Valorization of Bio-based Alcohols using Catalytic Technology

Angela Justina Kumalaputri

STELLINGEN

Behorende bij het proefschrift

Valorization of Bio-based Chemicals using Catalytic Technology

door Angela Justina Kumalaputri

1. DMF can be obtained by HMF hydrogenation with a Cu-based catalyst at relatively mild conditions (220 °C, 50 bar) in a non-toxic solvent (this thesis, Chapter 2 and 3).
2. The observation by Nan Yao *et al.* that the use of polyethylene glycol (PEG) during nanoparticle synthesis leads to smaller Ni nanoparticles is highly unlikely (Nan Yao *et al.*, J. Mater. Chem. 21 (2011) 17403-17412).
3. The observation by Onwudili et al. that the use of Ru-based catalysts for the gasification of biomass in supercritical water leads to gases enriched in hydrogen instead of methane is highly surprising (J. A. Onwudili *et al.*, Applied Catalysis B: Environmental 132-133 (2013) 70-79).
4. The conclusion by Pei *et al.* that gasification of biomass at lower temperatures favors hydrogen formation instead of methane is highly doubtful (A. Pei *et al.*, Front. Energy Power Eng. China (2009) 456-464).
5. The terms 'selectivity' and 'yield' are often used incorrectly (G. C. A. Luijkx *et al.*, Recueil des Travaux des Pays-Bas 110 (1991) 343-344 and G. C. A. Luijkx, *et al.* , Carbohyd. Res. 242 (1993) 131-139).
6. In contrast to reports by Modell et al., biomass gasification in supercritical water will always lead to solids formation (M. Modell *et al.*, Gasification process, US Patent 4113446, 1978).
7. Peaks in HPLC, GC or NMR spectra are just like major and minor melodies in music. When joined together they become a perfect harmony.
8. "I put my heart and my soul into my work, and I have lost my mind in the process" (Vincent van Gogh).
9. The years to finish a PhD shows a linear relation with the number of lost teeth: number of lost teeth = PhD_{time} +1.
10. "All things work together for the good" (Rome 8:28, KJV version).

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Contents

Chapter 1

Introduction

1.1 Background – Biomass-based vs fossil resources

The global demand for energy has been steadily growing in the last decades. The major drivers for this trend are a growth in global population and higher welfare levels. The main sources for primary energy generation are fossil-based ones, like coal, oil and gas, see Figure 1 for details.

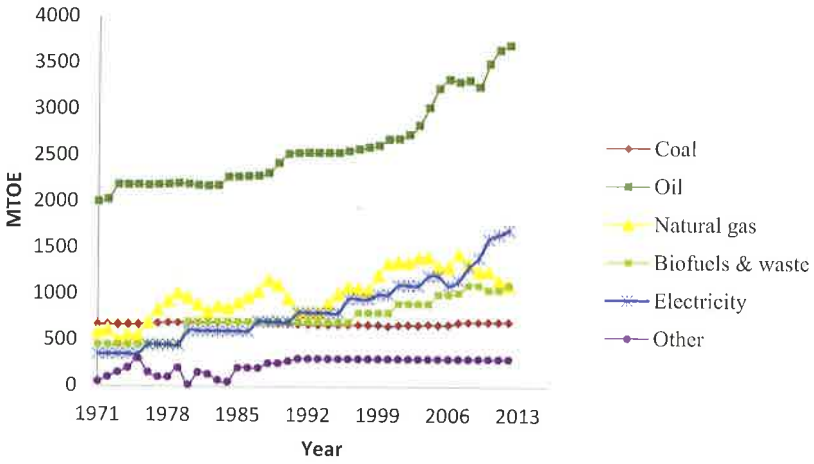

Figure 1. Total energy consumption in the world [1]

Due to the anticipated depletion of fossil resources and concerns about the environment due to CO_2 emissions, there is a huge interest in the generation of renewable energy. Examples of renewable resources are solar, wind, geothermal, hydropower and tidal energy. However, the estimated share of renewables in the total energy slate is still below 20 % (Figure 2). Biomass is expected to play a major role, for instance for heat and power generation and for the production of biofuels. However, besides conventional biomass burning for cooking and heating, the use of biomass in advanced power and heat generation and for biofuels is at the moment still limited. [2]

