the equivalent load seen by the regulator or compensator. To obtain the maximum advantages of DG's, they must be located in the proper sited, to not interfere with the distribution network and to reduce their limitations about power injection (Grisales Noreña, Restrepo Cuestas, & Jaramillo Ramirez, 2017; Lepadat, Helerea, Abagiu, & Mihai, 2017; López-Lezama, Buitrago, & Villada, 2015; Narváez, López-Lezama, & Velilla, 2015).

In (Granja, de Souza, Sobrinho, & Santos, 2018), the behavior and some solutions about power quality at the PCC of a MG are described, such as control strategies for voltage imbalance due to nonlinear and unbalance loads; the use of a series-parallel converter arrange to control the voltage imbalance and current demand caused by a fault in the network, also a closed-loop strategy for power quality are mentioned as well. The authors studied the power quality at the PCC of a low voltage grid located in Colombia with a photovoltaic system at the *Universidad de Ibagué,* analyzing the system efficiency and a methodology for assessment of energy quality was proposed.

Losses

Since is wanted to take the most of DG's, this implies to reduce electrical losses at its minimum. Here the location of generation units plays a fundamental role to achieve this objective, being comparable with shunt capacitors location for reactive compensation. The difference is that DG's have the capacity of injecting both, active and reactive power to the network, in a power factor range between 0,85 and 1,00, leading and lagging if they are inverter-based generators.

Generation units with power capacities near 10 % and 20 % of their feeder total capacity can reduce losses notably if they are at the proper site. Considering that most of the DG's are user-owned units and not from the grid operator, there is no strict control about the DG's installation. Therefore, if feeder limits and capacities are not taken into account, thermal limits of conductors and DG's can be exceeded, increasing the system losses, even though if they are at the right location.

Voltage flicker

Voltage flicker occurs mainly during the generators start-up, fluctuations in output voltage as usually occurs with PV systems and wind energy due to its resource variations, or significant events in DG's that affects voltage at the feeders. Also, voltage flicker and power oscillation can occur due to any disturbance in the generator shaft torque and due to generation units constructive asymmetries and may vary with the variation of the load as well (Armas teyra & Alvinn, 2013).

These flickers can be mitigated by reducing voltage at the generators start-up, a more rigorous and robust synchronization of synchronous machines and implementing power inverters to control inrush currents and soft starter applications, for example.

Harmonic distortion

Harmonics are introduced by DG's, their design type and power electronic devices associated with them as power inverters, which are used to convert DC signals into AC signals at the output.

The main consequences of harmonics into the network are the high distortion levels, capacitors bank resonance and heating of electrical equipment. For these reasons, voltage and currents harmonics control requirements have to be met in accordance with the standards, IEEE 519 for example. As indicated in (IEEE, 2014), the total harmonic distortion levels (THD) allowable for some voltage ranges are defined at the measurement point.

Table 1. Voltage distortion limits - IEEE 519

Bus Voltage at PCC	Individual harmonic (%)	Total harmonic distortion THD (%)
$V \leq 1{,}0$ kV	5,0	8,0
1,0 kV $< V \leq$ 69 kV	3,0	5,0
69 kV $< V \leq$ 161 kV	1,5	2,5
161 kV $< V$	1,0	1,5-2

Source: (IEEE, 2014)

In (Khaledian, Vahidi, & Abedi, 2014) an experimental microgrid is simulated to study the impacts of different harmonics distortions, and a control strategy is tested in order to reduce the THD in the source and other load sides.

Generators and transformers grounding system

Generators must be applied with an associated transformer and a solid grounding arrangement compatible with the electrical system, in order to avoid voltage swells, over voltages and possible damage in electrical equipment and generation units.

Distribution systems usually uses a four-wire-multigrounded-neutral system because this configuration allows to limit the voltage rise on unfaulted phases about to 125 % and 135 % of the prefault conditions for single line to ground faults. On the contrary, while not having a solid grounding system, voltage can increase about to 173 % of its prefault condition on the unfaulted lines for an undefine period of time, and could be dangerous if the DG in island mode of operation continues to serve a group of customers (Barker & De Mello, 2000). Also, a high-resistance grounding system can be implemented for a single DG unit, or a low-resistance system for several units connected in parallel o for auxiliary transformers, nonetheless, this configurations allow high magnitude fault currents (Torres, Marlés, & Caicedo, 2018).

To limit overvoltage's the abovementioned configurations can be applied, also different transformers arrangements or vector groups and finally, the use of the transformer saturation characteristics as described by (Barker & De Mello, 2000) and (Mozina, 2010).

Short circuit level

One of the most notable impacts over the electrical network and electrical devices is the short circuit level variation. Penetration of DG's, independently of their size or the operational mode of the MG, rises the magnitude of the fault current during a contingency.

All generation units contribute to load and short circuit current in the system (Urbina, 2015). In the case of IBDG units, fault current contributions are about 2 p.u and 3 p.u (per unit) of the nominal current, as indicated by (Muda & Jena, 2017b). Meanwhile synchronous and asynchronous generators have more considerable contributions depending on their location, size and number of units (Singh, 2013), (Coffele, Booth, & Dyśko, 2014).

Considering the fact that most MG's are DC types or may have many IBDG's, hence, have dc-link capacitor banks at their PCC or busbars. At the occurrence of a fault, the dc-link capacitor discharges causing a voltage drop at the busbar; immediately, the stored energy in the cable inductance is also discharged by the free-wheel diodes of the power inverters or VSC's, which leads the VSC to operates as an uncontrolled full-bridge rectifier because the main switches of the VSC's turn off to protect them against an overcurrent; then, the fault will be fed from the AC side of the grid. Therefore, there are three main sources for fault current during a fault in a MG besides the contributions from the elements in the AC MG that does not use converters; dc-link capacitors discharge current; cable inductance discharge through the free-wheel diodes; and the AC grid current.

