COMPARISON OF FLUIDISED BED AND SPOUTED BED FOR THE COMBUSTION OF RICE HUSK

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Dedicated to my respected parents

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ABSTRACT

The purpose of this study was to evaluate the characteristics and performance of fluidised and spouted bed for the combustion of rice husk. With the annual generation rate of rice husk of approximately 0.4 million metric tones in Malaysia, disposal of the husk was a problem. The calorific value of the husk and the amorphousity of the ash make combustion the better option due to the vast reduction in volume of rice husk and control in combustion temperature. Numerous combustion systems are currently available but fluidised and spouted beds have numerous advantages over the other systems. Hydrodynamic studies show that sand size range of 0.30 mm to 0.50 mm and 0.50 mm to 0.71 mm are suitable as the bed material for fluidised and spouted bed respectively. Combustion studies were conducted in a 90 mm OD combustor fitted with a 60° conical base using commercial sand grade 20/30 and 30/60. Autogenous combustion could be achieved at air factor 0.7 to 1.5 (static bed height = $0.5D_c$) in a fluidised bed and at air factor 1.0 to 1.5 (static bed height = $1.5D_c$) for a spouted bed fitted with a draft tube (SBDT). However, the study showed that combustion could not be achieved with the conventional spouted bed. Fluidising velocities of $4.5U_{mf}$ to $6U_{mf}$ and spouting velocities of $1.75U_{ms}$ to $2.85U_{ms}$ were optimised for autogenous combustion. Higher bed temperature was observed for fluidised bed combustion of rice husk. XRD analysis further showed that fluidised bed fly ash was amorphous. Performance evaluation revealed that fluidised bed was a better option than spouted bed. Autogenous combustion and amorphous ash could also be achieved when combustion was conducted in a large-scale fluidised bed (210 mm ID, static bed height = $0.5D_c$, sand 30/60). This study demonstrated that fluidised bed was suited for the combustion of rice husk compared to the spouted bed.

ABSTRAK

Matlamat penyelidikan ini adalah untuk menilai ciri-ciri dan prestasi lapisan terbendalir dan lapisan terpancut untuk pembakaran sekam padi. Dengan kadar penghasilan sekam padi sebanyak 0.4 juta tan metrik setahun, pembuangan sekam padi merupakan satu masalah. Dengan nilai kalori sekam padi dan abu yang bersifat amorfus, pembakaran adalah pilihan yang baik kerana pengurangan isipadu yang ketara dan kawalan suhu pembakaran. Walaupun terdapat banyak sistem pembakaran, lapisan terbendalir dan lapisan terpancut memiliki beberapa kelebihan. Kajian hidrodinamik menunjukkan pasir bersaiz 0.30 mm ke 0.50 mm dan 0.50 mm ke 0.71 mm sesuai menjadi bahan nadir lapisan terbendalir dan lapisan terpancut. Pembakaran dilakukan dengan turus 90 mm yang mempunyai dasar kon bersudut 60° dan pasir komersial gred 20/30 dan 30/60 merupakan bahan nadir. Pembakaran sekam padi yang stabil dapat dilakukan pada faktor udara 0.7 hingga 1.5 (ketinggian bahan nadir = $0.5D_c$) untuk lapisan terbendalir dan pada faktor udara 1.0 hingga 1.5 untuk lapisan terpancut yang dipasang dengan "*draft tube*". Kajian ini menunjukkan pembakaran sekam padi tidak dapat dilakukan dengan lapisan terpancut konvensional. Kelajuan terbendalir $4.5U_{mf}$ hingga $6U_{mf}$ dan kelajuan terpancut $1.75U_{ms}$ hingga $2.85U_{ms}$ sesuai untuk pembakaran sekam padi. Suhu pembakaran yang tinggi diperolehi untuk lapisan terbendalir. Analisis XRD menunjukkan abu sekam padi dari pembakaran dengan lapisan terbendalir berciri amorfus. Penilaian hasil kajian menunjukkan lapisan terbendalir adalah lebih baik dari lapisan terpancut. Pembakaran sekam padi dengan lapisan terbendalir skala-besar (210 mm OD, ketinggian lapisan nadir = $0.5D_c$, pasir komersial 30/60) juga memberi abu yang amorfus. Penyelidikan ini menunjukkan lapisan terbendalir adalah sesuai untuk pembakaran sekam padi berbanding dengan lapisan terpancut.

