UNIVERSITI PUTRA MALAYSIA

MODELING AND SIMULATION OF FLUIDIZED BED GASIFIER OF BIOMASS

SEYED SHAHABEDDIN NEHZATI

MODELING AND SIMULATION OF FLUIDIZED BED GASIFIER OF BIOMASS

By

Seyed Shahabeddin Nehzati

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, In Fulfilment of the Requirements for the Degree of Master of Science

January 2010

DEDICATION

Dedicated to:

my beloved spouse

Mina,

my parents,

Behrooz and Maryam,

and my sisters,

Taravat and Sheida

for supporting me through the years of study and their full encouragement. Thank you very much. I am sure it has meant more to me than I can even imagine.

Abstract of the thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

MODELING AND SIMULATION OF FLUIDIZED BED GASIFIER FOR BIOMASS

By

SEYED SHAHABEDDIN NEHZATI

January 2010

Chairman: Dayang Radiah Binti Awang Biak, PhD

Faculty: Faculty of Engineering

The ever increasing energy demand and the polluting nature of existing fossil fuel energy sources demonstrate the need for non-polluting and renewable sources of energy. Decentralized energy production from renewable sources of energy can be a feasible long term solution for this problem. The objectives of this research were (i) to estimate kinetics parameters of gasification process (including pyrolysis and combustion processes) using the thermogravimetric analysis (TGA) (ii) to develop a simulation block of a fluidized bed gasifier using Aspen Plus software (iii) and to compare the simulation results with the experimental results.

Three biomass samples were selected, namely palm kernel shell, coconut shell and bagasse. The results of non-isothermal thermogravimetric analysis of biomass samples were analyzed. The samples were heated at three different heating rates, namely 10°C/min, 20°C/min and 50°C/min using a step wise temperature program initialized at 30°C and ended at 1000°C. The TGA studies were carried out in three different atmospheres: nitrogen rich atmosphere for pyrolysis, atmosphere containing

air for combustion and carbon dioxide rich atmosphere for gasification. The values for all kinetic parameters in Arrhenius equation were estimated by three different models namely Kissinger model, Least Square Estimation (LSE) for first-order reaction models and distributed activation energy model (DAEM). The estimated values obtained from each model were compared. The results showed that LSE for first-order reaction model agree well with the experimental results, indicating that lignocellulosics components in the mixture behave in the same way as they do separately. The estimated activation energy for pyrolysis of hemicellulose and cellulose contents in coconut shell and palm kernel shell were close. The values for both were 118 kJ/mol and 157 kJ/mol, respectively. The activation energy estimated for cellulose and hemicelluloses contents found in bagasse were lower. This indicates that shell part of biomass have similar thermal conversion behaviors. Also it is seen that the decomposition process shifts to higher temperatures at higher heating rates as a result of the competing effects of heat and mass transfer to the material.

The estimated kinetics data were then used to simulate the operation of a fluidized bed gasifier using Aspen Plus software. The fluidized bed gasifier was divided into a number of blocks. The main block was developed in ASPEN CUSTOM MODELER. The simulation results showed that approximately 15-35% of hydrogen can be produced when the operating temperature is set between 750-1000°C. It is also found that higher operation temperature increases the amount of hydrogen produced. The same trend were observed in experimental results conducted by Alipour Moghadam (2010). For equivalence ratio (ER) values ranging between 0.23-0.27, it is observed that hydrogen production rates reduced as the ER value increased. The amount of methane produced in the lab was higher than the simulation values. Simulation block

used to emulate the actual pyrolysis process can be the contributing factor for this discrepancy.

To conclude, the kinetic data were obtained from TGA experiments for Malaysia-based agricultural wastes. Estimated data via LSE for first order reaction models fit well with the TGA data. Simulation and experimental results for hydrogen production were comparatively similar, yet, some discrepancies for the production rates of other volatile organic compound (VOC) were observed.

Sari tesis dipersembahkan kepada Senat Universiti Putra Malaysia dalam perlaksanaan separa keperluan untuk ijazah Master Sains

PEMODELAN DAN SIMULASI PENGGASAN LEPISAN TERBENDALIR UNTUK BIOJISIM

OLEH

SEYED SHAHABEDDIN NEHZATI

January 2010

Pengerusi: Dayang Radiah Binti Awang Biak, PhD

Fakulti: Kejuruteraan

Permintaan tenaga yang sentiasa bertambah dan kewujudan sumber fosil tenaga bahan api yang bersifat mencemarkan menunjukkan keperluan sumber tenaga yang tidak mencemarkan dan boleh diperbaharui. Penyahpusatan pengeluaran tenaga daripada sumber tenaga yang boleh diperbaharui boleh menjadi satu penyelesaian jangka panjang untuk masalah ini. Objektif penyelidikan ini adalah (i) untuk menganggar parameter kinetik bagi proses penggasan (termasuk pirolisis dan proses pembakaran) menggunakan analisis termogravimetri (ii) membangunkan blok simulasi penggas lapisan terbendalir menggunakan perisian Aspen Plus (iii) membuat perbandingan antara keputusan simulasi yang diperoleh dengan keputusan eksperimen serta membincangkannya.

