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FECHA: 30/10/2017

<b>N° PROYECTO :</b> 3150033	<b>DURACIÓN :</b> 3 años	<b>AÑO ETAPA :</b> 2017
<b>TÍTULO PROYECTO :</b> TOWARDS LIGNOCELLULOSIC BIOREFINERY: CONVERSION OF LIGNIN-DERIVED PHENOLICS OVER CARBON NANOFIBER-SUPPORTED REDUCIBLE METAL OXIDE CATALYSTS- EFFECT OF LOADING, PROMOTERS AND EXPERIMENTAL CONDITIONS		
<b>DISCIPLINA PRINCIPAL :</b> INGENIERIA QUIMICA		
<b>GRUPO DE ESTUDIO :</b> INGENIERIA 3		
<b>INVESTIGADOR(A) RESPONSABLE :</b> ISAAC TYRONE GHAMPSON		
<b>DIRECCIÓN :</b>		
<b>COMUNA :</b>		
<b>CIUDAD :</b> Santiago		
<b>REGIÓN :</b> METROPOLITANA		

**FONDO NACIONAL DE DESARROLLO CIENTIFICO Y TECNOLOGICO (FONDECYT)**

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# INFORME FINAL

## PROYECTO FONDECYT POSTDOCTORADO

### OBJETIVOS

Cumplimiento de los Objetivos planteados en la etapa final, o pendientes de cumplir. Recuerde que en esta sección debe referirse a objetivos desarrollados, NO listar actividades desarrolladas.

Nº	OBJETIVOS	CUMPLIMIENTO	FUNDAMENTO
1	Examine the structure sensitivity of phenol hydrodeoxygenation reaction over reducible carbon nanofiber-supported metal oxide catalysts by varying particle size and composition through preparation of catalysts with different loadings.	TOTAL	This objective was accomplished and the results were presented at a scientific congress in Brazil as well as published in ISI journal article.
2	Examine the effect of the nature and contents of metal promoters (Co, Ni, Ru and Re) on the reactivity of the best catalysts.	TOTAL	The results were published together with other results in two ISI articles.
3	Compare the reactivities of o-substituted phenols in order to elucidate the influences of the ortho-substituent on the C-O bond scission of phenol at selected conditions.	TOTAL	The reactivities of substituted phenols and other lignin model compounds (o-cresol, anisole, guaiacol, etc.) were additionally studied and the results were published as part of the study aimed at Objective No 1.
4	Evaluate the reactivity of the best catalysts for the aqueous phase HDO of lignin-derived compounds to validate the effectiveness of the catalyst in a typical bio-oil solvent.	NO	The studies developed in a way where it did not fit the narrative of the project to carry out this objective.
5	Compare the reactivity of the best catalysts for phenol HDO in different solvents to assess the influence of solvent on gas-liquid mass transfer, H <sub>2</sub> solubility, and hence on activity and DDO/HYD selectivity.	NO	During the course of the project, greater emphasis was placed on developing the metal-oxide based catalysts than on studying effects such as reaction solvent.
6	Conduct parametric studies of the best catalysts to examine the effect of temperature, pressure and space velocity on reactivity using model compounds to optimize catalysts performance, obtain plausible reaction sequence and kinetics, and indicate if deactivation occurs under continuous flow conditions.	PARCIAL	The results from this objective was published in an ISI paper, although they were conducted in a batch reactor rather than in a continuous flow set-up.
7	Perform simulation with Aspen to gain information on optimization of experimental conditions (temperature, pressure and space velocity).	NO	There was simply no time to accomplish this objective.

8	Test the best catalyst on a model mixture with similar physical/chemical properties to crude bio-oil to substantiate the prospects of the catalysts for bio-oil upgrading.	NO	There was no time to accomplish this objective.
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Otro(s) aspecto(s) que Ud. considere importante(s) en la evaluación del cumplimiento de objetivos planteados en la propuesta original o en las modificaciones autorizadas por los Consejos.