To avoid affecting the VSC's and other equipments from a fault, the AC circuit breakers should operate in faster, at the same time, electrical protection should act at the moment of the dc-link capacitors discharge and then, prevent the voltage drop and fault current flow to the VSC's. Differential and communication-assisted protective methods have been proposed as a fast and reliable solution, because they more sensitive methods than overcurrent and are able to detect faults and to disconnect DG's and DER's at ta proper time (Monadi et al., 2017).

Taking into account the consequences that a fault will lead in a distribution network with an integrated MG, is important to consider the impacts and functions of protective devices at the distribution level in the case of short circuit faults and the possible solutions proposed at this moment, due to the relevance of electrical equipment not only for the power system, but for the customers.

Impacts of MG's in electrical protections

As (Ramos, Bernardon, & Comassetto, 2013) reiterates, distribution networks protective devices must be effective and selective, this is, must isolate the faulted zone in a secure way and interrupting a minimum quantity of customers. All the impacts abovementioned have an impact over the electrical system and protective devices present in the MG, leading to a malfunction of electrical equipments and then, unnecessary losses of generation units and system's security and reliability (Almeida, E. Leite, H. Silva, 2014).

Nowadays, MG's have to cope with the impacts of integration of DG's in an electrical system that have not been designed for electricity generation at distribution or a customer level, that counts with unidirectional protective devices and do not consider a dynamic subsystem. According with several authors, (Almeida, E. Leite, H. Silva, 2014; Che et al., 2014; de las Casas & Boza, 2009; Hosseini et al., 2016; Urbina, 2015) the main challenges that MG's presents in conventional systems are at a protective level, some of them are as follows:

False tripping

At the occurrence of a fault at any point of the system, DG protections may act if current contribution of the unit is high enough, in spite of the faulty zone being located in another neighboring feeder, causing an unnecessary tripping of the unit even of the MG. This is also known as *sympathetic tripping* as illustrated by Figure 3, where the protective relay R-A is tripped by the DG's contribution for a fault occurred near R-B.

Blindness of protection

By connecting a DG or a DER into the network, the equivalent impedance seen from the feeder is increased and then, fault current is reduced. This affects the protective devices as relays with overcurrent characteristics because of their dependency of the system impedance, therefore, are unable to detect the fault for that they have been set for.

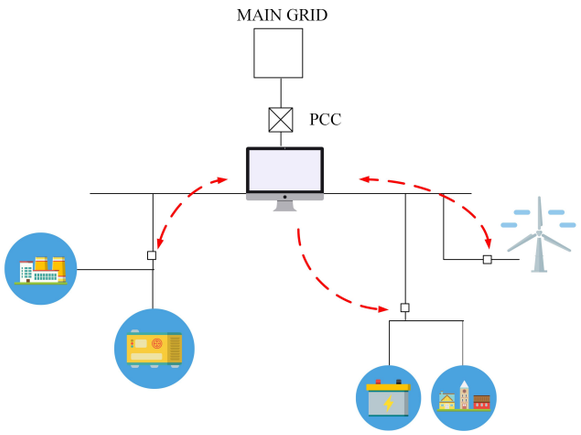

Figure 3. False tripping in a power system with an integrated MG.
Source: Authors

Unsynchronized reclosing

Synchronism of DG's with the grid has to be taken into account by the recloser, otherwise serious damages can be caused, affecting sensitive equipments connected into the grid and the DG as well.

Miscoordination

Most of distribution systems use overcurrent protective devices, such as fuses, in the case the fault current is significantly less than the equipments rated value they might not operate correctly because their filament won't melt and then, the circuit or faulty zone is not going to be isolated, leaving the fault still present in the system as the relays and reclosers won't be able to detect it either (Khederzadeh, 2012).

In addition, relay-fuse coordination is done according with the possible fault paths and in a MG, by including several DG's and different topologies possibilities, fault paths may be many (Piesciorovsky & Schulz, 2017). In case of recloser-fuse coordination, by varying the fault current according with system's topologies, the recloser and fuse may not detect the anomalies presented, even operate improperly (Su, Liu, Chen, & Hu, 2014).

Many possible solutions have been proposed to maintain protective coordination in conventional distribution networks to guarantee system's reliability. Some proposals haven been implementing a fly wheel as an storage system and generation units with high fault current contribution in the MG as a way to increase fault current in islanding mode for the overcurrent devices to be able to detect the fault (Che et al., 2014; L. L. Do Nascimento & Rolim, 2013; Mahat et al., 2011). At the time of changing from grid-connected mode to island mode, the relay protective scheme changes from overcurrent to distance (S. Voima et al., 2014). Implementing differential relays and voltage transformers to detect faults resistance is another alternative, nevertheless,

lots of information have to be transferred between protections devices and data concentrators, also, a complex software is needed (Ehrenberger, 2015). Is proposed by (Bhattarai, Bak-Jensen, Chaudhary, & Pillai, 2015) to disconnect all DG's and DER's once a fault have been detected in the MG to maintain protection coordination settings.

As it has been mentioned earlier, the integrations of DG's modify the system's existing conditions for protective devices. Settings and coordination can be set for a MG in islanding mode of operation, but at the moment it gets connected to the main grid these settings must be replaced for those according with the new operational characteristics of the MG, including the macrogrid and/or the effects of contingencies in the network. A fixed or static group of settings becomes a more complex decision due to the many possibilities or changes that can occur inside the MG.

Protection schemes that can operate in any situation and conditions are then required for both, grid-connected and islanding mode and with any number of DG's, DER's and storage systems during a specific time. In general, any scheme that considers a dynamic behavior without losing protective coordination and reliability. This is possible through more efficient protection devices, such as numerical relays, and more robust communication links, in order to obtain a more accurate response in the equipments present in the MG and implementations economically viable in comparison with the possible losses in a MG without the correct electrical protection. Another possible solution proposed to protect a MG integrated in a distribution network, are those protection schemes that consider the constant changes and variations mentioned above as a feedback, and with this information they adapt to every condition presented in the system.

