COMMISSIONING OF A PILOT SCALE FLUIDISED BED COMBUSTOR

MOHD. RUSWADI BIN JUSOH

UNIVERSITI TEKNOLOGI MALAYSIA

BAHAGIAN A – Pengesahan Kerjasama*

Adalah disahkan bahawa projek penyelidikan tesis ini telah dilaksanakan melalui kerjasama antara ________________________ dengan ________________________

Disahkan oleh:

Tandatangan : ……………………………………… Tarikh : ………………

Nama : ………………………………………

Jawatan : ………………………………………

(Cop rasmi)

** Jika penyediaan tesis/projek melibatkan kerjasama.*

BAHAGIAN B – Untuk Kegunaan Pejabat Sekolah Pengajian Siswazah

Tesis ini telah diperiksa dan diakui oleh:

Nama dan Alamat Pemeriksa Luar : ____

____

____

____

Nama dan Alamat Pemeriksa Dalam : ____

____

____

____

Nama Penyelia Lain (jika ada) : ____

____

____

____

Disahkan oleh Timbalan Pendaftar di SPS:

Tandatangan : ……………………………………… Tarikh : ………………

Nama : ………………………………………

COMMISSIONING OF A PILOT SCALE FLUIDISED BED COMBUSTOR

MOHD. RUSWADI BIN JUSOH

A dissertation submitted in partial fulfillment of the
Requirements for the award of the degree of
Master of Engineering (Environmental)

Faculty of Chemical and Natural Resources Engineering
Universiti Teknologi Malaysia

OCTOBER 2008

Ani, tiada ganti, diuji, penuh…

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my supervisor, Associate Professor Dr. Mohd. Rozainee bin Taib for his dedication, support and guidance throughout the whole period of this study work. His knowledge and experience in the field of fluidised bed combustor system has enlightened me and inspired me in the area of my study. Without his guidance and constructive criticism, this study would not have been gone that smoothly. I also appreciate the freedom that he had given to me in finishing my study in my own space.

ABSTRACT

The main purpose of this study is to perform a test and commissioning on a newly fabricated pilot scale fluidised bed combustor for the production of ash from rice husk. The combustor with the height of 6.0 mH and diameter of 0.5 mD has been designed and installed at the Faculty of Chemical and Natural Resources, Universiti Teknologi Malaysia. The scope of this study includes installation of the centrifugal exhaust fan, modification of the combustor feeding system, observation on the combustion temperature stability, oil palm shell usage as an igniter for the bed combustor start-up and flue gas measurement from the firing of rice husk in the pilot scale fluidised bed combustor. Under this study, a fluidising velocity of 4, 5, 6 and 7 U_{mf} were applied for the combustion temperature stability observation on the fluidised bed combustor. The oil palm shell obtained from the Kulai Palm Oil Mills of Federal Land Development Authority (FELDA) Johor, were used as an igniter to pre-heat the bed combustor in order to start-up the combustion process in a safe manner during the experimental works. In addition, an installation of the centrifugal exhaust fan and a modification on the feeding system was performed as a trouble-shooting measured during the study. The flue gas from the combustion of rice husk was analysed using the MRU Gas Analyser which showed that the gas generated consists of O_2, CO_2, CO, NO_x and SO_2 at the concentration of 7.7%, 11.2%, 0.5%, 189 ppm and 80 ppm, respectively. The newly fabricated pilot scale fluidised bed combustor was successfully commissioned with the production of ash from the firing of rice husk in the unit.