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## RESULTS OBTAINED:

For each specific goal, describe or summarize the results obtained. Relate each one to work already published and/or manuscripts submitted. In the Annex section include additional information deemed pertinent and relevant to the evaluation process.

**The maximum length for this section is 5 pages. (Arial or Verdana, font size 10).**

**Specific goal No 1:** Examine the structure sensitivity of phenol HDO reaction over reducible  $\text{MoO}_x/\text{CNF}$  and  $\text{VO}_x/\text{CNF}$  catalysts by varying particle size and composition through preparation of catalysts with different loadings.

Results: A series of carbon nanofiber (CNF)-supported molybdenum oxide and vanadium oxide catalysts with loadings ranging 1-7.8 wt.% were synthesized using incipient wetness impregnation and tested for the liquid-phase conversion of phenol at 300 °C and 3 MPa in a batch reactor. The conversion of all the 12 catalysts synthesized was very low, not exceeding 10% after 4 h of reaction. The low activity obtained contrasted with recent literature information on Mo and V oxide catalysts for gas-phase HDO reactions, in which creation of oxygen vacancy sites by partial reduction of the calcined catalysts led to significantly higher reactivity. This indicated that *in situ* reduction of the oxide catalysts, during the course of the reaction under our selected reaction condition, did not occur at a significant degree, leading to low activity. In order to obtain better catalytic performance, we were faced with three primary options: (1) apply severe reaction conditions to initiate partial reduction of Mo and V oxides; (2) conduct *ex-situ* partial reduction prior to activity test; (3) explore more reducible metal oxide catalysts. After consultation with my sponsoring researcher (Prof. Néstor Escalona), we decided to proceed with option No 3 because option No 1 was not viable due to the limitation of the reactor available in the laboratory while option No 2 ran counter to the objective of using unreduced metal oxide catalysts for HDO.

We selected rhenium oxide catalysts in order to align with the goals of the research project which was simultaneously being coordinated by Prof. Néstor Escalona. In addition, to the best of our knowledge, CNF-supported  $\text{ReO}_x$  catalysts were yet to be studied. The results obtained were published in the **Catalysis Science and Technology (Impact Factor: 5.773)** and are summarized below (Reference: *Catal. Sci. Technol.* 6 (2016) 4356-4369: <http://dx.doi.org/10.1039/C5CY01992C>)

The effect of  $\text{ReO}_x$  loading (2–13 wt%) and  $\text{H}_2$  pressure (0–5 MPa) for the hydrodeoxygenation of phenol has been studied for carbon nanofiber-supported  $\text{ReO}_x$  catalysts in a batch reactor at 573 K. Characterization of the supports and catalysts has been obtained from  $\text{N}_2$  physisorption, TPD, FTIR, XRD, potentiometric titration, TPR and XPS measurements, which revealed the presence of a crystalline and surface  $\text{ReO}_x$  phase whose particle size and surface coverage increased with loading. The reactivity of the catalysts was linked to the *in situ* partial reduction of  $\text{ReO}_3$  to form  $\text{Re}^{4+}$  and  $\text{Re}^{6-7+}$  sites, whose presence and relative amounts were determined by post-reaction XPS analysis. The reaction rate increased with  $\text{ReO}_x$  loading up to 10 wt%, attributed to the increase in Re surface coverage; a decrease in reaction rate at higher loading was ascribed to the

formation of aggregates. The study revealed a strong affinity for direct cleavage of the C–O bond to form benzene. The similar relative abundance of the Re species is responsible for the similar trend in product distribution of the catalysts. The dependence of activity and product distribution with respect to H<sub>2</sub> pressure has been related to kinetics and thermodynamics.

**Specific goal No 3:** Compare the reactivities of *o*-substituted phenols in order to elucidate the influences of the *ortho*-substituent on the C–O bond scission of phenol at selected conditions.