In the context of bioenergy, biomass refers to organic material from plants and animals. It is abundantly available on earth. About a decade ago, the steady growth in biofuels triggered a discussion whether it was ethical to use food products like wheat, soy, corn and vegetable oils for biofuels generation (food versus fuel debate). As a result, the focus has now shifted to the use of non-food biomass like

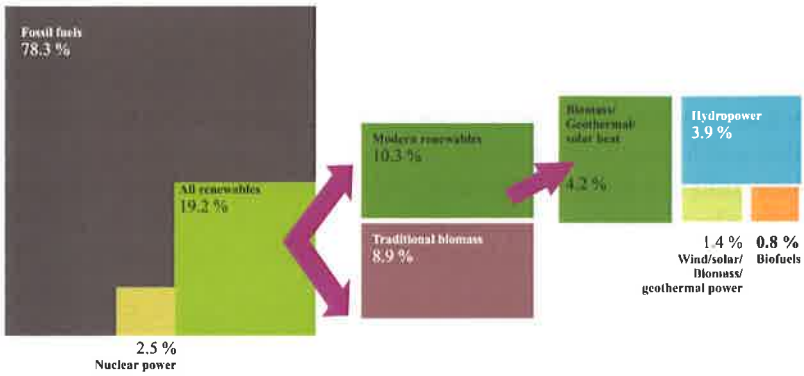

Figure 2. Estimated renewable energy share of global final energy consumption [2]

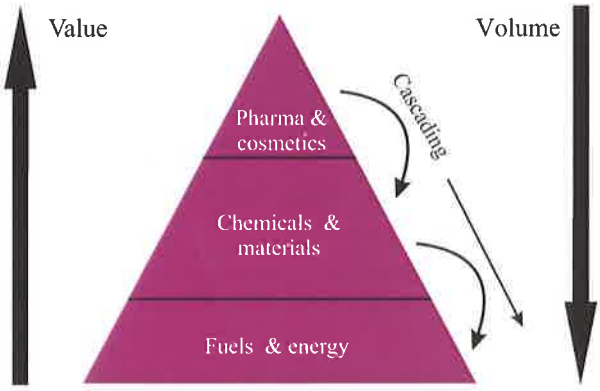

Figure 3. Bio-based product pyramid [6]

agricultural residues, residues from forestry, pulp and paper industry and municipal waste. Examples are second generation biofuels like bioethanol from lignocellulosic biomass and pyrolysis liquids. [3,4,5]

1.1.1 *Biomass for chemicals*

Besides the use for heat and power generation and biofuels production, biomass is expected to play an important role in the future chemical industry and particularly for the production of carbon-based products like many organic polymers (polyethylene, polypropylene and polystyrene). As the available global biomass sources are limited,

particularly when only considering non-food biomass, smart choices need to be made regarding the best possible use of biomass. To select the best option(s), the use of the so called value pyramid is useful (Figure 3). Here, the application sectors are grouped according to price and volume, with high volume-low price applications (heat and power) at the base and high value-low volume applications at the top.[6]

A highly advocated option involves the use of biomass primarily for bio-based chemicals production, rationalised by the fact that other renewable alternatives are not suitable for the production of the current carbon-based chemicals. In this scenario, by-products from bio-based chemicals production are used for energy generation.

When using biomass for bio-based chemicals production, two options may be considered, namely i) the production of existing bulk chemical products derived from fossil resources like olefins (butadiene, ethylene, propylene) and aromatics (benzene, toluene, xylene) and ii) the production of novel chemicals with high derivatization potential. The latter are also known as platform chemicals: biomass derived chemicals with a high application potential that can be produced in high yields. These platform chemicals may be viewed as the biomass-based alternatives for the base chemicals (ethylene, propylene, aromatics) in the petrochemical value chain.[6,7]

1.2 Bio-based platform chemicals

In 2004, the US Department of Energy (DOE) published a top 12 of bio-based platform chemicals, see Figure 4 for details. Initially, more than 300 compounds were selected and evaluated based on selection criteria like estimated costs of the raw materials, ease of processing, selling price, technical complexity, market potential, the possibility for direct replacement and novel properties.[7]