Adaptive protections

The dynamic behavior is one of the main characteristics or consequences due to the integration of MG's. Then, to operate normally and correctly the MG has to adapt to the variable parameters and the system demands. MG's must have an *administrative system* or *control system* that allows protective devices to act and behave as they should in each branch or section of the distribution system (Sitharthan, Geethanjali, & Karpaga Senthil Pandy, 2016). Hence, these systems will be capable to protect the MG in any of their operational modes (S. Voima et al., 2014).

In this context, a possible solution for the impacts of DG and MG's in electrical distribution networks, considering the attempts to maintain coordination and the protection of the network with conventional schemes, are those protection schemes that modify their settings according with topological and significant changes on the network parameters, the implementation of *adaptive protections* is then suggested.

The concept of the adaptive protection evolved in the 1980's due to the emergence of computer based relays, which allowed to implement several protection functions more easily and to modify their operational characteristics, qualities that were not found in electromechanical and static relays (Alstom Grid, 2011; CIGRÉ. Commitee 34, 1995; S. Voima et al., 2014). In this way, adaptive protections also makes sense under the concept of smart grids, where the grid tends to integrate the users and generators at any scale, in order to provide a more secure, economical, reliable and efficient electricity (Sampo Voima & Kauhaniemi, 2012). Then, adaptive protections can be defined as "a set of functions that allows the adjustment of their parameters according to modifications or new system requirements, making use of communication protocols" (Gómez-Luna, Candelo, Marlés, Guardiola, & de la Cruz, 2017).

Is necessary to detect the current state of the network according to the total number of connected and disconnected DG's to modify the settings of protective devices. Then some calculations have to be done to select the most accurate settings according with the protection function. Communication links are used among the different relays, generation and storage units in the MG and, as mentioned above, an *administrative system* capable to coordinate all the modifications in an efficient and correct manner in the whole distribution system with the MG. Nonetheless, this is not a task that can be achieved with any protection equipment.

The protection equipments, such as relays, must fulfill some basic characteristics, in order to be implemented in an adaptive scheme and to guarantee their correct operation. In accordance with (Khederzadeh, 2012) and (Hosseini et al., 2016), some of these requirements are:

- Being a digital or numerical relay.
- Several setting groups to be modify locally or remotely.
- Have a programmable logic and allow the interaction with the user.
- Self-testing capabilities, oscillography and sequence-of-events recordings.
- Data transfer through communicative protocols and a communicative infrastructure.

Another characteristic of adaptive protections is the way they interact with all the elements present in the network, a MG in this case; and the process in which coordination and interaction takes place, whether they are coordinated under a specialized management center or if the protection is adapted in an independent way according to the parameters it detects on its zone of operation. This protection schemes are identified as a centralized or decentralized structure and their applications is extended to both, AC and DC MG's. A centralized scheme consists on a central unit or management center that stores and analyzes all the information related to the MG. It establishes communication links and monitoring in every element, and sends control and trip signals one the network conditions have been modified (see Figure 4) (Hosseini et al., 2016; Kawano et al., 2010).

On the other hand, the decentralized scheme consists on agents (software and hardware) distributed along the equipments in the MG. These agents communicate to each

other and interact without a central or global unit, transmitting and analyzing data in a more simple and fast way, as illustrated by Figure 5. Even by dividing the electrical network into zones of operation, agents can establish a more accurate control and protection, this is another application of decentralized schemes that allows to locate and isolate faults in a more effective way (Alwala, Feliachi, & Choudhry, 2012; Brahma & Girgis, 2004; McArthur et al., 2007; Moradi, Razini, & Mahdi Hosseinian, 2016).

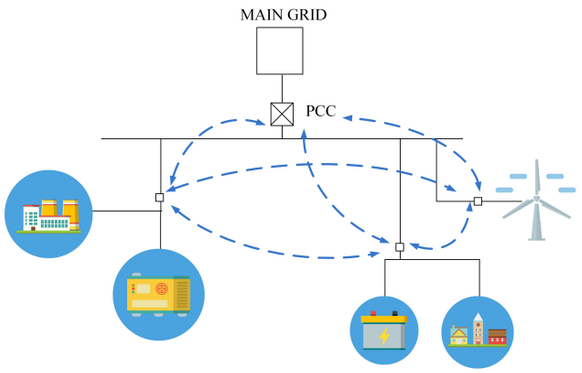

Figure 4. Decentralized adaptive scheme.
Source: Authors

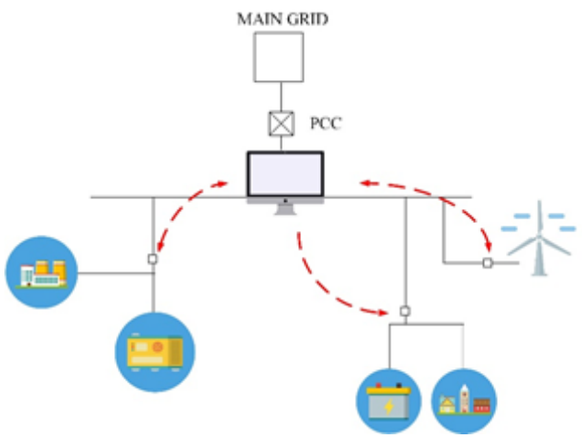

Figure 5. Centralized adaptive scheme.
Source: Authors

Benefits of adaptive protections

As has been mentioned, adaptive protections are an approach to overcome the impacts of the integration of DG's and MG's in electrical distribution networks, and to be able to get more out of the wide advantages they offer to the grid and customers by the integration of substation control and data acquisition with energy management systems. Even though, when modern electrical networks tend to customers and generators interconnection through technology and communication links.