Dengan menggunakan proses-proses penukaran termokimia, termasuk penggasan, pirolisis dan pembakaran, bahan yang boleh diperbaharui ini boleh ditukar kepada

bahan api berharga dan stok suapan kimia berharga. Kajian penyelidikan ini dibahagikan kepada dua bahagian, iaitu membuat anggaran nilai parameter kinetik bagi proses penggasan dan menggunakan data yang dianggar itu di dalam simulasi penggas lapisan terbendalir.

Tiga jenis sampel biojisim telah dipilih, iaitu tempurung isirung kelapa sawit, tempurung kelapa dan hampas tebu. Hasil analisis termogravimetri bukan isoterma bagi sampel biojisim tersebut telah dijalankan. Sampel tersebut telah dipanaskan pada tiga kadar pemanasan yang berbeza iaitu 10°C / min, 20°C / min dan 50°C / min menggunakan pemprograman suhu berlangkah bermula dari 30°C sehingga 1000°C. Kajian TGA dilaksanakan di dalam tiga jenis atmosfera yang berbeza iaitu atmosfera yang kaya dengan nitrogen untuk pirolisis, atmosfera mengandungi udara untuk pembakaran dan atmosfera yang kaya dengan CO_2 untuk penggasan. Nilai untuk semua parameter bagi Persamaan Arrhenius telah dianggar menggunakan kaedah/model Kissinger, Kaedah Anggaran Kuasa Dua Terkecil (LSE) bagi model Tindakbalas Tertib Pertama dan Model DAEM. Nilai anggaran yang diperolehi dari ketiga-tiga model telah dibandingkan. Dari perbandingan tersebut, didapati nilai yang diperolehi menggunakan kaedah anggaran kuasa dua terkecil bagi model. Tindakbalas Tertib Pertama sejajar dengan nilai yang diperolehi dari hasil eksperimen. Ini menunjukkan komponen lignosellulosa dalam campuran berkelakuan sama seperti ketika ianya terasing. Nilai tenaga pengaktifan yang dianggar untuk selulosa dan hemisellulosa yang terkandung di dalam hampas tebu adalah lebih rendah. Ia menunjukkan bahagian biojisim bersifat isirung mempunyai sifat pertukaran terma yang serupa. Ia juga menunjukkan yang proses penguraian beranjak ke suhu yang lebih tinggi apabila kadar pemanasan ditingkatkan kesan daripada persaingan pemindahan haba dan jisim ke bahan.

Data kinetik yang telah dianggarkan digunakan untuk membuat simulasi menggunakan perisian Aspen Plus bagi operasi sebuah penggas lapisan terbendalir. Penggas lapisan terbendalir tersebut dibahagikan kepada beberapa buah blok. Blok utama telah dibangunkan menggunakan ASPEN CUSTOM MODELER.

Hasil simulasi menunjukkan lebih kurang 15-35% hidrogen dapat dihasilkan apabila suhu operasi ditetapkan antara 750-1000°C. Jumlah hidrogen yang dihasilkan dapat ditingkatkan apabila suhu operasi dinaikkan. Keputusan ini bersesuaian dengan hasil kajian yang ada. Untuk nilai nisbah kesetaraan bagi julat 0.23 – 0.27, kadar penghasilan hydrogen berkurangan apabila nilai ER bertambah. Anggaran nilai Tenaga Pengaktifan untuk proses pirolisis hemiselulosa dan selulosa bagi sampel tempurung adalah hampir sama. Nilai untuk kedua-duanya adalah 118kJ/mol dan 157kJ/mol. Jumlah metana yang dihasilkan dalam makmal adalah lebih tinggi daripada nilai yang diperolehi dari proses simulasi. Blok simulasi yang digunakan untuk menyerupai proses pirolisis sebenar boleh menjadi faktor penyumbang kepada perbezaan tersebut. Data kinetik telah diperoleh daripada eksperimen menggunakan TGA untuk sampel sisa pertanian dari Malaysia.

Secara kesimpulannya, data diperolehi menggunakan LSE untuk model tindakbalas tertib pertama sangat bersesuaian dengan data diperolehi dari TGA. Kadar penghasilan hidrogen bagi proses simulasi dan eksperimen adalah hampir sama tetapi perbezaan dapat dilihat bagi kadar penghasilan jirim meruap yang lain.

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I have enjoyed very much the cooperation and a very friendly and supporting manner of my friends in the Faculty of Engineering and the Department of Chemical Engineering, during my study as an international post graduate student in UPM.

APPROVAL

I certify that an Examination Committee has met on …… to conduct the final examination of Seyed Shahabeddin Nehzati on his thesis entitled "Modeling and simulation of fluidized bed gasifier for malaysian-based biomass" in accordance with Universities and university Colleges Act 1971 and Constitution of the Universiti Putra Malayssia [P.U.(A) 106] 15 March 1998. The Committee recommends that the students be awarded the Master of Science.

Members of the Examination Committee were as follows:

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

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Date:

DECLARATION

I declare that the thesis on my original work except for quotation and citations, which have been duly acknowledged. I also declare that it has not been previously, and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or other institutions.

SEYED SHAHABEDDIN NEHZATI

Date: 31 January 2011

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