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Hydrocracking of waste chicken fat as a cost effective feedstock for renewable fuel production: A kinetic study

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Abstract In this study, low cost waste chicken fat (WCF) feedstock was used for fuel-like hydrocarbon production. The effects of varying reaction parameters on the hydrocracking of waste chicken fat using NiW/SiO_2–Al_2O_3 catalyst were investigated. The reactions were carried out in a fixed bed down flow reactor at reaction temperatures of 400–450 °C, liquid hourly space velocity (LHSV) of 1, 2, 4 h^{-1}, H_2/oil molar ratio of 450 v/v and hydrogen pressures of 6.0 MPa. The effects on hydrocracking conversion and distribution of products were investigated. The liquid product was analyzed using gas chromatography (GC) to quantify *n*-alkanes. Hydrocracking conversion and organic liquid products (OLPs) were evaluated by ASTM D-2887 distillation. The results showed that the catalytic hydrocracking of WCF generates fuels that have chemical and physical properties comparable to those specified for petroleum-based fuels. The amount of kerosene/diesel fractional product decreased with an increase in the temperature and a decrease in the LHSV; while gasoline like petroleum fuel increased. A considerable elimination of O_2 from chicken waste fat molecules has been indicated by FTIR analysis. The oxygen removal pathway of WCF over NiW/SiO_2–Al_2O_3 catalyst is primarily carried out by hydro-deoxygenation. The reaction was found to follow the second order mechanism, and the estimated activation energy E_a was 96 kJ mol^{-1}. The exploited catalyst was employed in another run where the results showed the catalyst stability and can be used for several times.
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1. Introduction

Demands for energy are increasing and fossil fuels are limited. Research is directed toward alternative renewable fuels [1–3]. High petroleum prices and the scarcity of known petroleum reserves demand the study of other sources of energy. In this

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context, agro-industrial wastes (animal and chicken fats, wood, manure ...etc.) play an important role as energetic materials. Vegetable oils and fats are basically triglycerides of long-chain fatty acids. The triglycerides have high viscosity which prevents them from being used as fuel in common diesel engines. Therefore, the high viscosity is reduced by the conversion into monoester through the catalytic transesterification reaction for biodiesel production or hydrocarbons are converted by catalytic hydroprocessing for renewable fuel production [4–7].

The feedstock issue is the critical point affecting the economic feasibility of biofuel production as it accounts around 80% of the biofuel total cost. In this context, several efforts have been carried out to reduce biofuel prices, essentially by altering lipid sources [8–10]. Nowadays, edible vegetable oils are the major starting materials for biofuel production. In consequence, prospection for novel feedstocks has been primarily attributed to investigate oleaginous species for inedible oil extraction. Recently, alternatively, lipid residues as waste frying oil, grease, and animal fats have also been receiving considerable attention from the biofuel sector. To take advantage of these low cost and low quality resources, a convenient action would be to reuse residues to integrate sustainable energy supply and waste management in food processing facilities. Poultry fat, with low-cost feedstock compared to high-grade oils, offers another promising feedstock source for biofuel production.

In 2010, chicken fats were the most common and widespread domestic species with an annual consumption of more than 8.6 million tonnes which are persistently growing according to the reports of FAO, of the United Nations. In Europe, the chicken consumption reached 20 kg/capita/year in 2007, according to FAO, while in USA; the chicken consumption has surpassed 50 kg/capita/year, deeming a mature chicken to weight 1.8–1.9 kg (1.5 of meat) [8]. Then a larger amount of waste fats from chicken processing-plants has been generated in countries. Within agro-industrial residues chicken fats may be used to solve inappropriate environmental disposal besides contributing to energy supply. Many studies investigated the availability of chicken fats for biodiesel production by transesterification [11–14]. Chicken fat was thermally treated in the presence of mono-functional acid catalysts by Tian et al. [15] in a pilot scale two-stage fluid catalytic cracking reactor. In another work, the same authors [16] examined the behavior of chicken fat at different temperatures with different catalysts (USY, HZSM-5, Al_2O_3 and SiO_2) in a fixed bed reactor, where they observed a high conversion rate using acid catalysts (USY and HZM-5). Scarce works have been devoted to investigate systematically the hydrocracking process of chicken fat using bi-functional catalysts (hydrogenation-dehydrogenation and acid functions) as sulfided $NiW/SiO_2–Al_2O_3$ catalyst.

This work focused on the effect of process parameters (temperature, and LHSV) on the hydrocracking of waste chicken fat to renewable fuel production to be in comparison with our previous study for WCO hydrocracking over the same catalyst [17].

2. Experimental

2.1. Materials

Waste chicken fat (WCF) feedstock was obtained from Koki Company for poultry shop products and services-Cairo, Egypt. DHC-8 commercial distillate-hydrocracking catalyst is provided by UOP.

Prior to analysis, waste chicken fat was filtered for impurities removal and then, heated with stirring for 3 h at 110 °C to remove moisture.

2.2. Characterization

2.2.1. Waste chicken fat characterization

The elemental composition of WCF was determined using an elemental analyzer with channel control model (Pw 1390-Philips) and spectrometer model Pw 1410. Fatty acid content in WCF was analyzed using an Agilent 6890N FID-GC with an Omnistar Q-mass, HP-624 Capillary column was used (Table 1). The physical characterizations of WCF feedstock were measured according to the American Society for Testing and Materials (ASTM) methods (Table 2).

2.2.2. Catalyst characterization

DHC-8 is a hydrocracking catalyst consisting of non-noble hydrogenation metals ($NiO–WO_3$) on an amorphous silica alumina support. Physicochemical properties were obtained from UOP; BET surface area and pore volume were determined by N_2 adsorption–desorption at −196 °C from linear BET plots using Micrometrics Gimini 2375 surface area analyzer, USA, while pore volume was determined by poresizer 9320-V_2-08, USA. The measurement was performed on sample heated at 200 °C for 2 h in pure nitrogen. The main properties of the catalyst are shown in Table 3.

2.2.3. Hydrocracking activity test

Hydrocracking of WCF was performed in a fixed bed down flow tubular reactor of 100 cm^3 effective volume (L = 50 cm, ID = 1.6 cm). Prior to the hydrocracking reaction, the catalyst was activated with cyclohexane-dimethyldisulfide (DMDS, 2 wt.%) as a sulfiding reagent, with a flow rate of 150 ml/min under 3.0 MPa hydrogen pressure and reaction temperature 260 °C for 3 h, and then 360 °C for another 3 h. After catalyst activation, the reactor was cooled to room temperature, pressurized with H_2 to 6 MPa hydrogen pressure, and then heated to the desired temperature. After reaching the desired reaction conditions, WCF and hydrogen were introduced into the reactor at 6 MPa hydrogen pressure, a fixed liquid hourly space velocity (LHSV) of 4, 2, or 1 h^{-1} and a H_2/oil molar ratio of 450 v/v. The liquid and gaseous products were collected for analysis.

2.2.4. Analysis of products

The product mixtures obtained from hydrocracking of WCF were separated to gas phase, water and liquid organic products

Table 1 Composition of WCF feedstock.

Elemental composition, wt.% (ASTM D4294-90)						
Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen		
74.9	12.73	0.08	0.008	12.28		
Species of fatty acids in WFC feedstock, wt.%						
C14:0	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3
0.3	21.0	4.5	5.0	38.0	31.0	0.2

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