ABSTRAK

Matlamat utama dalam kajian ini adalah untuk menjalankan ujian keupayaan terhadap loji pandu pembakar lapisan terbendalir untuk menghasilkan abu daripada sekam padi. Loji pandu pembakar lapisan terbendalir yang mempunyai ketinggian 6.0 meter dengan saiz diameter 0.5 meter telah berjaya direkabentuk di Fakulti Kejuruteraan Kimia dan Kejuruteraan Sumber Asli, Universiti Teknologi Malaysia. Skop kajian ini termasuklah pemasangan kipas ekzos terhadap loji pandu, modifikasi terhadap sistem suapan bahan bakar, ujian kestabilan suhu pembakaran loji pandu, penggunaan isirung kelapa sawit sebagai bahan pemula untuk pemanasan bahan lapisan terbendalir dan analisis terhadap gas yang terhasil daripada pembakaran sekam padi di dalam loji pandu pembakar lapisan terbendalir. Melalui kajian ini, halaju terbendalir terdiri daripada 4, 5, 6 dan 7 U_{mf} diaplikasi dalam proses pembakaran untuk menguji kestabilan suhu pembakaran loji pandu tersebut. Bagi memastikan keselamatan sepanjang proses ujikaji, isirung kelapa sawit yang diperolehi daripada Felda Taib Andak, Kulai digunakan sebagai bahan pemula untuk proses pemanasan bahan terbendalir di dalam loji pandu. Selain daripada itu, penambahan kipas ekzos terhadap loji pandu dan modifikasi terhadap sistem suapan bahan bakar dilakukan untuk mengatasi masalah yang dihadapi semasa proses ujian keupayaan dijalankan. Produk gas daripada pembakaran sekam padi di analisa menggunakan penganalisa Gas MRU, ujian analisis terhadap gas O_2, CO_2, CO, NO_x dan SO_2 yang terhasil masing-masing adalah sebanyak 7.6%, 11.2%, 0.5%, 189 ppm and 80 ppm. Ujian keupayaan telah berjaya dilakukan ke atas loji pandu pembakar lapisan terbendalir dengan penghasilan abu daripada pembakaran sekam padi melalui unit tersebut.

TABLE OF CONTENTS

2 LITERATURE REVIEW

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

ASEAN	-	Association of South-East Asian Nations
ASTM	-	American Society for Testing Materials
BET	-	Brunauer, Emmett and Teller Method
C	-	Carbon
CDM	-	Clean Development Mechanism
CH_4	-	Methane
CO	-	Carbon monoxide
CO_2	-	Carbon dioxide
CREDA	-	Chhattisgarh Renewable Energy Development Agency
D*c*	-	Column Diameter
FELDA	-	Federal Land Development Authority
FBC	-	Fluidised Bed Combustor
FKKKSA	-	Fakulti Kejuruteraan Kimia dan Kejuruteraan Sumber Asli
GHG	-	Green House Gas
GJ	-	Giga Joule
GWh	-	Giga Watt per Hour
H	-	Hydrogen
HP	-	Horse Power
H_2O	-	Water
H_2S	-	Hydrogen Sulphide
HCI	-	Hydrochloric Acid
HHV	-	Higher Heating Value
ID	-	Internal Diameter
LHV	-	Lower Heating Value, (MJ/kg)
LOI	-	Loss on Ignition

LPG	-	Liquefied Petroleum Gas
LPM	-	Litre per Minute
mD	-	Meters (inner diameter)
mH	-	Meters (height)
mm	-	Millimeters
m/s	-	Meter per Second
MSW	-	Municipal Solid Waste
MW	-	Mega Watt
N	-	Nitrogen
NA	-	Not Available
ND	-	Not Detectable
NO_2	-	Nitrogen Dioxide
NSTP	-	New Straits Times Press
O_2	-	Oxygen
OH	-	Hydroxyl
RHA	-	Rice Husk Ash
RM	-	Ringgit Malaysia
RMS	-	Root Mean Square
S	-	Sulphur
SEM	-	Scanning Electron Microscopy
SiO_2	-	Silica Dioxide
SO_2	-	Sulphur Dioxide
TDH	-	Transport Disengaging Height, (m)
TGA	-	Thermogravimetric Analysis
U_{mf}	-	Fluidising Velocity (number)
$U_{mf/m}$	-	Fluidising Velocities of the Mixture
USA	-	United State of America
USD	-	United States Dollar (USD 1 = RM 3.80)
UTM	-	Universiti Teknologi Malaysia
XRD	-	X-Ray Diffraction
z	-	Static Height of Bed Materials

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Rice covers 1% of the earth surface with approximately 600 million tonnes of paddy produced per year with average 20% of the rice paddy is husk of 120 millions tonnes. In majority of rice producing countries, most of the husk is either burnt or dumped as a waste. According to the statistic from Padiberas Nasional Berhad (BERNAS) in the year 2007, the potential energy generation in Malaysia from rice husk is at 300 GWh per annum. This translates to, an estimated potential revenue from electricity generation of RM44.7 million per annum.