Results: The reactivity of the best catalyst (10 wt.% ReO<sub>x</sub>/CNF) was evaluated for the HDO of guaiacol (2-methoxyphenol), anisole (methoxybenzene) and *o*-cresol (2-methylphenol) at 300 °C and 5 MPa H<sub>2</sub> pressure in a batch reactor. The results, which were also published in the previously mentioned paper, further demonstrated the ReO<sub>x</sub> catalyst's ability to selectively cleave the C–O bond in phenolic compounds without C–C bond cleavage, thereby retaining all carbon atoms. This demonstrates that the ReO<sub>x</sub> phase is hydrogen-efficient and carbon-atom economical.

**Specific goal No 2:** Examine the effect of the nature and contents of metal promoters (Co, Ni, Ru and Re) on the reactivity of the best catalysts.

Results: To avoid continuous overlap between my project and that of Prof. Néstor Escalona, we decided to modify the theme and specific objectives to focus mostly on the application of metal oxides for HDO reactions. After investigating metal oxide (ReO<sub>x</sub>) as an active phase using CNF as the support, the logical next step was to study the effect of metal oxide supports. Cobalt was chosen as the active metallic phase to investigate the effect of support due to the very little attention that cobalt has received in the literature for HDO reactions. The work also included the effect of rhenium as a promoter. The results obtained were published in the **Catalysis Science and Technology** (**Impact Factor: 5.773**) and are summarized below (Reference: *Catal. Sci. Technol.* 6 (2016) 7289–7306: <http://dx.doi.org/10.1039/C6CY01038E>):

In this work, the reactivity of supported Co catalysts as a function of the oxide support (alumina, silica-alumina, zirconia and titania) and Re promoter for the hydrodeoxygenation of phenol at 300 °C and 3 MPa H<sub>2</sub> using a batch autoclave reactor was investigated. The catalysts were prepared by wetness impregnation, calcined at 500 °C for 4 h, reduced in H<sub>2</sub> for 3 h, and passivated in 1% O<sub>2</sub>/N<sub>2</sub> for 2.5 h. The catalyst properties were obtained from N<sub>2</sub> physisorption, X-ray Diffraction (XRD), Atomic Absorption Spectroscopy (AAS), Temperature-Programmed Reduction (TPR), Temperature-Programmed Desorption of ammonia (NH<sub>3</sub>-TPD), H<sub>2</sub> chemisorption and X-ray Photoelectron spectroscopy (XPS). Characterization results revealed the presence of Co particles existing as Co metal and CoO whose surface properties were controlled by the surface behavior of the oxide supports. It was found that phenol conversion proceeded via three major pathways which were dictated by the support. The Co/Al<sub>2</sub>O<sub>3</sub> and Co/SiO<sub>2</sub>–Al<sub>2</sub>O<sub>3</sub> catalysts preferred the well-documented sequential ring hydrogenation–dehydration–hydrogenation (or dehydrogenation) route while phenol tautomerization, followed by hydrogenation and dehydration was observed in

the case of the Co/ZrO<sub>2</sub> catalyst. The catalytic activity was governed by a combination of metal sites and acid properties of metal–support interface and decreased in the order: Co/Al<sub>2</sub>O<sub>3</sub> > Co/SiO<sub>2</sub>–Al<sub>2</sub>O<sub>3</sub> > Co/ZrO<sub>2</sub> > Co/TiO<sub>2</sub>. The markedly low activity of the Co/TiO<sub>2</sub> catalyst was attributed to the presence of a thin TiO<sub>x</sub> layer which partially covered the active metal sites due to the strong metal–support interaction effect. The low activity, however, is offset by this catalyst's ability to catalyze the efficient production of benzene directly from phenol. The addition of Re to the supported Co catalysts had a beneficial effect on the activity, attributed to improved reducibility and the presence of additional hydrogenation sites. The strongest effect of Re addition on the activity and selectivity was observed for the TiO<sub>2</sub>-supported catalyst. The results further highlight the importance of the choice of support in HDO reactions.