In 2010, an updated version was published, see Figure 5. Compared to the original list in Figure 4, ethanol, furfural, 5-hydroxymethylfurfural, isoprene and lactic acid were added and a number of organic acids (fumaric acid, malic acid, aspartic acid, glucaric acid, glutamic acid and itaconic acid) as well as 3-hydroxybutyrolactone were removed. The list was updated by considering additional criteria, such as the potential for near-term deployment, anticipated (high) market volume and value, market maturity, feedstock flexibility, the potential for integration with hydrocarbon conversion pathways, competition with natural gas-derived petrochemicals and the possibility to

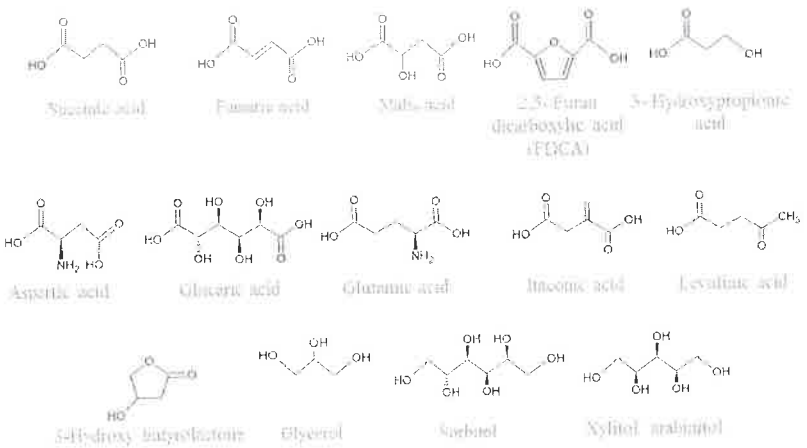

Figure 4. Top 12 sugar-derived building blocks [7]

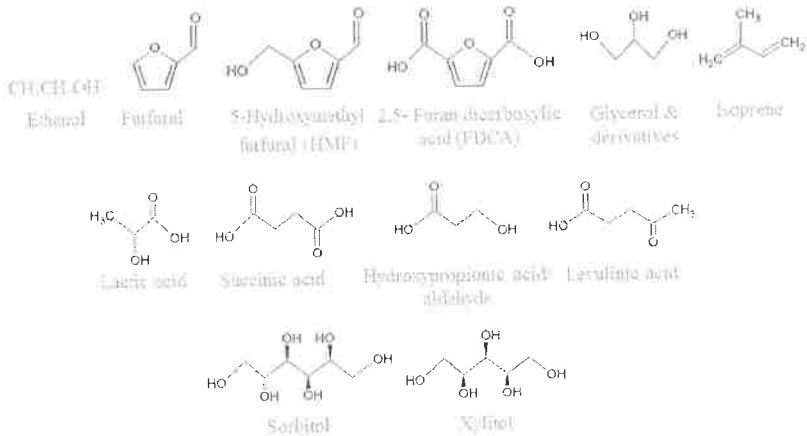

Figure 5. Top 10+4 bio-based chemicals [8]

be synthesized at a lower cost from biomass versus petroleum-based, anticipated growth, market pull and favorable life cycle analysis. [8]

Recently the National Renewable Energy Laboratory (NREL) made an updated version of the top list (see Figure 6). [9] The ranking was modified by considering additional selection criteria like the existence of extensive recent literature, multiple product applicability, possibility for direct substitution, potential market, platform potential and ease for industrial scale-up. [8] Compared to the older versions of the list, a number of the components are existing bulk chemicals derived from fossil resources and manufactured in million tons per