The utilisation of rice husk for energy production added ‘value’ to rice husk, which is otherwise deemed as a form of waste that have potential to create serious environmental and health problems if not managed in a proper and effective manner. Rice husk ash contains among the highest amount of biogenic silica still in its amorphous form (in the excess of 95 wt% silica, SiO_2) (James and Rao, 1986) compared to other biomass materials, such as ash from sugarcane bagasse (57 – 73% SiO_2) (Natarajan *et al*., 1998a).

The quality of amorphous silica resulting from the thermal treatment of rice husk is comparable with other expensive sources of silica. Furthermore, the utilisation of rice husk producing value added material from waste agriculture product as well as sodium silicate. The sodium silicate that could be produced in much cheaper route using amorphous silica from rice husk ash compared to conventional methods also has high market value. For example, the production of one tonne of sodium silicate requires approximately 135 kg of amorphous silica as raw material. Thus, one tonne of amorphous silica will produce an equivalent of 7.4 tonnes of sodium silicate, which in turn commands a price of RM 2,100 per tonne. Further, the residue from the production of sodium silicate from rice husk ash is a by-product which could be further processed into activated carbon or sold as it is as a carbon source.

Production of rice is dominated by Asia, where rice is the only food crop that can be grown during the rainy season in the waterlogged tropical areas. Most paddy is produced by China (31%) followed by India (21%). Assuming a husk to paddy ratio of 20% the total global husk production could be as high as 116,000,000 tonnes per year. Globally, rice production is increasing from 1992 – 2002 with an increase about 10%. Only China and Japan produced less rice in 2002 compared with 1992. Yields are affected by several factors, including the agronomy of the crop. This is influenced by the physical and cultural environment and scale under wish the rice is grown. International co-ordination in technological advance of rice production is providing alternatives to the limitation of cultures practices. Rice production is often set by weather, monsoons and droughts, but the effect of this are increasingly being limited by irrigation and water control systems.

In reality, it is estimated that only about 2% of the available rice husk is used for energy production in Malaysia. Similarly, in other rice producing countries, despite the huge potential, the utilisation of this abundant biomass is still very low. However, in the last few years, the utilisation of rice husk as an energy source has gained significant momentum. In reality, it is estimated that only about 2% of the available rice husk is used for energy production in Malaysia. Similarly, in other rice producing countries, despite the huge potential, the utilisation of this abundant biomass is still very low. However, in the last few years, the utilisation of rice husk as an energy source has gained significant momentum.

1.2 Problem Statements

A pilot scale fluidised bed combustor was successfully fabricated at Fakulti Kejuruteraan Kimia dan Kejuruteraan Sumber Asli (FKKKSA), Universiti Teknologi Malaysia. The combustor was of 0.5 mD (inner diameter) and 6.0 mH (height) which was installed in February 2006. Commissioning of the pilot scale fluidised bed combustor was carried out from March until July 2006.

The previous studies of rice husk combustion had been done in a lab scale of 80 mm inner diameter fluidised bed reactor (Ngo, 2002) to investigate the optimum set of operating parameters such as temperature, sand size, fluidising velocity and static bed height. A bed combustor pre-heating as a primary step in starting up the combustor was pre-heated through premixed combustion of liquefied petroleum gas (LPG) and air. An igniter such as kerosene or soaked tissue ball is dropped into the bed. Then, the premixed LPG and air is passed through the bed with its flowrate adjusted so as to enable the flame to remain in the bed. However, burning of the premixed gas mixture in the bed region will emit a loud ‘popping’ noise due to the eruption of bubbles in the bed during combustion.

In this study, the optimum set of operating parameters for production of amorphous silica ash from rice husk (Ngo, 2002) could be applied to commission the pilot scale fluidised bed combustor. Compared to the lab scale fluidised bed combustor, the pilot scale fluidised bed combustor was of 0.5 mD (inner diameter) and 6.0 mH (height) and the unit was facilitated with a gas analyser. During the testing and commissioning activities, an evaluation, installation and modification was carried out so as to ensure a good operation of the pilot scale fluidised bed combustor.