In line with the modified objectives, in which metal oxide was used as an active phase and support, another critical parameter to study is the application of metal oxide as a partial component with other metallic elements for HDO reactions. To this end, our initial interest in molybdenum oxide and vanadium oxide was revived. Furthermore, based on the previous study on the effect of oxide support, TiO<sub>2</sub> was selected as support due to its selectivity towards aromatic hydrocarbons. The main results of this study were published in **Applied Catalysis B: Environmental (Impact Factor: 9.446)** and are summarized below (Reference: *Appl. Catal., B* 208 (2017) 60-74 <http://dx.doi.org/10.1016/j.apcatb.2017.02.047>):

A series of catalysts consisting of a base-metal (rhenium, gallium, nickel and cobalt) in combination with reducible metal oxide (molybdenum and vanadium oxide) were prepared by successive impregnation, reduced in H<sub>2</sub> at 500 °C and passivated in 1% O<sub>2</sub>/N<sub>2</sub> for 2.5 h. The catalysts were initially screened for the conversion of anisole at 300 °C and 3 MPa H<sub>2</sub> in a batch reactor. The results showed that binary Ni-, Co- and Ga-based catalysts were unable to catalyze aromatic C-O bonds in anisole to produce benzene and toluene, rendering them unsuitable for HDO of phenolic compounds. However, due to its oxophilic nature monometallic Re/TiO<sub>2</sub> catalyst stood out for its unique ability for the production of aromatic hydrocarbons. Therefore, TiO<sub>2</sub>-supported Re-MoO<sub>x</sub> and Re-VO<sub>x</sub> catalysts were prepared with different Re and MoO<sub>x</sub> (or VO<sub>x</sub>) loadings and characterized by nitrogen physisorption, ICP-MS and AAS, XRD, FTIR, H<sub>2</sub>-TPR, NH<sub>3</sub>-TPD, H<sub>2</sub>-TPD, TEM and XPS techniques. The capability of monometallic Re catalyst was enhanced by pairing Re with partially reduced surface MoO<sub>x</sub> (or VO<sub>x</sub>) sites, particularly in equimolar proportions. The catalytic activity, expressed as intrinsic reaction rate, was found to rely on the nature of surface Re, Mo and V species: the activity of Re-MoO<sub>x</sub>/TiO<sub>2</sub> catalysts is dominated by exposed Mo<sup>5+</sup> sites while that of Re-VO<sub>x</sub>/TiO<sub>2</sub> catalysts is controlled by Re<sup>4+</sup> sites. The results also reveal that despite the highest intrinsic activity of Mo<sup>5+</sup> sites, they require the presence of a specific type of active sites such as Re, in appropriate amount, to enable the enhanced benzene/toluene production. The study emphasizes the importance of preparing catalysts that exhibit specific sites needed for desired product formation.

**Specific goal No 4:** Evaluate the reactivity of the best catalysts for the aqueous phase HDO of lignin-derived compounds to validate the effectiveness of the catalyst in a typical bio-oil solvent.

Comments: This goal did not fit with the modified objectives of the project. While the original objective called for continuous study on the viability of CNF-supported Mo and V oxide catalysts for HDO reactions through in-depth investigation of process conditions (e.g. aqueous-phase HDO reaction), the modified objective called for studies of catalytic properties of metal oxides. As a consequence, we did not think it was necessary to pursue this goal within the timeframe of this project.

**Specific goal No 5:** Compare the reactivity of the best catalysts for phenol HDO in different solvents to assess the influence of solvent on gas-liquid mass transfer, H<sub>2</sub> solubility, and hence on activity and DDO/HYD selectivity.

Comments: Similar to our thinking for Specific goal No. 4, this goal did not fit the sequence of investigation planned for the modified objective.