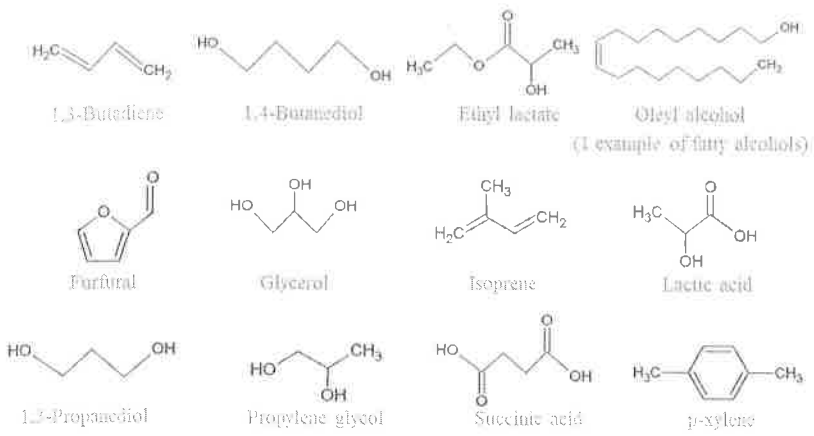

Figure 6. Updated top 12 chemical building blocks from biomass [9]

year. As such, it appears that the drop in approach is getting more attention, at the expense of new chemicals. [9]

1.3 Selected platform chemicals for study in this thesis

In this thesis, experimental studies will be reported on two main platform chemicals from biomass, HMF and glycerol, with the objective to convert them to interesting derivatives using catalytic methodology. In the case of HMF, the emphasis will be on the synthesis of reduced components like FDM, DMF as well as on the formation of BTO and for glycerol it will be on green gas. As such, this introduction will focus on the state-of-the-art regarding these transformations. Literature overviews of the various catalytic systems will be provided, reported and reviewed.

1.3.1 5-Hydroxymethylfurfural (HMF)

Lignocellulosic biomass is a good starting material for the production of C5 (xylose and arabinose) and C6 sugars (fructose, glucose, mannose and galactose). The C6 sugars can be converted into 5-hydroxymethylfurfural (HMF), a versatile furan-type compound. [10] As one of the top 10+4 bio-based chemicals, HMF is an interesting precursor for bulk chemicals to be applied for polymer synthesis, solvents and

Summary

The production of biofuels and biobased chemicals from lignocellulosic biomass is high on the international research agenda. A number of prospective molecules (platform chemicals) have been identified. Of high interest are biobased alcohols such as glycerol, and alcohol/aldehydes such as 5-hydroxymethylfurfural (HMF), which have shown to be very versatile precursors for a wide variety of derivatives. In this thesis, experimental studies are reported on two platform chemicals from biomass, HMF and glycerol, with the objective to convert them to interesting derivatives using catalytic methodology. In the case of 5-hydroxymethylfurfural (HMF), the emphasis will be on the synthesis of reduced components like 2,5-furandimethanol (FDM), 2,5-dimethylfuran (DMF) as well as on the formation of 1,2,4-benzenetriol (BTO). For the glycerol, the efficient conversion to green gas is aimed for. The overall objectives were to improve the product yields by selection and screening of suitable catalysts and to optimize process conditions. In addition, the conversions were preferably carried out using environmentally benign solvents like water and ethanol.

In **Chapter 2**, experimental studies are reported on the conversion of HMF to two important building blocks, *viz.* 2,5-furandimethanol (FDM) and 2,5-dimethylfuran (DMF). Noble-metal-free-catalysts and novel copper doped porous metal oxides (PMOs) with a very low ruthenium loading were prepared, characterized and tested in a batch reactor set-up. Process conditions like temperature (80–220 °C), and reaction time (1–18 h) and type of solvent (methanol, ethanol, isopropanol, and methyl isobutyl carbinol (MIBC)) were explored to maximize HMF conversion and FDM or DMF yield. A reaction network is proposed based on identification of intermediate products, such as 2,5-dimethyl-tetrahydrofuran (DMTHF), 2,5-tetrahydrofuran dimethanol (THFDM), 5-methyl-2-furanmethanol (MFM), 5-methylfurfural (MF), 5-methyl-2-tetrahydrofuranmethanol (THMFM), 1,2-hexanediol (1,2-HD), 1,2,6-hexanetriol (1,2,6-HT) and 2-(ethoxymethyl)-5-methylfuran (EMMF). Catalyst recycling experiments were performed to determine the stability of the catalysts. It was shown that catalyst activity is slowly reduced after multiple recycles. Catalyst activity was regained after a recalcination step. Further investigations on catalyst stability were performed in a flow set-up, and these confirmed the batch recycle experiments.