1.3 Objectives of Study

The main objective of this study is to commission a newly fabricated pilot scale fluidised bed combustor to produce ash from rice husk. The specific objectives of this study were:

1. To investigate and overcome the leakage of smoke (hot flue gas) at the combustor while the combustor is in operation.

2. To investigate the insufficient of the fuel feeding (rice husk) into the combustor during the combustion process.

3. To evaluate a bed combustor pre-heating method for starting up the pilot scale fluidised bed combustor by using an oil palm shell.

4. To investigate the combustion temperature stability of the fluidised bed combustor by using a different of fluidising numbers (U_{mf}).

5. To analyse a composition of flue gas generated from the rice husk firing in the pilot scale fluidised bed combustor.

1.4 Scopes of Study

The study work focused on commissioning the newly fabricated pilot scale fluidised bed combustor to produce ash from rice husk. The scopes of the study are as below:

1. The installation of centrifugal exhaust fan on the top of the combustor to provide the negative pressure on the chimney to prevent the escape of the smoke (hot flue gas) at the combustor.

2. The modification of secondary hopper in the combustor feeding system to avoid the insufficient of fuel feeding (rice husk) into the combustor due to the dead zone in the existing secondary hopper design.

3. The evaluation of combustor pre-heating method by using the oil palm shell and the time to achieve a bed desire temperature (700^{o}C) will be observed.

4. The observation of combustion temperature stability will be carried out for the rice husk firing in the combustor at fluidising numbers applied from 4 to 7 U_{mf}.

5. The measurement of flue gas will be carried out to determine a composition of gases from the firing of rice husk in the combustor.

1.5 Significance of Study

This study will contribute on providing the effective technology (Fluidised Bed Combustor) and solution for the utilisation of rice husk. It is in-line with the Malaysia Budget 2008, which highlighted the continued emphasis to further modernise and develop the agriculture sector industries. The study also explores the potential utilisation of rice husk such as renewable energy source (heat and electricity) and value added material (sodium silicate and activated carbon). The most significant benefit that could be gained from such approach is that the zero or most often negative investment that would have been expended to get rid of the agricultural wastes could in fact be transformed into an income generating business capable offering highly lucrative returns.

REFERENCES

Armesto, L.; Bahillo, A.; Veijonen, K.; Cabanillas, A. and Otero, J. (2002). *Combustion Behaviour of Rice Husk in a Bubbling Fluidised Bed*. Biomass and Bioenergy. 23: 171-179.

Ashish Bhat; Ram Bheemarasetti, J. V. and Rajeswara Rao, T. (2001). *Kinetics of Rice Husk Char Gasification*. Energy Conversion and Management. 42: 2061-2069.

Beagle, E. C. (1974). *Basic and Applied Research Needs for Optimizing Utilization of Rice Husk*. In Proc. of the Rice Husk By-Products Utilization, Int. Conf. Valencia. pp 1-43.

Beagle, E. C. (1978). *Rice Husk, Conversion to Energy*. FAO Agricultural Bulletin 31, Chap. 3. Rome.

Bingyan, X and Zhongnan, L. (1987). *A Study of Fluidized Bed Gasification Rice Hulls*. Advances in Solar Energy Technology, Biennial Congress, Hamburg, Germany. pp 2312-2316.

Bhattacharya, S. C. and Shah, N. (1987). *Spouted Bed Combustion of Paddy Husk*. Energy Research. 11: 429-432.

Bhattacharya, S. C. and Wu, W. (1989). *Fluidized Bed Combustion of Rice Husk for Disposal and Energy Recovery*. Energy from Biomass and Wastes. XII: 591-601.

Bhattacharya, S. C.; Shah, N. and Alikhani, Z. (1984). *Some Aspects of Fluidized Bed Combustion of Paddy Husk*. Applied Energy. 16(4): 307-316.

Black and Veatch (Thailand). (2000). *Thailand Biomass-Based Power Generation and Cogeneration within Small Rural Industries*. National Energy Policy Office (NEPO). Chapter 5, pp 5-4.

Blasi, J. S. M.; Teoman, Y. and Yuriger, K. R. (1999). *The Effect of Operating Temperature on the Velocity of Minimum Fluidisation Bed Voidage and General Behaviour*. Powder Technology. 31: 101-110.