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A	Surface reaction rate constant (87,100 $kgm^{-2}s$ atm)
A	Frequency factor
A_o	Theoretical air volume (L)
Ar	Archimedes number $= \frac{d_p{}^3 \rho_g (\rho_s - \rho_g) g}{\mu^2}$, dimensionless
A_w	Area of the wall surface submerged in the annular bed, (m^2)
C_D	Drag coefficient = $\frac{4 d_v g (\rho_s - \rho_f)}{3 \rho_f U_m{}^2}$
CI	Combustion intensity ($kghr^{-1}m^{-2}$)
C_o	Oxygen concentration inlet of the bed (g mole cm^{-3})
C_R	Oxygen concentration at particle surface (g mole cm^{-3})
C_b	Oxygen concentration in the bed (g mole cm^{-3})
c_p	Oxygen concentration in the fluidising air within the bed (kmol m^{-3})
d	Particle diameter, (m)
daf	Dry ash free
d_B	Density of the bed; cylinder bore, (kgm^{-3})
d_i	Initial particle of coal or diameter of solid fuel of char particle (m)
d_p	Diameter of inert particle, (m)
d^*_p	Dimensionless particle size
d_{pc}	Diameter of particle collected with 50% efficiency, (m)
D	Body diameter of cyclone; Nominal screw diameter, (m)
D_d	Dust outlet of cyclone, (m)
D_e	Outlet diameter of cyclone, (m)

D_c	Column diameter, (m)
D_G	Binary molecular diffusion coefficient of oxygen in the air (m^2s^{-1})
D_i	Diameter of gas inlet orifice, (m)
D_o	Diameter of the orifice, (m)
D_g	Diffusivity of oxygen gas (cm^2s^{-1})
D_p	Diameter of carbon particle (mm)
E	Activation energy (35,700 kcal mol^{-1})
E	Activation energy of carbon
F_H	Main resistances as the material continue to progress
F_H	Mass flow rates of hydrogen
F_m	Horse power factor for screw conveyor
F_N	Resistances due to the operating at no load
F_O	Mass flow rates of oxygen
F_{St}	Resistances due to the inclination
FR	Feed rate ($gmin^{-1}$)
g	Acceleration of gravity, (9.81 ms^{-2})
H	Inlet height, (m)
H_c	Height of conical section, (m)
ΔH	Enthalpy of thermal decomposition of a fuel into char and volatile matter
H_m	Maximum spoutable bed depth, (m)
I_M	Capacity of the screw conveyor, ton $hour^{-1}$
k_c	Reaction rate constant (s^{-1})
$k_{ov,\, i}$	Frequency factor
L	Length (m)
L_B	Body length of cyclone, (m)
L_C	Cone length of cyclone, (m)
m_{ov}	Total volatile content (kg)
m_v	Volatile burned (kg)
m_{oc}	Total char content (kg)
m_c	Char burned (kg)

m_c	Mass of the unburnt carbon, (kg)
	Mass flow rate for feeder, ($kghour^{-1}$)
N	Number of particles
n	Number of samples
Nu	Nusselt number = ($\frac{h_w d_p}{\lambda_f}$)
ΔP_b	Pressure drop across the bed, (Nm^{-2})
ΔP_{max}	Peak pressure drop, prior to spouting, (Nm^{-2})
Pt	Fractional penetration
Q	Volumetric flow rate of the air supplied (liter/min)
R	Ideal gas characteristics, Universal gas constant (1.986 kcal $kmol^{-1}$ K^{-1})
r	Radius of solid fuel (m)
$Re_{p,mf}$	Reynolds number, (dimensionless)
S	Outlet length of cyclone, (m)
Sc	Schmidt number = $\mu_f / \rho_f D_g$, (dimensionless)
Sh	Sherwood number = $\frac{k_g d_c}{D_g}$, (dimensionless)
Sh_b	Mean Sherwood number in spouted bed
Sh_i	Intrinsic Sherwood number
S_p	Surface area of particle, (m^2)
T	Temperature, (K or °C)
t_b	Burn-out time of a single char particle (s)
T_m	Temperature of the air flow meter, (K)
T_p	Solids temperature in the annulus
T_s	Absolute temperature of the carbon surface
t_d	Time for complete devolatilisation (s)
T_{bed},T_d	Temperature of the bed and devolatilisation of solid fuel (°C)
T_d, T_f	Temperature of the furnace and particle (°C)
T_c	Combustion temperature (°C)
T_p	Temperature of the particle (°C)
u^*	Dimensionless gas velocity