In **Chapter 3,** experimental studies on the hydro(deoxy)genation of HMF to DMF using a number of commercial copper-containing nanopowders with different elemental compositions are described. The

catalysts were characterized by elemental analysis and XRD and these revealed that the CuZn nanoalloys contain predominantly β-CuZn and CuO phases. Ethanol was used as the solvent and the reactions were carried out at a temperature of 220 °C using 30 bar H_2 pressure for 6 h. A catalyst screening study showed that CuZn was the best catalyst, with 95 % yield of FDM at >99 % conversion. This catalyst was used for further optimization studies by investigating a range of process conditions such as H_2 pressure and the type of solvent (isopropanol, MIBC, 2-methyltetrahydrofuran and cyclopentyl-methyl-ether (CPME)). Recycling experiments for DMF synthesis showed that catalyst stability is good. Transmission electron microscopy (TEM) measurements gave more insight into morphological changes of this intriguing class of materials during catalysis. The one-pot conversion of fructose to valuable furan-ethers was also explored.

When using the CuZn catalyst in combination with Amberlyst 15, full fructose conversion was obtained and 7 % of FDM was formed.

In **Chapter 4,** experimental studies on the synthesis of 1,2,4-benzenetriol (BTO), a 'forgotten' biobased aromatic chemical, from HMF using Lewis and Brønsted acid catalysts in a batch set-up with water as the solvent are reported. Screening studies using a range of Lewis acid catalysts (300 °C, >120 bar, 1.2 mM catalyst) were performed. In particular, catalysts with a high pKh and low Brønsted acidity such as $ZnCl_2$, $Zn(OTf)_2$, $Fe(OTf)_2$ and $MgCl_2$ appeared suitable catalysts, showing a significant BTO yield improvement compared to the uncatalysed reaction (15 mol % BTO). Best results were obtained using $ZnCl_2$ giving a BTO yield of 54 % at 89 % HMF conversion. When Brønsted acid catalysts are used, HMF is converted into humins, levulinic acid and formic acid instead of BTO. BTO was shown to be slowly converted into a 5,5' C-C bonded homodimer (2,2',4,4',5,5'-hexahydroxybiphenyl) at ambient conditions in air. The molecular structure was confirmed by X-ray diffraction. Catalytic hydrodeoxygenation of BTO towards cyclohexanone in water was achieved in yields up to 45 % using 5 wt % Pd on Al_2O_3 combined with $AlCl_3$ or $Al(OTf)_3$ as catalysts. This demonstrated catalytic hydrodeoxygenation of BTO to cyclohexanone comprises a new route towards biobased nylons.

A catalyst screening study on the methanation of glycerol in supercritical water is reported in **Chapter 5.** A number of mono-and bimetallic Ru and Ni catalysts were prepared on various supports such as TiO_2, SiO_2, ZrO_2, CeO_2, Al_2O_3, C and C nanotubes. The reactions were carried out in a batch reactor set-up using 10 wt % of glycerol in water, pressures between 200 and 300 bar at 400 °C for 20 minutes.

Selectivity to gas phase components proved to be a strong function of the catalyst used, with the Ru catalysts giving mainly methane whereas the Ni catalysts mainly produced hydrogen. Intermediate performance was observed for the bimetallic Ru-Ni catalysts. The best results when aiming for methane were obtained using the monometallic Ru/TiO_2 catalyst (2 wt %), which gave a methane yield of 1.43 mol/mol glycerol at essential quantitative glycerol conversion. The gas phase in this case consisted of 40 mol % of methane, which is 4 % below the calculated equilibrium value. Stability of this catalyst was investigated by performing several recycle experiments, showing a significant reduction in catalytic activity after 5 runs. Regeneration of the catalyst proved possible by an oxidative treatment. Catalyst characterization studies on fresh and spent catalyst revealed that coke formation on the catalyst is the major source for deactivation, in line with the recycle/regeneration studies.

