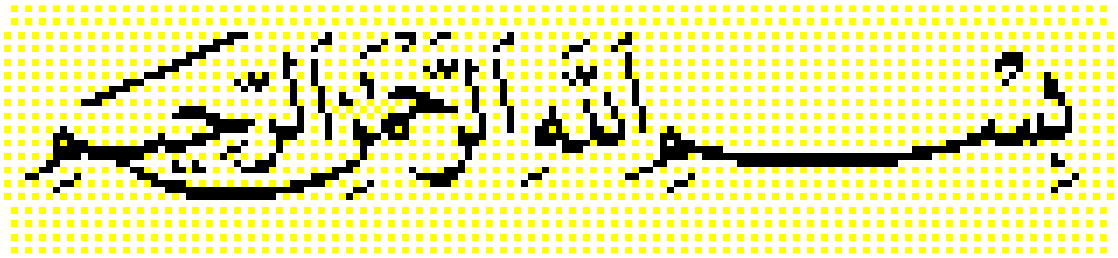
APPLICATION OF THEORETICAL COMBUSTION ANALYSIS IN DETERMINING THE OPTIMUM FIBRE/SHELL RATIO FOR OIL MILL BOILER

By

HARIMI MOHAMED

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

January 2006



DEDICATION

To my Grand Mother Dahbia

Abstract of thesis presented to the senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

APPLICATION OF THEORETICAL COMBUSTION ANALYSIS IN DETERMINING THE OPTIMUM FIBRE/SHELL RATIO FOR OIL MILL BOILER

By

HARIMI MOHAMED

January 2006

Chairman: Associate Professor Megat Mohamad Hamdan Megat Ahmad, PhD

Faculty: Engineering

Currently from 50 million tons of fibre and shell generated yearly, only 60% are used in all palm oil mills as solid fuel for steam boilers. The only problem when incinerating the fibre and shell in a random mixture, the amount of air required would be difficult to control or to maintain and consequently, the control of flue gas emissions become the most difficult task. If the excess air is well optimised with respect to a given ratio of fibre-to-shell, then whatever the variation of that ratio, the appropriate amount of air should be allotted to that mixing [fibre and shell] based on the optimisation value of excess air. In this study, five different compositions of fibre and shell were obtained from five different palm oil mills in Malaysia, and have been tested with other data obtained from Malaysian Palm Oil Board [MPOB] database. The results confirmed statistically, that those data obtained from the five different palm oil mills represent the Malaysian local data.

Twenty-six chemical species were selected, and based on chemical reaction stoichiometry method [CRS] and chemical equilibrium reactions [CER], the stability of the system was determined. It was found that, the 26 chemical species should be listed from major species to minor species when using CRS in order to get all CER independent from each other, and thus system is more stable. With the existence of powerful software STANJAN code, the emissions of flue gases were computed using all the data from the five palm oil mills. Huge data output were obtained, and therefore minimisation of data was carried out using statistical method namely analysis of variance [ANOVA], and from which the difference between the data output from the five palm oil mills are statistically not significant, and therefore palm oil mill number three was selected as base data.

The thermal analysis of heat losses from boiler was presented in details based on direct and indirect method. The second method was used based on ASME PTC4.1 standard, where the first five heat losses were considered, because fibre and shell contain low ash content and therefore heat loss from this source is not so critical. For the heat loss due to radiation and convection, maximum of 2% of heat loss are counted. The main reason of not considering the last two heat losses is also because, many practical data are needed and specially the heat loss due to ash which is really another topic of research.

The results obtained from STANJAN code were validated, using theory of combustion based on major chemical species, and also with some practical data from palm oil mills

in Malaysia. The output from STANJAN code is of great importance either for theory or practical side. The validation of the results obtained using ASME PTC4.1 standard were valid with the validity of the results obtained from STANJAN software, and also related to the properties of the air. The properties of the air were taken as an average value of temperature and humidity of 28 ^{o}C and 80% respectively; therefore the results obtained are acceptable within that average.

For the part of boiler thermal analysis, it was observed that the heat loss due dry flue gases is the most dominant heat loss, except at very high fibre content of 60% and above, where the heat loss due to moisture in the fuel takes place. The heat loss due to incomplete combustion was found highly affected by the variation in excess air, but not too much affected by the ratio of fibre-to-shell. The t-test confirmed that the heat loss due to moisture and hydrogen in the fuel was found much more affected by the variations of fibre-to-shell ratios.