**Specific goal No 6:** Conduct parametric studies of the best catalysts to examine the effect of temperature, pressure and space velocity on reactivity using model compounds to optimize catalysts performance, obtain plausible reaction sequence and kinetics, and indicate if deactivation occurs under continuous flow conditions.

Results: Every catalytic study requires an understanding of the effect of reaction conditions in order to elucidate the reaction sequence and provide additional insights into the behavior of the catalyst. Thus, this goal was performed albeit with the use of batch reactor. The results have been published in **Applied Catalysis A: General (Impact Factor: 4.339)** and are summarized as follows (Ref: Appl. Catal., A 549 (2018) 225-236; <https://doi.org/10.1016/j.apcata.2017.10.009>)

A well-characterized Re-MoO<sub>x</sub>/TiO<sub>2</sub> catalyst was used to investigate the reaction sequence involved during the hydrodeoxygenation of anisole in a batch reactor by varying the initial anisole concentration in the reactant mixture (0.182-0.382 mol L<sup>-1</sup> corresponding to 2.6-5.4 wt.%), the reaction temperature (250-325 °C) and hydrogen pressure (30-60 bar). The effects of these process variables on product selectivity, calculated at 10% anisole conversion, and reaction rate, estimated from the initial slope of anisole conversion vs. time, were discussed. The initial reaction rate was observed to increase to a maximum at anisole concentration of 0.282 mol L<sup>-1</sup> and then decrease at higher concentrations. Mathematical modeling of the proposed reaction network revealed that the decreased activity at higher anisole concentration is related to diminished ability to cleave C-O bonds on phenol and cresols, probably due to increased surface coverage by the reactant on the oxophilic sites on the catalyst which limits access to surface reactive hydrogen for transformation. In regards to the influence of reaction temperature, high temperature favors the formation of cresols at the expense of benzene which was confirmed by the estimated apparent activation energy of the different pathways. On the other hand, the observed strong dependence of benzene/phenol ratio on H<sub>2</sub> pressure is attributed to increased availability of surface reactive hydrogen surface to aid in oxygen removal. Results from this study and the literature indicates that C-O bond breaking is preceded by either protonation of oxygen on anisole or by partial

hydrogenation of the aromatic ring to lower the C-O scission barrier. Analysis of the conversion of intermediate compounds confirmed the reaction sequence and preferences during anisole HDO on Re-MoO<sub>x</sub>/TiO<sub>2</sub> catalyst.

**Specific goal No 7:** Perform simulation with Aspen to gain information on optimization of experimental conditions (temperature, pressure and space velocity).

Comments: This goal was not accomplished due to insufficient time.

**Specific goal No 8:** Test the best catalyst on a model mixture with similar physical/chemical properties to crude bio-oil to substantiate the prospects of the catalysts for bio-oil upgrading.

Comments: This study was initially planned as the final part of the exploration of Mo and V oxide catalyst for HDO reaction. In our study, we found Re-MoO<sub>x</sub>/TiO<sub>2</sub> to have great potential for hydrodeoxygenation reaction of model compounds of bio-oil. However, due to lack of time, real bio-oil feed was not investigated.

**OTHER ACHIEVEMENTS OF THE PROJECT:**

- Research visit(s) to other institution(s).
- Outreach activities related to the project's main topic.
- Any other contribution, not addressed elsewhere, that you consider important.