Samenvatting

De productie van biobrandstoffen en biobased chemicaliën uit lignocellulose biomassa staat hoog op de internationale onderzoeksagenda. Er zijn een aantal potentiële moleculen (platformchemicaliën) geïdentificeerd. Van groot belang zijn biobased alcoholen zoals glycerol en gecombineerde alcohol/ aldehyden zoals 5-hydroxymethylfurfural (HMF), die zeer veelzijdige start materialen voor een grote verscheidenheid aan derivaten zijn. In dit proefschrift worden experimentele studies gerapporteerd over twee platformchemicaliën uit biomassa, te weten HMF en glycerol, met als doel ze om te zetten in interessante derivaten met behulp van katalytische methodologie. In het geval van 5-hydroxymethylfurfural (HMF) de nadruk op de synthese van gereduceerde componenten zoals 2,5-furandimethanol (FDM), 2,5-dimethylfuran (DMF) en op de vorming van 1,2,4-benzeentriol (BTO). Voor glycerol is gekeken naar de efficiënte omzetting naar groen gas. De algemene doelstellingen waren het verbeteren van de productopbrengsten door selectie en screening van geschikte katalysatoren en om de procesomstandigheden te optimaliseren. Daarnaast werden de omzettingen bij voorkeur uitgevoerd in milieuvriendelijke oplosmiddelen zoals water en ethanol.

In hoofdstuk 2 worden experimentele studies beschreven naar de omzetting van HMF to twee belangrijke bouwstenen, namelijk. 2,5-furandimethanol (FDM) en 2,5-dimethylfuran (DMF). Edelmetaalvrije metaal katalysatoren en nieuwe koper gebaseerde poreuze metaaloxiden (PMO's) met een zeer lage rutheniumbelading werden bereid, gekarakteriseerd en getest in een batch reactoropstelling. Procesomstandigheden zoals temperatuur (80–220 °C) en reactietijd (1–18 uur) en type oplosmiddel (methanol, ethanol, isopropanol en methylisobutylcarbinol (MIBC) werden onderzocht om de HMF omzetting en de FDM of DMF opbrengsten te maximaliseren. Daarnaast is een reactie netwerk op gesteld op basis van identificatie van intermediaire producten, zoals 2,5-dimethyl tetrahydrofuran (DMTHF), 2,5-tetrahydrofuran dimethanol (THFDM), 5-methyl-2-furan methanol (MFM), 5-methylfurfural MF), 5-methyl-2-tetrahydrofuranmethanol (THMFM), 1,2-hexaandiol (1,2-HD), 1,2,6-hexaantriol (1,2,6-HT) en 2-(ethoxymethyl) 5-methylfuran (EMMF). Katalysator recycling experimenten werden uitgevoerd om de stabiliteit van de katalysatoren te bepalen. Er werd aangetoond dat de katalysator activiteit langzaam verminderd na een aantal recylces. De katalysator kon worden gereactiveerd met een calcinerings stap. Verdere onderzoek naar

katalysator stabiliteit werd uitgevoerd in een continue opstelling, en deze bevestigden de batch recycle experimenten.

In hoofdstuk 3 worden experimentele studies naar de hydro-(deoxy)genering van HMF naar DMF met behulp van een aantal commerciële koperhoudende nanopoedermiddelen met verschillende elementaire samenstellingen beschreven. De katalysatoren werden gekarakteriseerd met element analyse en XRD en tonen aan dat de CuZn nanoalloy overwegend β-CuZn en CuO fases bevat. Ethanol werd gebruikt als het oplosmiddel en de reacties werden uitgevoerd bij een temperatuur van 220 °C onder gebruikmaking van 30 bar H_2 druk gedurende 6 uur. Een katalysator screenings studie toonde aan dat CuZn de beste katalysator is , met 95 % opbrengst aan FDM bij >99 % HMF conversie. Deze katalysator werd gebruikt voor verdere optimalisatie studies waarbij procesomstandigheden zoals H_2 druk en het type oplosmiddel (isopropanol, MIBC, 2-methyltetrahydrofuran en cyclopentylmethylether (CPME) bestuurd zijn. Recycling experimenten voor DMF synthese toonden aan dat de katalysator stabiliteit goed is. Transmissie elektronenmicroscopie (TEM) metingen leverden meer inzicht in morfologische veranderingen tijdens de katalyse. De één-pot conversie van fructose naar waardevolle furanethers werd ook onderzocht. Bij gebruik van de CuZn-katalysator in combinatie bij Amberlyst 15 werd een volledige fructose conversie verkregen en 7 % FDM gevormd.