U	Fluidising gas velocity, (ms^{-1})
U_{mf}	Minimum fluidising velocity-superficial, (ms^{-1})
U_{ms}	Minimum spouting velocity-superficial, (ms^{-1})
U_t	Terminal velocity $U_t = \left(\frac{4d\rho_p g}{3C_D \rho} \right)^{1/2}$ (ms^{-1})
V_i	Amount of volatile
V^*	From V_i when t approaches infinity
V_p	Volume of particle, (ms^{-1})
W	Inlet width of cyclone, (m)
X	Weight of sample left after thermal treatment (gm)
Y	Weight of sample used (gm)

Greek Letters

α, β	Molar flow rate of air supplied in the dry flue gas, (mol/min)
γ	Cone angle (radian)
λ	Particle shape factor
$\varepsilon, \varepsilon_o$	Bed voidage, Mean voidage around the burning char particle
ε_{mf}	Bed voidage at minimum fluidization
π	Constant, 3.142
ρ_b	Bulk density of the bed, (kgm^{-3})
ρ_g	Density of gas, (kgm^{-3})
ρ_f	Fluid density, (kgm^{-3})
ρ_m	Density of solid fuel (kgm^{-3})
ρ_i, ρ_c	Density of initial solid fuel and char (kgm^{-3})
ρ_s, ρ_p	Particle density, (kgm^{-3})

ϕ_s Particle sphericity

θ Effective number of turns made in traversing the cyclone,

$$\left[\frac{\pi}{H}\left(2L_b + L_c\right)\right]$$

μ, $\mu_{f,}$ Fluid viscosity, ($kgm^{-1}s^{-1}$)

μ_g Viscosity of fluidising gas ($kgm^{-1}s^{-1}$)

η_{CE} Combustion efficiency, (%)

κ Thermal conductivity ($Wm^{-1}K^{-1}$)

τ Thermal diffusivity ($K\rho_i^{-1}C_p^{-1}$)

Ω Air factor

Abbreviation

AR Air factor

CSA Cross sectional surface area (m^{-2})

CV Calorific value, ($kJkg^{-1}$)

CV_c Calorific value of carbon, (18.5 $kJkg$ $carbon^{-1}$).

EA Excess air

FB Fluidised bed

HCV_f Higher caloric value of the solid fuel (rice husk)

HHV Higher heating value

ID Internal diameter

LHV Lower heating value

LPG Liquefied petroleum gases

LPM Liters per minute

OD Outer diameter

RH Rice husk

RHA	Rice husk ash
RT	Room temperature
SB	Spouted bed
SBDT	Spouted bed draft tube
SFBC	Spout-fluidised bed combustion
TGA	Thermogravimetric analysis
XRD	X-Ray Diffraction

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CHAPTER 1

INTRODUCTION

1.1 Disposal of Rice Husk

With the country's economy mostly contributed by the agriculture sector, Malaysia will have an abundance of biomass for disposal (Table 1-1). An example of this biomass is rice husk. Rice husk weights approximately 20 % of the paddy weight (Natarajan *et al.,* 1998a). With the production of paddy in Malaysia of around 2.2 million metric tonnes (Paddy Statistics of Malaysia, 1996), the generated husk quantity is about 400,000 metric tonnes. Due to the vast volume of rice husk, disposal is a problem. As it has a low bulk density and high ash content, handling of the husk is also a problem (Jain *et al.,* 1995). The physical form of rice husk which is seldom homogenous caused it not to be free flowing.

Due to the large quantities of rice husk, it is also an environmental problem if it is not fully utilized (Lu and Woo, 1986) or not properly disposed (Yeoh and Ong, 1989). Currently, Beras Nasional (BERNAS, 2003) is looking into ways of disposing the rice husk such as landfilling, control burning for power generation, pulverized and reclamation of rice husk in other products. Landfilling however created environmental problems besides the shortage of suitable sites. The pulverization plant is costly for BERNAS with each of the plant having an average cost of about RM250, 000.00. The reason for pulverization is to increase the density of the husk and making it readily available for marketing. Reclamation of rice husk by BERNAS such as the production of fertilizer, composite plastic and the manufacturing of fiber reinforce composite from black rice husk ash is not feasible due to the low market demand for these products.