**The maximum length for this section is 1 page. (Arial or Verdana, font size 10).**

I spent a six-month research stay with the Oyama-Kikuchi laboratory in the Chemical System Engineering Department of The University of Tokyo from 1<sup>st</sup> September 2016 to 5<sup>th</sup> of March 2017. This research group is one of the leading catalysis and membrane groups in the world, and the leader of the group Prof. S. Ted Oyama is recognized worldwide for his outstanding contributions to the field of environmental catalysis. I focused on advanced synthesis of bimetallic catalysts using a novel method which has received very limited attention. In my initial work, I demonstrated the method for a difficult platinum-nickel system, which involved producing nickel nanoparticles in the liquid phase, using NaBH<sub>4</sub> as a reducing agent, and then using the metallic Ni species to reduce Pt ions in their proximity. The synthesis method using NaBH<sub>4</sub> is a substantial departure from previously reported methods and allows for the expansion of the galvanic method to many other bimetallic compositions where one of the elements is difficult to reduce. During my time at The University of Tokyo, I was entrusted with providing guidance to both doctoral and masters students in the research pursuits. I became familiarized with catalyst characterization techniques (X-ray absorption spectroscopy and in situ spectroscopy) not available in Chile. The research I conducted in Tokyo is still ongoing and will likely have an impact in catalysis development research. On my return to Chile, I taught students in our group the synthesis method I learned in Tokyo which will immediately improve the quality of their research and also serve to advance collaboration between Pontificia Universidad Católica de Chile and The University of Tokyo.

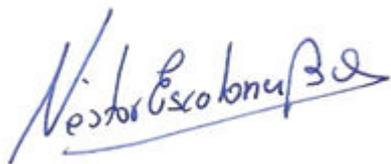
During my postdoctoral fellowship, I collaborated on several research studies with professors at the Faculty of Chemical Science of the Universidad de Concepcion, culminating in four additional journal articles, one book chapter, and three submitted papers. I also edited manuscripts and grant proposals for my collaborating partners.

I have been a reviewer for several respected journals in catalysis (Applied Catalysis B: Environmental and Catalysis Science and Technology), and I also gave well-received presentations at national and international (Brazil and Italy) conferences.

## INFORME DE EVALUACION DEL (DE LA) INVESTIGADOR(A) PATROCINANTE

NOMBRE: Néstor Escalona Burgos \_\_\_\_\_

El señor Isaac Tyrone Ghampson durante el desarrollo de su investigación tuvo que modificar algunos objetivos específicos, sin embargo estas modificaciones fueron conducidas con éxito y pudo obtener resultados muy interesantes. El Dr. Ghampson no solo trabajo en su investigación, si no también colaboró con estudiantes y colegas en sus investigaciones, además participó como profesor de laboratorio en un curso de pregrado. Durante su investigación el Dr. Ghampson realizó una estadía de investigación en la Universidad de Tokio, Japón. Esta estadía no solo ayudo en el desarrollo de su investigación, sino que también abrió una nueva colaboración para nuestro grupo. Como producto de su investigación el Dr. Ghampson pudo publicar varios artículos científico, destacando su publicación en la revista Applied Catalysis B: Environmental, cuyo índice de impacto es 9.446. En resumen el Dr. Ghampson realizó una estadía de investigación postdoctoral exitosa. Personalmente, el Ghampson es un investigador excepcional que potencio nuestro grupo de investigación.



Firma Investigador(a) Patrocinante

Fecha: 25/10/2017 \_\_\_\_\_

# PRODUCTOS

## ARTÍCULOS

Para trabajos en Prensa/ Aceptados/Enviados adjunte copia de carta de aceptación o de recepción.

**N° :** 1  
**Autor (a)(es/as) :** Ghampson, IT.; Sepúlveda, C.; Garcia, R.; Fierro, JLG.; Escalona, N.  
**Nombre Completo de la Revista :** Catalysis Science & Technology  
**Título (Idioma original) :** Carbon nanofiber-supported ReOx catalysts for the hydrodeoxygenation of lignin-derived compounds  
**Indexación :** WoS  
**ISSN :** 2044-4753  
**Año :** 2016  
**Vol. :** 6  
**N° :**  
**Páginas :** 4356-4369  
**Estado de la publicación a la fecha :** Publicada  
**Otras Fuentes de financiamiento, si las hay :**

