MODELING AND ANALYSIS OF OIL-PALM BIOMASS (OPB) PYROLYSIS

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We hereby declare that we have checked this thesis, and, in our opinion, this thesis is adequate in terms of scope and quality for the award of Master of Science.

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institution.

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ABSTRAK

Pirolisis berasaskan biojisim menimbulkan minat yang semakin meningkat pada masa kini kerana ia boleh mengurangkan pencemaran sisa dan menyediakan bekalan tenaga bio, bahan api bio dan bahan kimia. Sisa biojisim kelapa sawit adalah bahan mentah yang paling banyak didapati di Malaysia. Pelupusan sisa ini dalam persekitaran yang mesra adalah tugas yang mencabar. Dalam kajian ini, tiga jenis sisa biojisim kelapa sawit iaitu - tandan buah kosong (EFB), tempurung isirung sawit (PKS), dan gentian mesocarp sawit (PMF) - diperiksa untuk menghasilkan bio-char, bio-oil dan bio-syngas. Hasil khusus produk ini bergantung pada keadaan operasi proses pirolisis, seperti suhu, tekanan, kadar alir bahan suapan dan kadar alir gas lengai. Keadaan operasi ini boleh dioptimumkan untuk memaksimumkan output. Bio-char mempunyai pelbagai kegunaan seperti dalam pengubahsuaian kualiti tanah, penyimpanan karbon, pengurusan sisa, mitigasi perubahan iklim, sumber tenaga dan bahan penapis. Bio-oil boleh digunakan sebagai bahan api bio, sumber tenaga, dan bahan kimia. Walaupun bio-syngas boleh digunakan sebagai sumber kuasa, bahan api bio untuk pengangkutan boleh menggantikan gas asli. Khususnya, produk pirolisis boleh diperbaharui untuk aplikasi tenaga dan faedah ekonomi dan alam sekitar. Objektif kajian ini adalah untuk membangunkan model berkeadaan tetap untuk mensimulasikan pirolysis sisa biojisim kelapa sawit menggunakan perisian ASPEN Plus V11, untuk meramal dan mengoptimumkan keadaan operasi pada hasil pengeluaran, dan untuk mengoptimumkan potensi ekonomi sistem tersebut. Sistem pirolisis terdiri daripada pengering, pemisah, rektor pirolisis utama dan sekunder, pemisah pepejal-gas, dua penyejuk, dan pemisah cecair-gas. Pirolisis telah dimodelkan menggunakan kaedah tenaga bebas Gibbs minimum. Walaupun model simulasi adalah berasaskan keseimbangan termokimia, ia adalah sah, terutamanya dalam menentukan keadaan operasi optimum proses pirolisis. Selain itu, fungsi pengoptimuman yang terdapat di dalam Aspen plus telah digunakan untuk mengoptimumkan potensi ekonomi daripada keseluruhan sistem. Julat keadaan operasi yang telah digunakan dalam kajian ini ialah 300 – 1000 °C, 1-10 bar, 10-100 kg/j suapan, dan 10-100 kg/j gas lengai. Dua senario yang digunakan dalam pengoptimuman ekonomi ialah model pengoptimuman tanpa kekangan bio-oil dan model pengoptimuman dengan bio-oil ≥ 10 kg/j sebagai kekangan dan kadar aliran suapan adalah sama atau kurang daripada 100 kg/j dalam kedua-dua senario. Hasil simulasi menunjukkan bahawa semua sisa biojisim kelapa sawit menunjukkan hasil bio-syngas yang tinggi (51.02%), hasil bio-char sederhana (29.9-34.4%), dan hasil bio-oil yang rendah (14.6-16.1%) pada keadaan pirolisis biasa. Hasilnya adalah menepati dengan literatur yang dilaporkan (Visconti et al., 2015). Keputusan menunjukkan bahawa EFB adalah yang paling sesuai untuk bio-syngas dan penjanaan bio-oil, manakala PMF sesuai untuk pengeluaran bio-char. Keuntungan optimum diperoleh daripada EFB kira-kira RM 357.8 sejam dan RM 294.8 sejam dalam senario pertama dan kedua. Hasil model simulasi semasa diharapkan dapat membantu menentukan nilai optimum keadaan operasi proses pirolisis dan membantu memilih bahan mentah untuk penjanaan tenaga bio melalui proses pirolisis. Perlu diingatkan bahawa kod Aspen tidak dapat meramalkan komposisi sisa cecair.

ABSTRACT

Biomass-based pyrolysis is raising a growing interest nowadays because it can alleviate the pollution of biomass wastes and provide a supply of bio-energy, bio-fuels, and chemicals. Oil palm biomass wastes are Malaysia's most widely available and promising candidate feedstocks. The disposal of these wastes in a friendly environment is challenging. In this work, three types of oil palm biomass wastes - empty fruit bunch (EFB), palm kernel shell (PKS), and palm mesocarp fiber (PMF) - are examined to produce bio-char bio-oil and bio-syngas. The specific yields of these products depend on operating conditions of the pyrolysis processes, such as temperature, pressure, feedstock flowrate, and inert gas flowrate. These operating conditions can be optimized to maximize outputs. Bio-char has a variety of uses, such as in soil amendment, carbon storage, waste management, mitigation of climate change, energy source, and filter material. Bio-oil can be used as bio-fuel, energy sources, and chemicals. While bio-syngas can be used as a power resource, transportation bio-fuel can substitute natural gas. Specifically, the pyrolysis products are renewable for energy applications and economic and environmental benefits. The objectives of this study were to develop a steady-state model to simulate the pyrolysis of oil palm biomass wastes using ASPEN Plus V11, to predict and optimize the operating conditions on the production yields, and to optimize the economic potentials of the pyrolysis system. The pyrolysis system consists of a dryer, separator, primary and secondary pyrolyzers, solid-gas separator, two coolers, and liquid-gas separator. The pyrolyzer was modeled using the minimum Gibbs free energy method. Even though the simulation model is thermochemical equilibrium-based, it is valid, especially in determining the optimal operating conditions of the pyrolysis process. In addition, the Aspen plus optimization tool was used to optimize the economic potential of the system. The range of the operating conditions that have been applied in this study were 300 – 1000 °C, 1-10 bar, 10-100 kg/h of feed, and 10-100 kg/h of inert gas. Two scenarios applied in the economic optimization are the optimization model without bio-oil constrain and the optimization model with bio-oil ≥ 10 kg/h as a constraint and the feed flow rate was equal or less than 100 kg/h in the two scenarios. Simulation results showed that all the oil palm biomass wastes displayed a high syngas yield (51.02%), a moderate bio-char yield (29.9-34.4%), and a low bio-oil yield (14.6-16.1%) at standard pyrolysis conditions. The results perfectly agree with the reported literature (Visconti et al., 2015). The results show that the EFB is the best suited for syngas and bio-oil generation, whereas the PMF is appropriate for bio-char production. The optimum profit was obtained from EFB of approximately RM 357.8 per hour and RM 294.8 per hour in the first and second scenarios. It is hoped that the current simulation model outcomes can help to determine the optimal values of the operating conditions of the pyrolysis process and help to select feedstocks for bio-energy generation through the pyrolysis process. It has to be noted that the Aspen code could not predict the composition of the liquid residue.

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