In hoofdstuk 4 wordt een experimentele studie beschreven naar de synthese van 1,2,4 benzeentriol (BTO), een 'vergeten' biobased aromatische verbinding, uit HMF met Lewis- en Brønsted-zur, katalysatoren in een batch opstelling met water als oplosmiddel. Screening studies met een reeks Lewis-zure katalysatoren (300 °C, >120 bar, 1,2 mM katalysator) werden uitgevoerd. In het bijzonder bleken katalysatoren met een hoge pKh en lage Brønsted-zuurgraad zoals $ZnCl_2$, $Zn(OTf)_2$, $MgCl_2$ geschikte katalysatoren, die een significante BTO opbrengst verbetering vertonen in vergelijking met de niet-gekatalyseerde reactie (15 mol % BTO). De beste resultaten werden verkregen met behulp van $ZnCl_2$ met een BTO-opbrengst van 54 % bij 89 % HMF omzetting. Waneer Brønsted-zure katalysatoren worden gebruikt, wordt HMF omgezet in humines, levulinezuur en mierenzuur in plaats van BTO. BTO wordt langzaam omgezet in een 5,5 'C-C gebonden homodimeer (2,2', 4,4 ', 5,5'-hexahydroxybifenyl) bij kamer temperatuur in lucht. De moleculaire structuur werd bevestigd met röntgendiffractie. De katalytische hydrodeoxygenering van BTO met 5 gew. % Pd op Al_2O_3 gecombineerd met $AlCl_3$ of $Al(OTf)_3$ in water gaf cyclohexanon

in opbrengsten tot 45 %. Cyclohexanon is met bestaande technologie om te zetten in caprolactam, een bouwsteen voor nylon kunststoffen. Deze route dus een mogelijke interesant groen alternatief voor bio-based nylons.

In **hoofdstuk 5** wordt een katalysator screenings studie beschreven naar de methanering van glycerol in superkritisch water. Een aantal mono- en bimetallischee, Ru en Ni katalysatoren op verschillende dragers zoals TiO_2, SiO_2, ZrO_2, CeO_2, Al_2O_3, C en C nanotubes zijn gesynthetiseerd en gekarakteriseerd. Met deze katalyzatoren zijn reacties uitgevoerd in een batch reactor opstelling met 10 gew. % glycerol in water, drukken tussen 200 en 300 bar, 400 °C gedurende 20 minuten. Selectiviteit voor gasfase componenten bleek een sterke functie te zijn van de gebruikte katalysator, waarbij de Ru katalysatoren voornamelijk methaan en de Ni katalysatoren voornamelijk waterstof gaven. Intermediaire gas samenstellingen werden waargenomen voor de bimetallische Ru-Ni katalysatoren. De beste resultaten voor methaan werden gevonden met de monometallische Ru/TiO_2 katalysator (2 gew. %), met een methaanopbrengst van 1.43 mol/mol glycerol bij volledige glycerol conversie. De gasfase in dit geval bestond uit 40 mol % methaan, wat 4 % lager is dan de berekende evenwichtswaarde. Stabiliteit van deze katalysator werd onderzocht door het uitvoeren van recycle-experimenten. Er werd een significante vermindering van de katalytische activiteit waargenomen na 5 recycles. Regeneratie van de katalysator bleek mogelijk door middel van een oxidatieve behandeling bij verhoogde temperatuur. Katalysator karakterisering studies laten zien dat coke vorming op de katalysator de belangrijkste bron voor deactivering is, in lijn met de recycle/regeneratie studies.

Acknowledgements

14 years ago, in the second year of my Bachelor degree program, I was dispirited. I realized that Chemical Engineering was far from my childhood dream to become a (medical) doctor. The same experience happened again during the last year of my Master degree program. Surprisingly, exactly the same feeling came again during the first 2 years of my PhD period, since my dream to go to Europe was to be a musician. But, I believe that everything that happens is not a coincidence, eventhough may start by mistake. It happens for a reason, so I need to be responsible to finish it with a victory. Without abundant love and support from people surrounding me, I could not have finalized my PhD thesis. I would like to sincerely express my deepest gratitude to them.