From both protective schemes described in the last section, is necessary to recognize the benefits and advantages they have to offer. The centralized scheme provides a complete and constant monitoring of the MG. Hence, with any change in their characteristics, the central unit will receive signals from any equipment and device and then, evaluate the networks conditions according to the operational state of every unit and if necessary, update their protective settings or control parameters. The central unit will store the new characteristics of the MG in the case that this configuration is presented again in the future. Worth noting that this scheme ensures a adequate protection coordination because no element acts or modify it parameters arbitrarily until they have been validated by the central unit or management center (Azari, Ojaghi, & Mazlumi, 2015; Hosseini et al., 2016).

In general, the decentralized scheme offers the possibility of addressing major problems by dividing it among the different agents present in the MG, where each of those have a specific function and responsibility. Their evaluation process and analysis is limited by the interaction with nearer agents, present in their zones of influence. The protection coordination and control is done only by the information that the others agents can provide. A great advantage of this scheme is the flexibility and modularity of their application, since they allow and easy incorporation and extraction of agents as the MG is extended or modified (Moradi et al., 2016). One of the agents application is the implementation of a protection coordination platform known as *MAS-ProteC* in another platform to simulate future power systems and manage smartgrid markets (Oliveira, Pinto, Morais, & Vale, 2012).

Conclusions

The use of alternative and renewable energy resources might be very advantageous, mainly by the fact of reducing the use of fossil fuel-based energies. However, the inclusion of energy sources or distributed generation units into the electrical system, forming distribution subsystems as microgrids, must be study and analyze carefully. The impacts over the power system must be reduced, in order to obtain the maximum advantage of these resources and to guarantee the quality of electrical service, and security for the wells and customers utilities.

Impacts of distributed generation in microgrids can be very significant since the electrical protection point of view. This is why this paper aimed to contextualize the impacts and challenges of integration of distributed generation over the protective devices, presenting one of the alternatives proposed by several researchers as adaptive protections.

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Optimal vehicle-to-grid strategy for a fleet of EVs considering the batteries aging

Estrategia óptima de vehículo-a-red para vehículos eléctricos considerando el envejecimiento de sus baterías

Semaria Ruiz[1] and Jairo Espinosa[2]

ABSTRACT

The use of electric vehicles for public transportation is a practice that has spread widely in recent years, in response to the needs of reducing global polluting gases emissions and decrease vehicle ownership. However, nowadays some issues need to be addressed to provide this type of services with electric vehicles, such as the low-profit margins that can be achieved by the fleet operators. This paper addresses this issue giving to the public EVs the feature of providing power to the electrical network. Hence, a control system based on optimization is proposed to perform profitable management of the charge and discharge of the EVs that are used to provide public transport services by an operator, which also have the possibility of delivering power to the electrical network. Furthermore, this control system will also take into account the batteries wear cost.

Keywords: Batteries aging, Electric vehicles, Nonlinear optimization, Renewable sources, Vehicle-to-grid.

RESUMEN

El uso de vehıculos electricos para transporte publico es una practica que se ha extendido ampliamente en los ultimos años, en respuesta a las necesidades de reducir las emisiones globales de gases contaminantes y disminuir los vehıculos de uso privado. Sin embargo, hoy en dıa es necesario superar algunos retos para proporcionar este tipo de servicios con vehıculos electricos, como los margenes de baja ganancia que pueden tener los operadores de la flota. Este documento aborda este desafıo, dando al EV publico la funcion de proporcionar energıa a la red electrica. Por lo tanto, se propone un sistema de control basado en la optimizacion para realizar una gestion economicamente rentable de la carga y descarga de los EV que se utilizan para proporcionar servicios de transporte publico por parte de un operador, los cuales tambien tienen la posibilidad de entregar energıa a la red electrica. Ademas, este sistema de control tambien tendra en cuenta el costo de desgaste de las baterıas.

Palabras clave: Envejecimiento de baterıas, Fuentes renovables, Optimizacion no lineal, Vehıculo a red, Vehıculos electricos.

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Introduction

Nowadays a change in the mobility paradigm is emerging regarding the replacement of private usage of fossil-fueled vehicles by more eco-friendly and energy-efficient mobility services, such as the electro-mobility for public transport and the electric car-sharing (Firnkorn and Müller, 2015; Seign, Schüssler, and Bogenberger, 2015). Moreover, the adoption of electric vehicles presents an opportunity to provide energy storage-based ancillary services to the power grid, such as supporting grid frequency stability, contributing to the voltage regulation system, and smoothing intermittency due to renewable energy sources (Kang, Duncan, and Mavris, 2013), which is called vehicle-to-grid operation mode (V2G). However, this operation mode imposes additional challenges, such as the management of bi-directional power flows, and the design and implementation of more complex operation strategies that must achieve the economic sustainability of the service. Therefore, it is necessary to propose decision-making tools that allow the operator to take the best economic and operational decisions for the EVs, such as those presented by previous authors (Alkhafaji, Luk, and Economou, 2017; Rabiee, Sadeghi, Aghaeic, and Heidari, 2016; Wu, Yang, Bao, and Yan, 2013). However, these previous works do not consider the batteries wear due to the adoption of the V2G strategy. The wear of the EVs batteries is a critical aspect, as highlighted by Semanjski and Gautama (2016), to reach the satisfactory commercial feasibility of a transport system that involves electric vehicles. As a result, some studies have focused on the inclusion of batteries wear cost when the EVs are featuring the V2G operation mode. Various authors have addressed this issue (Choi and Kim, 2016; Correa-Florez, Gerossier, Michiorri, and Kariniotakis, 2018; Han,

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Han, and Aki, 2014; Xu, Shi, Kirschen, and Zhang, 2018) using the Achievable Cycle Count function defined by the battery manufacturer, as in Choi and Kim (2016) and Han et al. (2014), or with the Rain-flow algorithm to cycle counting, as in Xu et al. (2018). Authors as Bocca, Chen, Macii, Macii, and Poncino (2018) proposed to use the Arrhenius equation to evaluate the wear of EVs for residential usage and established an optimal charging plan to reduce the charging and wear costs. Nevertheless, all the previous cited studies only calculate the wear of all the EVs aggregated in a set and not individually. The study of Choi and Kim (2016) only considers one EV. These calculations are an approximation, as for a fleet of EVs, each vehicle will have a different wear cost, depending on the routes assignment.