The huge volume of rice husk also is also a management problem. This is due to open burning of the husks and the straws which would emit thick smoke and thus reduces the visibility range. As shown in Appendix A-1, the accident at Bukit Ko'bah was due to such practice.

Table 1-1: The planted area of main crops in Malaysia (Department of Statistics, 1996).

Crop	Biomass	Land area (hectares)	Production per year (tonnes)
Oil palm	Shell, fiber, empty fruit branches	2.69×10^6	$^*8.35 \times 10^6$
Coconut	Husk, shell, copra cake	0.23×10^6	$^\$26.91 \times 10^3$
Rubber	Wood	1.64×10^6	1.08×10^6
Pineapple	Bran	7.1×10^3	121.91×10^3
Paddy	Husk	0.68×10^6	$^\#1.44 \times 10^6$

* As crude palm oil
$ As coconut oil
# As rice

However, with proper management of rice husk, amorphous silica could be obtained. In addition, the calorific value of rice husk makes it a potential renewable energy source. Further usage of amorphous silica, methods of obtaining amorphous and the potential of rice husk as a replenish energy source are mentioned in Section 2.1.1 and Section 2.2.2.

1.2 Combustion of Rice Husk

With the vast volume of rice husk, disposal options that are currently available besides thermal treatment has many disadvantages such as time consuming, difficulty to find suitable sites for landfill and inability for fast volume reduction. In addition, if land filling is not carried out properly, it can be a major source of air, soil and water pollution for many years. Briquetting of rice husk is also not feasible due to the nature of the rice husk itself and it is costly to pulverize the husks. Since rice husk has low bulk density, transportation is a problem due to huge volume. Thus, combustion will be a good option as the reduction of volume can be done promptly and on the site in order to obtain rice husk ash residue that is useful for other commercial applications besides the production of heat energy for other on site applications such as power generation and drying processes.

1.2.1 Advantages of Combustion

The advantages of incineration are as follows (Hoi, 1996): -

i) Hazardous components of the waste and toxic organic can be destroyed
ii) Great volume reduction (up to 90 % from the original size) can be achieved and immediately disposal of waste can be carried out
iii) Waste can be incinerated on site without much of transportation

iv) The discharge of air can be controlled

v) The obtained ash residue is sterile and non-hazardous

vi) The production of heat energy can be used for other applications

There are many existing combustion technologies for rice husk. However, it is important to evaluate each technology before deciding on the technology to be used.

1.2.2 Existing Combustion Technologies for Rice Husk

With the increasing of waste worldwide and in Malaysia coupled with the publics' concern on the quality of the environment, new technologies are needed for volume reduction of waste. Numerous incineration technologies are available for the disposal of rice husk. The available technologies for the treatment of rice husk are as below:-

a) Rotary kiln
b) Cyclonic combustor
c) Plasma technology
d) Grate-fired furnace
e) Furnace
f) Fluidised bed combustors

The disadvantages of the current technologies besides the fluidised bed combustors are mentioned in Section 2.1. The types of fluidised bed available are mentioned in Section 2.1.1.

1.2.3 Advantages of Fluidised and Spouted Bed

With the advancement of fluidisation technology, the fluidised and spouted bed would have the potential to be used for combustion of rice husk. Both these system do offer some advantages. Fluidised bed combustors are suitable for recovery of energy from biomass and have successfully burned a wide variety of wastes like agricultural wastes, sludges, wood wastes, and hazardous wastes.

Spouted bed had also been shown to be able to combust solid, liquid and gases fuels (Khoshnoodi and Weinberg, 1978; Arbib and Levy, 1982; Lim *et al.*, 1988; Khosnoodi and Rozana, 1994). Therefore, spouted bed also has the potential for the combustion of rice husk. The advantages of spouted bed (SBC) and fluidised bed are shown in Table 1-2 (Zhao *et al.*, 1987; Ho *et al.*, 1988; Howard, 1989b; Affendi *et al.*, 1991; Olazar *et al.*, 1994; Werther *et al.*, 2000).

1.3 Purpose of the Study

In general, the purpose of this research is to evaluate between fluidised and spouted bed which system has the potential to combust rice husk within a short period besides obtaining amorphous ash. Preliminarily, hydrodynamic studies would be performed to determine the optimum operating parameter for the combustion of rice husk.