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Dr. Angela Justina Kumalaputri

List of Publications

1. A. J. Kumalaputri, G. Bottari, P. M. Erne, H. J. Heeres and K. Barta, Tunable and Selective Conversion of 5-HMF to 2,5-Furandimethanol and 2,5-Dimethylfuran over Copper-Doped Porous Metal Oxides, ChemSusChem 7 (2014) 2266 – 2275.
2. G. Bottari, A. J. Kumalaputri, K. K. Krawczyk, B. L. Feringa, H. J. Heeres and K. Barta, Copper-zinc alloy nanopowder: A robust precious-metal-free catalyst for the conversion of 5-hydroxymethylfurfural, ChemSusChem 2015, 8, 1323 – 1327
3. A. J. Kumalaputri, H. J. Heeres, Green gas by gasification of wet biomass in supercritical water, Asian Pacific Confederation of Chemical Engineering (APCChE) Conference, Melbourne, Australia, 2015 (Oral presentation).
4. A. J. Kumalaputri, V. Hornillos, L. Carnaúba, K. Krawczyk, A. Kloekhorst, B. L. Feringa, H. J. Heeres, Green gas reforming by wet biomass supercritical water, 2nd International Conference on Renewable Energy Gas Technology (REGATEC), Barcelona, Spain, 2015 (Poster presentation).
5. A. J. Kumalaputri, V. Hornillos, L. Carnaúba, K. Krawczyk, A. Kloekhorst, B. L. Feringa, H. J. Heeres, Green gas reforming by wet biomass supercritical water, Energy Delta Gas Research (EDGAR) Closing Project Conference, Amsterdam, The Netherlands, 2015 (Poster presentation).
6. A. J. Kumalaputri, G. Bottari, K. Barta, H. J. Heeres, From biomass to biobased products: Catalytic hydrogenation studies on the 5-hydroxymethylfurfural platform using supported Cu catalysts, NPS 14 (Netherlands Process Technology Symposium), Utrecht, The Netherlands, 2014 (Oral presentation)

Valorization of Bio-based Alcohols using Catalytic Technology

The foreseen shortages and environmental issues associated with fossil-based resources has stimulated research and development activities on the use of renewables for energy, transportation fuels and chemicals. One of the most prospective candidates is biomass which is abundantly available and cheap. A number of prospective biofuels and bio-based chemicals from biomass has been identified. In this PhD thesis, the use of bio-based alcohols like 5-hydroxymethylfurfural (HMF) and glycerol for the synthesis of green gas (glycerol) and starting materials for plastic (HMF) is described. Novel catalytic protocols have been developed and process conditions have been optimized to obtain the desired product in high yields.

Angela Justina Kumalaputri was born on February 6th, 1985 in Cirebon, Indonesia. She moved to Bandung for pursuing her Bachelor degree (2002-2006) in Chemical Engineering at Parahyangan Catholic University (UNPAR) where she also worked as a laboratory assistant. She started to work as a temporary lecturer in 2007 and pursued her Master degree in Chemical Engineering (minor: Food Engineering) at the same university in 2009. She graduated her Master study with a predicate of summa cum laude on August 2011 and was appointed as a non-full time-permanent lecturer at UNPAR. On June 2012, she was elected as one of the DIKTI (Indonesian Directorate General of Higher Education) scholarship awardee to pursue her doctoral degree. She moved to Groningen and started her PhD project on September 1st, 2012. She joined the Chemical Reaction Engineering Department in Rijksuniversiteit Groningen (RUG) under the supervision of Prof. H. J. Heeres and Prof. K. Barta & Dr. P. J. Deuss as co-promotor. A part of her research was related to AGATE (Advanced Green Gas Technology) project from EDGAR (Energy Delta Gas Research) research program. She was officially appointed as a full time-permanent lecturer at UNPAR since May 1st, 2017.

Angela's life cannot be separated from art. She is a musician, to be exact an organist and was a violinist. She used to sing as a soprano in several choirs. Angela enjoys taking photographs, especially landscape and macro photography. Related with her hobies, during her PhD she found out a new hobby, travelling. She has been traveled to 42 countries and still counting. She also has a lot of interest in food art (including cooking and baking) and graphic design.

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