This paper proposes a control strategy for the optimal management of a fleet of EVs that are used to provide public transport services and operate in V2G mode. The proposed control strategy, based on optimization, makes a trade-off between the charging costs of the EVs and the revenues obtained by delivering power to the electric network, considering the battery wear cost of each vehicle in the fleet. The decision variables calculated are the charging and discharging power and the route assignment for each EV. The control strategy is applied to the study case proposed by Ruiz, Arroyo, Acosta, Portilla, and Espinosa (2018).

The contributions of this paper cover two issues. The first one is the individual calculation of batteries wear, i.e. for each EV, which is performed simultaneously with the assignment of routes to the EVs in the fleet, and the estimation of charging/discharging profiles. The second issue is the proposal of an explicit mathematical function for calculating the peaks in the energy of the battery, which allows counting the charging/discharging cycles using the Rain-flow algorithm.

This paper is divided as follows. The *Methodology* section describes the theoretical framework and the optimization approach. The section *Study case* contains the data of the study cases used to compare the wear results and to apply our proposed control strategy. At last, *Results and analysis* contain the obtained results and their interpretation.

Methodology

In this study, we considered that all the electric vehicles are parked at the same place and that they are connected to the same charging station. Additionally, round-trip travels are assumed. Hence, an EV can be charged or discharged at any moment after finishing the travel.

Figure 1 depicts the structure of the proposed control algorithm. The algorithm is composed of a stage of estimation of the required travels and the calculation of the power consumption in them. These procedures are performed by software of traffic microsimulation, entering specific fluxes of passengers at some places (stations of the EVs) in the traffic network. Once the number of passengers that need to be transported to a defined destination point is established, the required departures of the vehicle are calculated. With the calculated route and with a "typical" speed profile, the power consumption of the vehicle is estimated. After the estimation of both variables for a typical day, the estimated data are entered as the input of the control algorithm block.

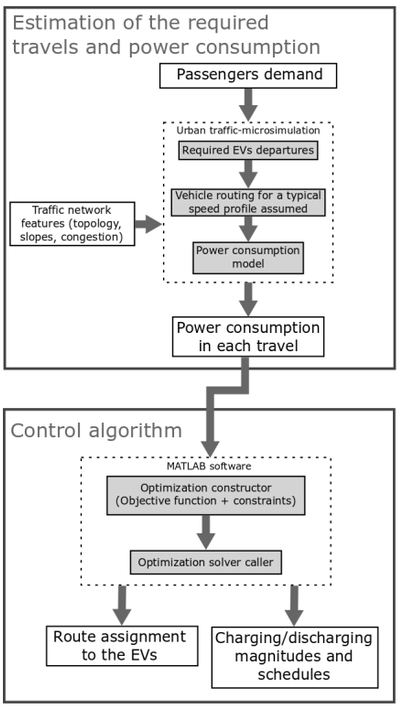

Figure 1. Control strategy scheme
Source: Authors

In the control algorithm block, an optimization is constructed. The aim of this optimization is the reduction of the energy and battery wear costs. The energy cost takes into account the expenses for purchasing energy to charge the EVs and the revenues generated by the delivering power from EVs to the electric network. Furthermore, the constraints include the operational limits of the EVs and guarantee the coverage of the required routes assigning each travel to one of the vehicles in the fleet. The outputs of the optimization are a binary matrix that indicates the vehicle selected to perform each travel and the magnitudes of the charging and discharging powers for each EV and each time step. The mathematical approach used by the constructor of the optimization is described below.

Mathematical approach of the optimization

Objective function and constraints:

First, the decision variables are defined. They are the real-valued matrices $\boldsymbol{P_c} \in \mathbb{R}^{n \times v}$ that represent the charging power for each EV in the set $V = \{1, \ldots, v\}$, where v is the total amount of vehicles in the fleet considering each time step in the set $N = \{1, \ldots, n\}$ and n is the number of steps in the calculation period; and $\boldsymbol{P_d} \in \mathbb{R}^{n \times sv}$ that represents the discharging power for each EV. Additionally, the optimization has other two decision variables with binary values. The first one is the matrix $\boldsymbol{A_v} \in \mathbb{R}^{r \times v}$ whose elements (i, j) have

unitary values if the j-th vehicle performs the i-th travel, which belongs to the set of travels $R = \{1, \ldots, r\}$. Hence, if vehicle number 4 performs the first travel, then $\boldsymbol{A_v}(1,4) = \mathbf{1}$. The second one is the matrix $\boldsymbol{A_c} \in \mathbb{R}^{n \times v}$ that indicates if a vehicle is charging and contains unitary values in the positions corresponding to the time steps at which a vehicle is charging.