Table 1-2: Advantages of fluidised and spouted bed technology.

Features	Fluidised Bed	Spouted Bed
1) Simplicity in design	No moving parts.	No distributor. Could be used in scarcely located paddy schemes. Economically to construct due to lower pressure drop.
2) Versatile Operation	All types of fuel could be burned. Fluctuation in the feed rate is easily tolerated.	Has the ability to burn lower quality fuel and fuel with high ash content.
3) Combustion efficiency	Up to 99 %. 96 % of sludge waste can be combusted within the first minute of incineration	Above 90 %.
4) Stable Continuous Combustion	Large heat capacity of the sand helps to maintain the operation.	Large heat capacity of the sand helps to maintain the operation.
5) Uniform temperature	Turbulent mixing of solids prevents hot spots.	No hot spots and thus materials of thermal sensitive could be treated.
6) Low Air Pollution Emission	Due to low combustion temperature (below 850°C), NO_x formation and evaporation rate of heavy metals could be minimised. The highly mixed oxygen-rich environment is good for complete combustion.	Due to low combustion temperature (below 850°C), NO_x formation could be minimised.
7) High Heat-Transfer	Possible for energy recovery.	Possible for energy recovery.
8) Material Handling	Could be fed either with over-bed or under-bed feeding.	Could be fed either with over-bed or under-bed feeding.

1.4 Justification and Objectives of the Study

With the disposal problem of rice husk in rice producing countries such as Malaysia coupled with the potential of amorphous rice husk ash and energy recovery from rice husk, combustion of rice husk rather than direct disposal is a better option. Therefore, evaluation of combustion system for rice husk is important in order to provide a better option for vast volume reduction, energy recovery and obtaining amorphous silica. This could be achieved by studying the mixing pattern of the bed as bad mixing would give rise to incomplete combustion, causing detrimental effect to the environment besides giving low quality ash.

With the setbacks of other combustion systems, fluidised and spouted bed has the potential to be used for rice husk combustion besides these two systems had been successfully applied in the field of combustion of a variety of fuel. However, no evaluation study on these two systems had been carried out for combustion of rice husk. In addition, previous studies on combustion of rice husk with fluidised bed were also carried out in different geometric shape and did not present the details of the bed hydrodynamics, the effect of fluidising air and the characteristics of the obtained fly ash.

Therefore, the objectives of this study were:-

i) To design and develop a laboratory-scale rig for fluidised and spouted bed studies. Initial hydrodynamic studies were conducted with the developed rig. Then, combustion studies of rice husk were performed on the same rig.

ii) To evaluate between fluidised and spouted bed the system of choice for combustion of rice husk.

iii) To conduct a trial run of the system of choice in a large-scale combustor.

1.5 The Scopes of the Study

The scopes of this study were presented. Initial determination of characteristics of the research materials (rice husk, rice husk ash and sand) were carried out to assist in the feeding of the husk and isolation of the ash. The chemical properties of rice husk were to assist in combustion studies.

This was followed by the development of the rig optimum design parameters of the laboratory-scale fluidised and spouted bed combustor system (column geometry and height, distributor design, cyclone design and feeding system).

Upon completion, hydrodynamic studies were performed to determination to determine the operating bed height and the sand size to be sued as the bed material for fluidised and spouted bed. Once this had been known, the determination of the optimum operating parameters for the combustion of rice husk in fluidised and spouted bed (such as fluidising/spouting number, combustion temperature profiles and air factors) were investigated. During the combustion studies, the collected fly ash would be analysed to determine on the combustion performance of the fluidised and spouted bed.

Upon the completion of the combustion studies, evaluation between fluidised and spouted bed were conducted to determine the system for the combustion of rice husk in a large-scale combustor. Once the system had been chosen, further verification on the system of choice was carried out in a large-scale combustor with pre-fixed operating parameters. The collected fly ash from the large-scale combustion would be analysed to determine any improvement on the combustion with a large-scale rig.

1.6 Outline of the Thesis

This thesis describes the research work to evaluate the system of choice for rice husk combustion between spouted bed and fluidised bed in term so overcoming the environmental problem besides obtaining amorphous ash. This study investigates the fundamental operating parameters of spouted bed and fluidised bed at a laboratory scale and applying the obtained results to a large-scale rig.