The mathematical models of CO, CO_2, combustion efficiency, and boiler efficiency with respect to percentage excess air and ratio of fibre-to shell were obtained. From the mathematical model of CO, the relation of excess air with respect to the ratio of fibre-to-shell was deduced mathematical and numerically by fixing the concentration of CO to 9 ppmv [DOE]. From the data obtained from the mathematical models of the optimum value of excess air with respect to the ratio of fibre-to-shell, it was found that the combustion efficiency is constant at any excess air, and thus the optimum point of fibre-to-shell ratio of 55:45 was computed based on the average value of the boiler efficiency,

with 75% excess air. The palm oil owners or users are not forced to use such optimum point, but for any given ratio of fibre-to-shell, its appropriate percentage of excess air should be maintained, so that high combustion efficiency and less heat losses are attained.

Abstrak tesis yang dikemukakam kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah doctor falsafah

APLIKASI ANALISIS PEMBAKARAN TEORETIKAL DALAM MENENTUKAN NISBAH GENTIAN/TEMPURUNG OPTIMUM BAGI DANDANG KILANG MINYAK SAWIT

Oleh

HARIMI MOHAMED

Januari 2006

Pengerusi: Profesor Madya Megat Mohamad Hamdan Megat Ahmad, PhD

Fakulti: Kejuruteraan

Kini daripadasebanyak 50 juta tan gentian dan tempurung terhasil setahun, dimana 60% digunakan oleh kilang kelapa sawit sebagai bahan api pepejal untuk dandang pengewapan. Masalah hanya timbul apabila proses pembakaran gentian dan tempurung dalam campuran secara rawak, sejumlah udara diperlukan adalah sukar untuk mengawal atau menyelenggara dan ini menyebabkan kesukaran untuk mengawal pelepasan gas serombong. Jika lebihan udara yang berhubung kait dengan nisbah gentian terhadap tempurung dioptimumkan begitu baik, jadi apa juga perubahan nisbah tersebut, jumlah udara yang sesuai perlu diagihkan kepada campuran tersebut [gentian dan tempurung] berasaskan kepada nilai pengoptimuman lebihan udara. Dalam kajian ini, lima

komposisi yang berlainan bagi nisbah gentian dan tempurung telah diperolehi dari lima kilang sawit di Malaysia, dan telah diuji dengan data lain diperolehi daripada pangkalan data Malaysian Palm Oil Board [MPOB]. Keputusan mengesahkan bahawa secara statistik data daripada lima kilang minyak sawit berlainan mewakili data tempatan Malaysia.

Dua puluh enam spesis kimia telah dipilih, dan berdasarkan kepada kaedah stoikiometri tindak balas kimia [CRS] dan tindak balas keseimbangan kimia [CER], kestabilan bagi sistem telah ditentukan. Telah didapati bahawa, 26 spesis kimia disenaraikan daripada spesis major [besar] kepada spesis minor [kecil] bila menggunakan CRS bagi mendapatkan CER bebas daripada satu sama lain, maka sistem lebih stabil. Dengan kewujudan perisian kod STANJAN, pelepasan gas enapcemar diperolehi dengan menggunakan kesemua data daripada 5 kilang kelapa sawit. Banyak data telah dihasilkan, maka pengecilan data telah dijalankan melalui kaedah statistik yang dinamakan analisis variasi [ANOVA] dan daripadanya perbezaan antara data output yang dihasilkan dari 5 kilang kelapa sawit secara statistik tidak penting dan dengan ini kilang kelapa sawit nombor 3 telah dipilih sebagai data asas.

Analisis terma bagi kehilangan haba yang diperolehi dari dandang dibentang secara terperinci berdasarkan kepada kaedah langsung dan tidak langsung. Kaedak kedua telah digunakan berdasarkan kepada piawai ASME PTC4.1, di mana lima kehilangan haba yang pertama dipertimbangkan, kerana gentian dan tempurung mengandungi kandungan

abu yang rendah dan dengan demikian kehilangan haba daripada sumber ini adalah tidak kritikal. Untuk kehilangan haba melalui radiasi dan olakan sebanyak 2% kehilangan haba maksimum diperolehi. Sebab utama dua kehilangan haba yang terakhir tidak dipertimbangkan kerana banyak data praktikal diperlukan dan khasnya kehilangan haba melalui abu adalah sebenarnya satu tajuk penyelidikan yang berasingan.