The objective function is the minimization of the EVs operative costs, which include the expenses for purchasing energy to charge the EVs and the batteries wear cost. Additionally, the revenues generated by delivering power from EVs to the electric network are included. This objective function is indicated in Equation (1).

$$f = \boldsymbol{E_p} \cdot \sum_{i \in V} \boldsymbol{p_{c(i)}} - \boldsymbol{E_p} \cdot \sum_{i \in V} \boldsymbol{p_{d(i)}} + \sum_{i \in V} w(\boldsymbol{SOC_{(i)}}) \quad (1)$$

where $\boldsymbol{p_{c(i)}}$ and $\boldsymbol{p_{d(i)}}$ are the column vectors of the matrices $\boldsymbol{P_c}$ and $\boldsymbol{P_d}$, respectively; w is the wear cost function, $\boldsymbol{E_p} \in \mathbb{R}^n$ is the electricity price at each time step, and $\boldsymbol{S_{(i)}}$ are the column vectors of the state of charge matrix $\boldsymbol{S} \in \mathbb{R}^{(n+1) \times v}$, which is also called SOC and is calculated using the Equation (2) for the i-th vehicle at the j-th time step.

$$S(j+1,i) = S(j,i) \cdot (1-\sigma) + \frac{(P_c(j,i) - P_d(j,i) - P_r(j,i))\Delta t}{E_M} \quad (2)$$

$\boldsymbol{P_r} \in \mathbb{R}^{n \times v}$ is the matrix that contains the power consumption for the travels performed by each EV at each time step, after each travel is assigned one of the EVs. σ is the self-discharging factor of the batteries and E_M, the maximum energy that can be stored in them.

The matrix $\boldsymbol{P_r}$ depends on the travels assignment. Equation (3) indicates how to calculate this variable.

$$\boldsymbol{P_r} = \boldsymbol{C_t} \cdot \boldsymbol{A_v} \quad (3)$$

$\boldsymbol{C_t} \in \mathbb{R}^{n \times r}$ is the matrix that contains the power consumption in each travel, which is the output of the urban traffic microsimulation,

Furthermore, the optimization constraints, are shown in Equations (4)-(12):

$\boldsymbol{P_r}$, $\boldsymbol{P_c}$, and $\boldsymbol{P_d}$ must be positive real-valued matrices:

$$P_c(j,i) \geq 0, \;\; P_d(j,i) \geq 0, \;\; P_r(j,i) \geq 0 \;\; \forall i \in V \quad (4)$$

The state of charge of the batteries must be kept between the minimum allowed energy content S_m, and 1.

$$S_m \leq S(j,i) \leq 1 \quad (5)$$

The total power consumption in the travels at each time step, must be equal to the total power that the EVs spend during their assigned travels each time step:

$$\sum_{i=1}^{r} C_t(j,i) - \sum_{i=1}^{v} P_r(j,i) \leq 0 \;\; \forall j \in N \quad (6)$$

Travels must be assigned only to one vehicle:

$$\sum_{i=1}^{v} A_v(j,i) = 1 \;\; \forall j \in R \quad (7)$$

The charging power of the EVs must be kept between 0 and its rated value defined by the manufacturer $P_{c,m}$, at the time steps when EVs are charged (indicated by ones in the $\boldsymbol{A_c}$ matrix).

$$P_c(j,i) \leq P_{c,m} A_c(j,i) \;\; \forall j \in N \;\; \forall i \in V \quad (8)$$

The discharging power of the EVs must be kept between 0 and its rated value defined by the manufacturer $P_{c,m}$, at time steps when EVs are discharged, i.e. when they are not performing a travel or charging

$$P_d(j,i) \leq P_{c,M}(1 - A_c(j,i) - U(j,i)) \;\; \forall j \in N \;\; \forall i \in V \quad (9)$$

where $\boldsymbol{U} \in \mathbb{R}^{n \times v}$ is a binary matrix calculated with Equation (10). The rows of $\boldsymbol{U}$ correspond to the time steps and its columns to the ID number for each EV in the fleet. This matrix has ones in the time steps when a vehicle is performing a travel, and 0 otherwise.

$$\boldsymbol{U} = \boldsymbol{A_v A_t^T} \quad (10)$$

Being $\boldsymbol{A_t} \in \mathbb{R}^{n \times r}$ a binary matrix that contains ones at time steps where travel is required, it has as many columns as required travels. This matrix is obtained from the output data of the urban traffic microsimulator and entered as the input of the optimization. Furthermore, the sum of the elements of the binary matrix that indicate the charging status and those that show the running status for a vehicle performing travel must be less than 1, as indicated in Equation (11)

$$U(j,i) + A_c(j,i) \leq 1 \;\; \forall j \in N \;\; \forall i \in V \quad (11)$$

Finally, the power charged or discharged from the EVs in the fleet must be lower than the power capacity of the feeder (P_l) to which the charging station is connected:

$$\sum_{i=1}^{v} P_c(j,i) \leq P_l, \;\; \sum_{i=1}^{v} P_d(j,i) \leq P_l \;\; \forall j \in N \quad (12)$$

Batteries wear modeling:

The function w in Equation (1) is calculated in two ways:

a) The wear is calculated with the methodology presented by Xu et al (2018) using the Rain-flow algorithm.

This algorithm identifies the peak points of the charging/discharging profile. Then, from, these peak data, the half and complete equivalent cycles from the profile are calculated, using the algorithm detailed by Blumenthal (1935), and entered as inputs of the wear function that is described in Equation (13)

$$w = \sum_{i \in V} \sum_{j \in C_i} C_b k_1 \lambda(j,i) (1 - S(j,i))^{k_2} \quad (13)$$

where the constant C_b takes into account the equivalent present value of the replacement costs for a defined *Capital Recovery Factor*, and the constants k_1, k_2 are defined by the battery manufacturer. The variable λ takes a value of 1 for complete cycles, and a value of 0,5 for half cycles.