FONDECYT Regular No:1140528

**Envía documento en papel :** no

**Archivo(s) Asociado(s) al artículo :**

CNF\_supp\_ReOx\_catal\_for\_HDO\_of\_lignin\_derived\_cmpds.pdf

[https://servicios.conicyt.cl/sial/index.php/investigador/f4\\_articulos/descarga/23852389/3150033/2017/100971/1/](https://servicios.conicyt.cl/sial/index.php/investigador/f4_articulos/descarga/23852389/3150033/2017/100971/1/)

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**N° :** 2  
**Autor (a)(es/as) :** Ghampson, IT.; Sepúlveda, C.; Dongil, AB.; Pecchi, G.; Garcia, R.; Fierro, JLG.; Escalona, N.  
**Nombre Completo de la Revista :** Catalysis Science & Technology  
**Título (Idioma original) :** Phenol hydrodeoxygenation: effect of support and Re promoter on the reactivity of Co catalysts  
**Indexación :** WoS  
**ISSN :** 2044-4753  
**Año :** 2016  
**Vol. :** 6  
**N° :**  
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Phenol\_HDO\_\_Co\_catalysts\_\_Effect\_of\_support\_and\_Re\_promoter.pdf

[https://servicios.conicyt.cl/sial/index.php/investigador/f4\\_articulos/descarga/23852389/3150033/2017/100972/1/](https://servicios.conicyt.cl/sial/index.php/investigador/f4_articulos/descarga/23852389/3150033/2017/100972/1/)

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**Nº :** 3  
**Autor (a)(es/as) :** Ghampson, IT.; Pecchi, G.; Fierro, JLG.; Videla, A.; Escalona, N.  
**Nombre Completo de la Revista :** Applied Catalysis B: Environmental  
**Título (Idioma original) :** Catalytic hydrodeoxygenation of anisole over Re-MoOx/TiO2 and Re-VOx/TiO2 catalysts  
**Indexación :** WoS  
**ISSN :** 0926-3373  
**Año :** 2017  
**Vol. :** 208  
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**Páginas :** 60-74  
**Estado de la publicación a la fecha :** Publicada  
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[https://servicios.conicyt.cl/sial/index.php/investigador/f4\\_articulos/descarga/23852389/3150033/2017/100973/1/](https://servicios.conicyt.cl/sial/index.php/investigador/f4_articulos/descarga/23852389/3150033/2017/100973/1/)

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**Nº :** 4  
**Autor (a)(es/as) :** Ghampson, IT.; Canales, R.; Escalona, N.  
**Nombre Completo de la Revista :** Applied Catalysis A: General  
**Título (Idioma original) :** A study of the hydrodeoxygenation of anisole over Re-MoOx/TiO2 catalyst  
**Indexación :** WoS  
**ISSN :**  
**Año :** 2018  
**Vol. :** 549  
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**Nº :** 5  
**Autor (a)(es/as) :** Toledo, F.; Ghampson, IT.; Sepúlveda, C.; García, R.; Fierro, JLG.; Videla, A.; Serpell, R.; Escalona, N.  
**Nombre Completo de la Revista :** Catalysis Science & Technology

**Título (Idioma original) :** Conversion of furfural over supported ReOx catalysts: Effect of support, metal loading and reaction conditions

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**ISSN :**

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## OTRAS PUBLICACIONES / PRODUCTOS

**Nº :** 1

**Autor (a)(es/as) :** Pecchi, G.;Escalona, N.; Ghampson, IT.; Morales, R.

**Título (Idioma original) :** Energy Production, Decontamination, and Hydrogenation Reactions over Perovskite-Type Oxide Catalyst

**Tipo de publicación o producto :** Capítulo de Libro

**ISBN :**

**Editor (es) (Libro o Capitulo de libros) :** Likun Pan; Guang Zhu

**Nombre de la editorial /Organización :**

**País :** CROACIA

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**Vol. :**

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**Archivo(s) Asociado(s) al artículo :**

Energy\_production\_decontamination\_\_BOOK\_CHAPTER.pdf

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## **ANEXOS**

A continuación se detallan los anexos físicos/papel que no se incluyen en el informe en formato PDF.

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