Keputusan yang diperolehi daripada kod STANJAN telah disahkan, walaupun ramai penyelidik di seluruh dunia menggunakan kod ini untuk mengesahkan data practical. Pengesahan data dibuat berdasarkan kepada formula secara menyeluruh untuk menganggar lebihan udara daripada pengiraan oleh gas enap cemar terutamanya O_2, N_2, dan CO. Oleh kerana kebanyakan kilang kelapa sawit membakar sisa buangan pada lebihan udara lebih daripada 50%, maka keputusan daripada kod STANJAN dengan ralat relatif maksimum sebanyah 4% telah disahkan. Pengesahan keputusan yang diperolehi dengan menggunakan piawai ASME PTC4.1 adalah sah dengan pengesahan keputusan yang diperolehi daripada perisian STANJAN dan juga dikaitkan dengan sifat-sifat udara. Sifat-sifat udara diambil sebagai nilai purata suhu pada 28 ^{o}C dan kelembapan 80% dengan itu keputusan yang diperolehi boleh diterima dalam lingkungan purata tersebut.

Model matematik telah digunakan untuk tujuan korelasi sejumlah data berangka dengan persamaan matematik untuk mengoptimum peratus lebihan udara pada apa jua nisbah gentian terhadap tempurung, berdasarkan kepada CO yang dihadkan kepada 9 ppmv. Telah diperhatikan bahawa, kehilangan tenaga malalui gas enap cemar kering adalah

kehilangan haba yang paling dominan, kecuali pada kandungan gentian tinggi 60% ke atas, di mana kehilangan haba melalui kelembapan dalam bahan api berlaku. Kehilangan haba melalui pembakaran tak lengkap didapati sangat dipengaruhi oleh variasi dalam lebihan udara tetapi tidak banyah dipengaruhi oleh nisbah gentian terhadap gentian. Ujian t mengesahkan bahawa kehilangan haba melalui kelembapan dan hydrogen dalam bahan api didapati dipengaruhi oleh variasi bagi nisbah gentian terhadap tempurung.

Daripada data yang diperolehi daripada model matematik nilai pembakaran optimum bagi lebihan udara yang berhubung kait dengan nisbah gentian terhadap tempurung, telah didapati bahawa kecekapan pembakaran adalah malar pada mana-mana lebihan udara, dan oleh itu titik optimum bagi nisbah gentian terhadap tempurung 55:45 telah dikira berasaskan nilai purata kecekapan dandang. Nisbah 55:45 merujuk kepada peratus lebihan udara 75%, dan telah dinyatakan bahawa pemilik atau pengguna kilang minyak sawit tidak dipaksa unutuk menggunakan titik optimum tersebut, tetapi jika lebihan udara yang sesuai yang berhubung kait dengan nisbah gentian terhadap tempurung digunakan, jadi peningkatan dalam kecekapan pembakaran dan kehilangan haba adalah lebih dijangkakan.

ACKNOWLEDGEMENTS

I would like to express my sincere appreciation to Associate Professor Dr. Megat Mohamad Hamdan Megat Ahmad, Associate Professor Ir. Dr. Mohd Sapuan Salit and Professor Dr. Azni Bin Hj. Idris for their guidance, suggestions, advices, supportive encouragement and time spent throughout this study.

I extend my utmost appreciation to Ir. Fuad Abas for his help, technical support and encouragement and also to Associate Professor Dr. Abdul Noor @ Yeo Kiam Beng from Universiti Malaysia Sabah, School of Engineering & IT. Finally, special thanks to Mr. Eris Elianddy Supeni and Mr. John Posko for their technical support.

I deeply thank my mother, father and sisters for their worrying, and encouragements, and also the big part of my family; my wife and my daughter for sacrificing their time.

I certify that an Examination Committee has met on 4th January 2006 to conduct the final examination of Harimi Mohamed on his Doctor of Philosophy thesis entitled "Application of Theoretical Combustion Analysis in Determining the Optimum Fibre/Shell Ratio for Oil Mill Boiler" in accordance with Universiti Pertanian Malaysia (Higher Degree) Act 1980 and Universiti Pertanian Malaysia (Higher Degree) Regulations 1981. The Committee recommends that the candidate be awarded the relevant degree. Members of the Examination Committee are as follows:

Abdel Magid Hamouda, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Nor Mariah Adam, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Wong Shaw Voon, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Internal Examiner)

Farid Nasir Ani, PhD
Professor
Faculty of Engineering
Universiti Teknologi Malaysia
(External Examiner)

_____
HASANAH MOHD. GHAZALI, PhD
Professor/Deputy Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

This thesis submitted to the senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee are as follows:

Megat Mohamad Hamdan Megat Ahmad, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohd Sapuan Salit, PhD
Associate Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Azni Bin Hj. Idris, PhD
Professor
Faculty of Engineering
Universiti Putra Malaysia
(Member)

AINI IDERIS, PhD
Professor/Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

DECLARATION

I hereby declare that the 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 UPM or other institutions.

HARIMI MOHAMED

Date: 4 January 2006

TABLE OF CONTENTS