This study proposes a novel approach to calculate the peak data from the charging/discharging profile in order to compute the Rain-flow algorithm and calculate the sub-gradient of this function for solving the optimization problem with nonlinear methods based on the gradient. The peak data from the charging/discharging profile for the i-th EV and the j-th time step can be extracted using Equation (14)

$$\begin{aligned} \boldsymbol{y_i} &= j \in N / \tanh(S(j+1,i) - 0.5) - \tanh(S(j,i) - 0.5) = 0 \\ \boldsymbol{C_i} &= RF(\boldsymbol{y_i}) \end{aligned} \tag{14}$$

The logic of the Rain-flow (RF) can be implemented using conditional operators, to identify the half and complete cycles from the peak data. The objective function is not differentiable at some points, the cycle junction points. Therefore, the sub-gradient function is defined in Equation (15) based on the approach presented by Xu et al. (2018).

$$\begin{aligned} \frac{\partial f(i,j)}{\partial \boldsymbol{P_c}} &= E_p(j) \\ &\quad + \sum_{i\in V}\sum_{j\in N} k_1 k_2 \cdot \lambda(j,i) \min\left\{(1 - S(j_1,i), (1 - S(j_2,i))\right\}^{k_2-1} \\ \frac{\partial f(i,j)}{\partial \boldsymbol{P_d}} &= -E_p(j) \\ &\quad + \sum_{i\in V}\sum_{j\in N} k_1 k_2 \cdot \lambda(j,i) \min\left\{(1 - S(j_1,i), (1 - S(j_2,i))\right\}^{k_2-1} \end{aligned} \tag{15}$$

where the points j_1 and j_2 are the cycle junction points between the point j.

However, considering a fleet of more than 1 EV, the nonlinear optimization problem described in Equations (1)-(15) becomes a mixed-integer nonlinear problem. Hence, in order to achieve results with a lower complexity and computation time, the wear calculation is reformulated.

b) The wear is calculated with the Achievable Cycle Count (ACC), based on the approaches presented by Choi and Kim (2016) and Han et al. (2014).

The wear can also be calculated using the cycle life curves of the battery, given by the manufacturer. This cycle life is determined by how deeply the battery is used, i.e. by the depth of the discharge ($D = 1 - S$). Hence, a relationship between D and the life cycle must be established. In the literature, this relationship is commonly modeled by a polynomial function as in the studies of Choi and Kim (2016) and Han et al. (2014), where the cycle life N_{cycle} is determined with the polynomial function of Equation (16).

$$N_{cycle} = \frac{a}{D^b} \tag{16}$$

where constants a and b are estimated from the manufacturer data. The wear cost is calculated as Choi and Kim (2016):

$$w = \sum_{i\in V}\sum_{j\in N}\left|\int_{S(j,i)}^{S(j+1,i)} w_d(s)ds\right| \tag{17}$$

$w_d(s)$ is the wear-out density function, which is calculated as Equation (18) shows:

$$w_d(s) = C_b \frac{b\cdot(1-s)^{b-1}}{a} \tag{18}$$

In Equation (18), the constant C_b takes into account the equivalent present value of the replacement costs for a defined Capital Recovery Factor. Hence, the complete expression for the battery wear is given in Equation (19).

$$w = \sum_{i\in V}\sum_{j\in N}\left|C_b \frac{(1 - S(j,i))^b - (1 - S(j+1,i))^b}{a}\right| \tag{19}$$

A linear approximation for polynomial expressions is proposed on the integral calculated in the Equation (19). Thus, the approximated wear is:

$$w = \sum_{i\in V}\sum_{j\in N}\left|C_b \frac{p_1(S(j+1,i) - S(j,i))}{a}\right| \tag{20}$$

where p_1 is the slope of the linear function approximating the polynomial expression of Equation (19).

Once the wear function of Equation (20) is considered, the optimization problem becomes a mixed-integer convex problem, whose solution is presented in the *Results and analysis* section.

Study case

Two study cases are considered. The first one, which is more reduced than second, is used to compare the wear obtained using both proposed approaches. The second study case, which contains the data demand described in Ruiz et al. (2018), is used to apply the proposed control algorithm for a fleet of EVs.

First study case:

The first study case considers one electric vehicle, a Renault Twizy. The travels performed by the EV in the evaluation period are predicted from the behavior of co-housing users described by Semanjski and Gautama (2016). The operating hours of this vehicle are between 5:00 and 16:00. The energy consumption in each travel is calculated with the daily travels, which are generated randomly. The random generation of daily travels uses a normal distribution for the distance of each travel and the number of travels per day, taking into account the next parameters: a daily average traveled distance of 8,4 km, and a daily average of travels performed of 3. Three days were simulated. The parameters considered for the wear function were taken from the study of Correa-Florez et al. (2018) and are presented in Table 1.

Hence, with the energy consumption data already calculated, this study case only requires the execution of the steps indicated in the Control Algorithm block in Figure 1. The optimization, including the wear cost, was solved using Matlab 2015b. Three optimization cases were taken into account: the first case without considering the wear cost, the second case using the Rain-flow algorithm to calculate the wear cost, and the third case that includes the wear cost and uses the ACC function to calculate it. The solutions of the first and third optimization problems were found with the CVX optimization tool and the Gurobi solver, as both

are convex problems. Gurobi uses the Branch and Cut algorithm. The solution of the second case was found using the fmincon function of the MATLAB Optimization Toolbox with the Active-Set optimization algorithm.

Table 1. Features of the electric vehicles

PARAMETER	k	a	b	p_0	p_1
VALUE	540 USD	5 136	1,76	1,02	-0,87

Source: (Correa-Florez et al., 2018)

Second study case:

The study case used to apply the algorithm of Figure 1 includes the traffic network, and the passengers demand described by Ruiz et al. (2018), which presents a study case applicable for the city of Medellín, Colombia. The urban traffic microsimulation to calculate the required travels and power consumption in them was performed using the software SUMO. The electric vehicles considered are BRTs Type 1, as described in Ruiz et al. (2018), whose energy capacity is 324 kWh. The data of the required travels and power consumption in them were taken from Ruiz et al. (2018), taking into account only the travels performed by BRTs Type 1. The electricity price time series and the power limit for the feeder of the charging station were also taken from the aforementioned study.

The parameters considered for the evaluation of the batteries aging are presented in Table 1 with a replacement cost of batteries of USD 5 400. This wear calculation was done only with the ACC approach, using Equation (20). Time steps of 10 minutes were considered, a simulation period of 24 hours, a fleet size of 5 BRTs, and 21 travels required to cover the passenger demand. The software used to compute the optimization was Matlab 2015b with the Gurobi solver.