Boateng, A. A.; Walawender, W. P.; Fan, L. P. And Chee, C. S. (1992). *Fluidized-Bed Steam Gasification of Rice Hull*. Bioresource Technology. 40: 235-239.

Briens, C. L.; Bergougnou, M. A. And Baron, T. (1988). *Prediction of Entrainment from Gas-Solid Fluidized Beds*. Powder Technology. 54: 86-196.

Chakraverty, A. and Kaleemullah, S. (1991). *Conversion of Rice Husk into Amorphous Silica and Combustible Gas*. Energy Convers. Mgmt. 32(6): 565-570.

Chakraverty, A.; Mishra, P. and Banerjee, H.D. (1988). *Investigation of Combustion of Raw and Acid-Leached Rice Husk for Production of Pure Amorphous White Silica*. J. Mater. Sci. 23: 21-24.

Chen, G. Y.; Fang, M. X.; Luo, Z. Y.; Yu, C. J.; Li, X. T.; Ni, M. J. and Cen, K. F. (1998). *The Study of Combustion Characteristics of Rice Husk-Fired Fluidized Bed Boiler*. Journal of Combustion Science and Technology. 4(2): 193-198. In Mandarin language.

Chouhan, R. K.; Kujur, B.; Amritphale, S. S. and Chandra, N. (2000). *Effect of Temperature of Ashing of Rice Husk on the Compressive Strength of Lime-Rice Husk Silica Mortar*. Sil. Ind. 65(5-6): 67-71.

Davidson, J. F. and Harrison, D. (1963). *Fluidised Particles*. Cambridge University Press, New York.

De Souza, M. F.; Batista, P. D. S. and Liborio, J. B. L. (2004). *Oxides Extracted from Vegetal Matter and Process Therefor*. U. S. Patent Application Publication No. US 2004/0175321 A1, Sept. 9, 2004.

Department of Statistics Malaysia (2007). *Key Statistics*. Website: http://www.statistics.gov.my/English/keystats.htm (accessed on 05[ft] February 2008)

Dutta, S. and Wen, C. Y. (1977). *Reactivity of Coal and Char and Ash 2. In Oxygen-Nitrogen Atmosphere.* Ind. Eng. Chem. Process Des. Dev. 16(1): 31-37.

Fang, M.; Yang, L.; Chen, G.; Shi, Z; Luo, Z. and Cen. K. (2004). *Experimental Study on Rice Husk Combustion in a Circulating Fluidised Bed*. Fuel Processing Technology. 85: 1273-1282.

Flanigan, V. J.; Xu, B. Y. and Huang, E. (1987). *Fluidized Bed Gasification of Rice Hulls*. The Tenth Annual Energy-Sources Technology Conference and Exhibition, Dallas, Texas. pp 19-34.

Hamad, M. A. (1981 – 1982). *Combustion of rice hulls in a static bed*. Energy in Agriculture. 1: 311-315.

Hamad, M. A. and Khattab, I. A. (1981). *Effect of the Combustion Process on the Structure of Rice Hull Silica*. Thermochimica Acta. 48: 343-349.

Hartiniati, A.; Soemardjo, A. and Youvial, M. (1989). *Performance of a Pilot-Scale Fluidized Bed Gasifier Fuelled by Rice Husk*. Proc. Int. Conf. Pyrolysis and Gasification. pp 257-263.

Henrich, E.; Bürkle, S.; Meza-Renken, Z. I. And Rumpel, S. (1999). *Combustion and Gasification Kinetics of Pyrolysis Chars from Waste and Biomass*. Journal of Analytical and Applied Pyrolysis. 49: 221 – 241.

Ho, T. C.; Paul, K. and Hopper, J. R. (1988). *Kinetic Study of Biological Sludge Incineration in a Fluidized Bed*. AIChE Symposium Series 84(262): 126-133.

Howard, J. R. (1989). *Fluidized Bed Technology*. New York: Adam Hilger.

Huang, S.; Jing, S.; Wang, J. F.; Wang, Z. W and Jin, Y. (2001). *Silica White obtained from Rice Husk in a Fluidized Bed*. Powder Technology. 117: 232-238.

