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STUDI EKSPERIMENTAL PENGARUH METODE CO-IMPREGNATION DAN SEQUENTIAL IMPREGNATION SERTA RASIO BIMETALIK Ni-Fe/HZSM-5 TERHADAP KINERJA PIROLISIS MINYAK JELANTAH
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INTISARI

Minyak jelantah (WCO) merupakan limbah yang berpotensi dimanfaatkan sebagai bahan bakar alternatif melalui proses pirolisis. Namun, *bio-oil* yang dihasilkan masih memiliki kandungan senyawa beroksigen yang dapat menurunkan kualitasnya. Penelitian ini bertujuan untuk mengkaji pengaruh metode sintesis katalis Ni-Fe/HZSM-5 (*co-impregnation* dan *sequential impregnation*) serta variasi rasio Ni terhadap karakteristik katalis, distribusi produk, dan kualitas *bio-oil* hasil pirolisis kontinu katalitik minyak jelantah.

Katalis Ni-Fe/HZSM-5 disintesis dengan variasi rasio Ni:Fe sebesar 10:1, 5:1, 1:1, 1:5, dan 1:10. Pirolisis dilakukan pada temperatur 450 ºC selama 2 jam menggunakan *fixed-bed continuous reactor*. Karakterisasi katalis dilakukan menggunakan *Brunauer-Emmett-Teller* (BET) dan *Barrett-Joyner-Halenda* (BJH), sedangkan produk dianalisis melalui pengukuran *yield*, *Higher Heating Value* (HHV), densitas, viskositas, *Fourier Transform Infrared Spectroscopy* (FTIR), komposisi gas, dan *Energy Recovery* (ER).

Hasil penelitian menunjukkan bahwa impregnasi bimetalik Ni-Fe meningkatkan luas permukaan spesifik, volume pori total, dan diameter pori rata-rata dibandingkan HZSM-5. Seluruh katalis menunjukkan isoterm adsorpsi-desorpsi tipe IV dengan *hysteresis loop* H4 yang mengindikasikan struktur mesopori. *Yield bio-oil* yang diperoleh berada pada rentang 47,61-52,80 wt%, dengan hasil tertinggi pada Co-1Ni10Fe sebesar 51,90 wt% untuk metode *co-impregnation* dan Seq-1Ni5Fe sebesar 52,80 wt% untuk metode *sequential impregnation*. Nilai HHV *bio-oil* meningkat dibandingkan WCO, dengan nilai tertinggi sebesar 40,91 MJ/kg pada katalis Seq-1Ni1Fe. Densitas *bio-oil* berada pada rentang 0,84-0,87 g/mL dan viskositas kinematis berada pada rentang 1,83-2,87 cSt. Hasil FTIR menunjukkan pergeseran pita karbonil dari 1743-1745 cm^{-1} menjadi 1708-1712 cm^{-1} yang mengindikasikan transformasi gugus ester selama proses pirolisis. Nilai *energy recovery* berada pada rentang 48,68-54,69%. Secara keseluruhan, metode *sequential impregnation* menghasilkan performa yang lebih baik dibandingkan *co-impregnation*. Katalis Seq-1Ni5Fe menghasilkan kuantitas *bio-oil* tertinggi, sedangkan katalis Seq-1Ni1Fe menghasilkan kualitas *bio-oil* terbaik berdasarkan nilai kalor yang diperoleh.

Kata kunci: minyak jelantah, pirolisis kontinu katalitik, Ni-Fe/HZSM-5, *co-impregnation*, *sequential impregnation*.

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ABSTRACT

Waste Cooking Oil (WCO) is a waste material with significant potential to be utilized as an alternative fuel through the catalytic pyrolysis process. However, the resulting bio-oil still contains oxygenated compounds that can reduce its fuel quality. This study aimed to investigate the effects of Ni-Fe/HZSM-5 catalyst synthesis methods (*co-impregnation* and *sequential impregnation*) and Ni ratios on catalyst characteristics, product distribution, and bio-oil quality obtained from continuous catalytic pyrolysis of waste cooking oil.

Ni-Fe/HZSM-5 catalysts were synthesized with Ni:Fe ratios of 10:1, 5:1, 1:1, 1:5, and 1:10. Pyrolysis was conducted at 450 ºC for 2 h using a fixed-bed continuous reactor. Catalyst characterization was performed using Brunauer-Emmett–Teller (BET) and Barrett-Joyner-Halenda (BJH) analyses, while the products were evaluated in terms of yield, Higher Heating Value (HHV), density, viscosity, Fourier Transform Infrared Spectroscopy (FTIR), gas composition, and Energy Recovery (ER).

The results showed that Ni-Fe bimetallic impregnation increased the specific surface area, total pore volume, and average pore diameter compared to the parent HZSM-5 catalyst. All catalysts exhibited type IV adsorption-desorption isotherms with H4 hysteresis loops, indicating a mesoporous structure. The bio-oil yield ranged from 47.61 to 52.80 wt%, with the highest yield obtained using Co-1Ni10Fe (51.90 wt%) for the co-impregnation method and Seq-1Ni5Fe (52.80 wt%) for the sequential impregnation method. The HHV of the bio-oil increased compared to the WCO feedstock, reaching a maximum value of 40.91 MJ/kg for the Seq-1Ni1Fe catalyst. Bio-oil density ranged from 0.84 to 0.87 g/mL, while kinematic viscosity ranged from 1.83 to 2.87 cSt. FTIR analysis revealed a shift in the carbonyl absorption band from 1743-1745 cm^{-1} to 1708-1712 cm^{-1}, indicating the transformation of ester functional groups during pyrolysis. The Energy Recovery values ranged from 48.68 to 54.69%. Overall, the sequential impregnation method exhibited better performance than the co-impregnation method. The Seq-1Ni5Fe catalyst produced the highest bio-oil yield, while the Seq-1Ni1Fe catalyst generated the highest-quality bio-oil based on its heating value.

Keywords: waste cooking oil, continuous catalytic pyrolysis, Ni-Fe/HZSM-5, co-impregnation, sequential impregnation.