Results and analysis

Results for the first study case:

Figure 2 illustrates the SOC of the battery without considering the wear, considering the wear and calculating it with the Rain-flow algorithm (RF) and with the Achievable Cycle Count ACC.

The value of the wear is USD 0,04 calculated with the integral of the ACC, and USD 0,07 with the Rain-flow algorithm.

Figure 2 shows the SOC for the wear calculated with the Rain-flow algorithm. The result is more conservative compared with the other cases, because the Rain-flow algorithm performs two approximations. The first approximation evaluates the wear function for the difference of SOC between two points, instead of calculating the difference of the wear function evaluated at two different points, as in the wear density function presented in Equation (19). The second approximation is the cycle account, in which the non-peak data from the SOC profile is neglected, and half cycles are added. In addition, to extend the Rain-flow algorithm for a fleet of EVs, the use of Mixed-Integer Nonlinear optimization methods is required, which have a higher computational complexity than methods based on Mixed-Integer Linear Programming.

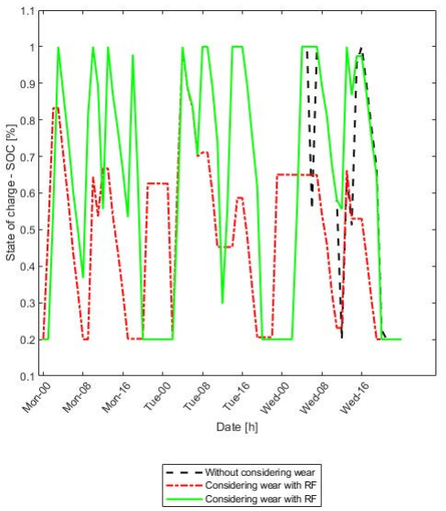

Figure 2. Comparison of the SOC for the different presented approaches for the wear calculation.
Source: Authors

The computing time was 379 seconds for the wear calculated with the Rain-flow algorithm, and 6 seconds using the linear approximation for the integral of the wear density function. Hence, for the second study case, the wear density function is used.

Results for the second study case:

The SOC for the fleet of EVs is illustrated in Figure 3. This Figure shows that the SOC of all the EVs in the fleet increases around the time intervals 2:00 - 5:00, and 16:00 - 18:00. Those intervals correspond to the lowest electricity price hours for non-operating hours, i.e. the vehicles are charged at hours when the electricity is cheaper.

Furthermore, from the results shown, it can be concluded that allowing the V2G mode, the fleet operating costs are reduced by 50 %. The obtained average SOC for the EVs in the fleet is illustrated in Figure 4, without considering the batteries wear cost and considering it.

The average SOC presents a peak reduction considering the wear cost. This smoothing in the SOC impacts on the revenues that can be obtained by delivering power to the electric network, since the charging/discharging power cycles are more constrained and generate an overrun cost of USD 0,59 per day. This overrun cost is compensated with the savings in the batteries wear, which represents 26,03 % of the operating costs. The obtained error compared with the non-approximated wear cost presented in Equation (19) was 20,7 %, which is equivalent to USD 0,01 per day.

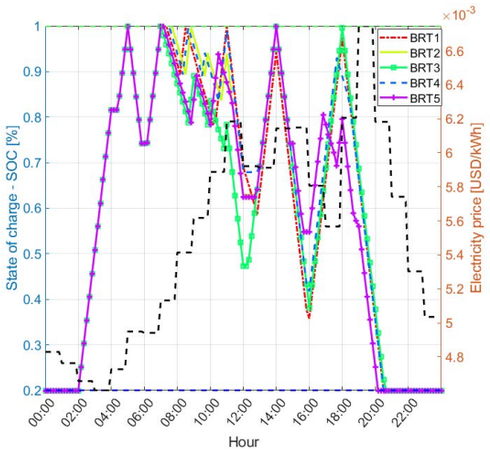

Figure 3. SOC for each EV in the fleet.
Source: Authors

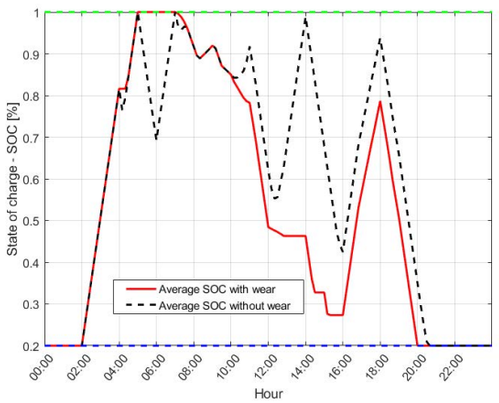

Figure 4. Comparison of the average batteries SOC with and without the inclusion of the wear cost.
Source: Authors

Conclusions

This paper presents a control strategy to manage the charging and discharging power of a fleet of EVs that participate actively with the power network in V2G mode. This control strategy includes the wear of batteries in the operative costs, which are minimized. Two approaches were used for the wear calculation: the Rain-flow algorithm and the integral of the wear density function. Also, the control strategy, considering the integral of the wear density function, was applied to a fleet of EVs for the individual calculation of batteries wear, which is performed simultaneously with the assignment of routes to the EVs in the fleet and the calculation of charging/discharging profiles. Results showed that with the inclusion of the wear cost, the V2G mode is still profitable, but the revenues of the fleet operator are reduced to half approximately. The Rain-flow method delivers more conservative results for the wear estimation since it counts half cycles, but the ACC method allows the linearization of the optimization problem. Hence, a lower computational complexity is required to solve the optimization problem.

Additionally, the proposed control strategy depends on the parameters of the wear function given for the battery. This function must be approximated applying operative tests. Hence, to extend the proposed strategy the validity of the wear parameters must be verified for the batteries of the considered fleet.

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