James, J. and Rao, M. S. (1986). *Silica from Rice Husk through Thermal Decomposition*. Thermochimica Acta. 97: 329-336

Jenkins, B. M.; Baxter, L. L.; Miles Jr., T. R. and Miles, T. R. (1998). *Combustion Properties of Biomass*. Fuel Processing Technology. 54: 17-46.

Kaupp, A. (1984). *Gasification of Rice Hulls: Theory and Practices*. Eschborn: Deutsches Zentrum Fuer Entwicklungs Technologien (GATE).

Kapur, P. C. (1985). *Production of Reactive Bio-Silica from the Combustion of Rice Husk in a Tube-in-Basket (TiB) Burner*. Powder Technology. 44: 63-67.

Kawser, J. and Farid, N. (2000). *Oil Palm as a Source of Phenol*. Journal of Oil Palm Research Vol. 12 No. I, June 2000, p. 86-94.

Krishnarao, R. V.; Subrahmanyam, J. and Jagadish Kumar, T. (2001). *Studies on the Formation of Black Particles in Rice Husk Silica Ash*. Journal of the European Ceramic Society. 21: 99-104.

Kulasekaran, S.; Linjewile T. M.; Agarwal, P. K. and Biggs, M. J. (1998). *Combustion of a Porous Char Particle in an Incipiently Fluidized Bed*. Fuel. 77(14): 1549-1560.

Levi, K. S. (1991). *A Process Development for Gasification of Rice Husk*. Fuel Processing Technology. 55: 185-192.

Lim, S. Y. (2002). *Combustion Efficiency of Palm Wastes in Spouting and Bubbling Fluidised Beds*. Universiti Teknologi Malaysia: Master Thesis.

Liou, T.H. (2004). *Preparation and Characterization of Nano-Structured Silica from Rice Husk*. Materials Science and Engineering A364: 313-323.

Liu, H. and Lin, Z. (1995). *Combustion Characteristics of Rice Husk in Fluidised Beds*. Proceedings of the 13th International Conference on Fluidised Bed Combustion. 1: 615-618.

Madhiyanon, T.; Piriyarungnoj, N. and Soponnarit, S. (2004). *A Novel Vortex-Fluidized Bed Combustor with Two Combustion Chambers for Rice-Husk Fuel*. Songklanakarin J. Sci. Technology. 26(6): 875-893.

Mahlia, T. M.; Abdulmuin, M. Z.; Alamsyah, T. M. And Mukhlisien, D. (2001). *An Alternative Energy Source from Palm Waste Industry for Malaysia and Indonesia*. Energy Conversion and Management 42 (2001): 2109-2118.

Mansaray, K. G. and Ghaly, A. E. (1997). *Physical and Thermochemical Properties of Rice Husk*. Energy Sources. 19: 989-1004.

Mansaray, K. G., Ghaly, A. E.; Al-Taweel, A. M.; Hamdullahpur, F. and Ugursal, I. (1999). *Air Gasification of Rice Husk in a Dual Distributor Type Fluidized Bed Gasifier*. Biomass and Bioenergy. 17: 315-332.

Mukunda, H. S.; Shrinivasa, U.; Paul, P. J.; Dasappa, S. and Rajan, N. K. S. (1996). *Stand Alone Small Power Level Systems*. Presented at the 7th Annual Conference of India Nuclear Society on India's Energy Needs and Options, BARC, Mumbai, April 1996.

Muthukrishnan, G.P. and Sundarajan, N. A. (1995). *Greenhouse-Gas Emission from Biomass Energy Use: Comparison with other Energy Technologies*. Presented at the 7th Annual Conference of India Nuclear Society on India's Energy Needs and Options, BARC, Mumbai, April 1995.

Natarajan, E.; Nordin. A and Rao, A. N. (1998a). *Overview of Combustion and Gasification of Rice Husk in Fluidized Bed Reactors*. Biomass and Bioenergy. 14(5/6): 533-546.

Ngo, S. P. (2002). *Production of Amorphous Silica Ash from Rice Husk*. Universiti Teknologi Malaysia: Phd Thesis.

Niessen, W. R. (1995). *Combustion and Incineration Processes: Applications in Environmental Engineering*. 2nd Edition. New Yorl: Marcel Dekker, Inc.

Peel, R. B. and Santos, F. J. (1980). *Fluidized Bed Combustion of Vegetable Fuels*. In Proc. of Int. Conf. On Fluidized Bed Combustion: Systems and Applications. pp IIB.2.1-IIB.2.9.

Perry, R. H.; Green, D. W. and Maloney, J. O. (Eds.) (1997). *Perry's Chemical Engineer's Handbook*. 7th Edition. New York: McGraw-Hill.

Pongsak, P. (1992). *Preparation of Silica from Rice Husk by Fluidised Bed Method*. Chulalongkorn University (Dept. of Chemical Technology): Master Thesis.

Preto, F.; Anthony, E.J.; Desai, D. L. and Friedrich, F. D. (1987). *Combustion Trials of Rice Husk in a Pilot-Scale Fluidized Bed*. Proceeding of the 9^{th} International Conference on Fluidized Bed Combustion. 2: 1123-1127.

Rao, T. R. and Bheemarasetti, J. V. R. (2001). *Minimum Fluidization Velocities of Mixtures of Biomass and Sands*. Energy. 26: 633-644.

Real, C.; Alcala, M. and Criado, J.M. (1996). *Preparation of Silica from Rice Husks*. J. Am. Ceram. Soc. 79(8): 2012-2016.

Rozainee, M.; Ngo, S. P.; Salema, A. A.; Tan, K. G.; Ariffin, M. and Zainura, Z. N. (2007). *Effect of fluidising velocity on the combustion of rice husk in a bench-scale fluidised bed combustor for the production of amorphous rice husk ash.* Bioresource Technology 99 (2008) 703–713.

Sen, R. and Ghosh, D. N. (1992). *Fluidization and Combustion Characteristics of Rice Husk*. Indian Chemical Engineer. 34(4): 206-211.

Sridhar, G.; Sridhar, H. V.; Dasappa, S.; Paul, P. J.; Rajan, N. K. S.; Shrinivasa, U. and Mukunda, H. S. (1996). *Technology for gasifying pulverised bio-fuels including agricultural residues. Energy for Sustainable Development*. 3(2): July 1996.

Sumran, M. and Kongkachuichay, P. (2003). *Synthesis of Silica from Rice Husk by One-Step Combustion, Fluidised Bed Combustion and Alkaline Extraction*. KKU Engineering Journal. 30(2): 165-172.

Van den Aarsen, F. G.; Beenackers, A. A. C. M. and van Swaij, W. P. M. (1982). *Performance of a Rice Husk Fluidized Bed Pilot Plant Gasifier*. In Producer Gas 1982: First Int. Conf., Sri Lanka. pp 381-391.

Wen, C. Y. and Yu, Y. H. (1966). *A Generalized Method for Predicting the Minimum Fluidising Velocity*. AIChE Journal. 12: 610-612.

Wu, G.; Wang, J.; Shen, J.; Tang, T.; Zhang, Q.; Zhou, B.; Deng, Z.; Bin, F.; and Zhang, F. (2000). *Properties of Sol–Gel Derived Scratch-Resistant Nano-Porous Silica Films by a Mixed Atmosphere Treatment*. Journal of Non-Crystalline Solids. 275(3): 169-174.

Xia, J. L.; Yadigaroglu, G.; Liu, Y. S.; Schmidli, J. and Smith, B. L. (1998). *Numerical and Experimental Study of Swirling Flow in a Model Combustor*. Int. J. Heat Mass Transfer. 41(11): 1485-1497.

Xu, B. Y.; Huang, W. C.; Flanigan, V. J. and Sitton, O. C. (1985). *Design and Operation of a 6 Inch Fluidized Bed Gasifier for Rice Hulls.* Symposium on Energy from Biomass and Waste **IX**. Organised by IGT, Chicago, U. S. A. pp 595-613.

Yalçin, N. and Sevinç, V. (2001). *Studies on Silica Obtained from Rice Husk.* Ceramics International. 27: 219-224.

Yin, X. L.; Wu, C. Z.; Zheng, S. P. and Chen, Y. (2002). *Design and Operation of a CFB Gasifier and Power Generation System for Rice Husk.* Biomass and Bioenergy. 23: 181-187.

Zenz, F. A. and Weil, N. A. (1958). *A Theoretical-Empirical Approach to the Mechanism of Particle Entrainment from Fluidised Beds.* AIChE Journal. 4:472.