Chapter 1 described a brief introduction on the problem of rice husk as a waste in countries like Malaysia It also briefly describes the available thermal treatment technologies for rice husk. and its disadvantages. The purpose, the objectives, scope and an outline of the study are also mentioned.

Chapter 2 briefly describes the disadvantages of the available thermal treatment technologies for rice husk. The importance of rice husks as a source for amorphous ash and energy is also mentioned. The chapter also describes a review of the related theories of fluidisation in a bubbling fluidised bed and spouted bed. A review on the combustion of rice husk in spouted bed and fluidised bed is also mentioned. This chapter also covers the related theories on combustion of solids.

Chapter 3 described research design, the rig description of the laboratory scale and the large scale, the materials in the present study and the research methodology. The basis of design for the main components of the rig starting from the distributor plate, the cone, the column, the cyclone and the fuel feeding system are also described besides the method of start-up. The characteristics of the research materials (rice husk, rice husk ash and sand) were also described.

Chapter 4 presented the results on the hydrodynamics of spouted bed and fluidised bed for sieved sand to determine the sand size. The result on hydrodynamics of draft tube on the spouted bed with commercial sand is also mentioned. Results from hydrodynamic studies on commercial sand for fluidised bed were also disclosed.

Chapter 5 covered the combustion results for conventional spouted bed, effect of draft tube (SBDT) and fluidised bed. The effect of air supply, primary inlet velocity and the optimum operating spouted bed height are discussed. The quality of the obtained fly ash is also presented. Finally, an evaluation on the performance of fluidised and spouted bed is presented.

Chapter 6 disclosed combustion performance and the quality of the fly ash from a trial run on the selected system of choice (fluidised bed) for the combustion of rice husk in a large-scale 210 mm ID column.

Chapter 7 provided the conclusion on the overall studies and recommendations of the study.

BIBLIOGRAPHY

Abdul Halim, S. and Mohd Tusirin, M.N. Design Considerations for Fluidised Bed Combustion of Oil Palm Solid Wastes. In: *Proceedings of Asean Conference on Energy from Biomass;* 13 - 15 October 1986: Penang, Malaysia: 62 - 75.

Abdullah, M.Z., Husain, Z. and Yin Pong, S.L. (2003). Analysis of Cold Flow Fluidisation Test Results for Various Biomass Buels. *Biomass and Bioenergy;* 24: 487 - 494.

Affendi, M., Martosudirjo, S., Susanto, M. and Susanto, H. Potential of the Spouted/Fluidised Bed Combustor for Waste Utilization. In: *Proceedings of the Third ASEAN Fluidised Bed Combustion Workshop;* 6 - 9 November 1991: Bangkok and Chiang Rai.

Agamuthu, P. (1997). Thermal Treatment of Solid Waste and Pyrolysis. In: *Effective Solid Waste Management.* Eds. Agamuthu, P. and Nather, K. Ecotone Management Sdn Bhd. Pages 8.1 - 8.15.

Ahmad, S.A. and Syred, N. Experimental Investigations of Biomass Pyrolisation Characteristics in a 200 kW Pyrolyser. In: *European-Asean Conference on Combustion of Solids and Treatment of Products;* 16 - 17 February 1995: Bangkok, Thailand: 97 - 105.

Ajiwe, V. I. E.; Okeke, C. E. and Akigwe, F. C. (2000). "A Preliminary Study of Manufacture of Cement from Rice Husk Ash". *Bioresource Technology*; 73: 37 - 39.

Albina, D.O. (2003). Combustion of Rice Husk in a Multiple-Spouted Fluidised Bed. *Energy Sources;* 25 (9): 893 - 904.

Altwicker, E.R. and Konduri, R.K.N.V. (1992). Hydrodynamic Aspects of Spouted Beds at Elevated Temperatures. *Combusion Science and Technology;* 87: 173 - 197.

Andrei, M.A., Sarofim, A.S. and Beer and Beer, J.M. (1985). Time Resolve Burnout of Coal Particles in a Fluidised Bed. *Combustion and Flame;* 61: 17 - 27.

Anuradha, G., Prem, D.G. and Ramachandralyer, P.V. (1992). Combustion and Gasification Charatceristics of Rice Husk. *Fuel;* 71: 889 - 994.

Arbib, H.A. and Levy, A. (1982). Combustion of low heating value fuels and wastes in the spouted bed. *Canadian Journal of Chemical Engineering;* 60: 528 - 531

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

Babu, B.V. and Chaurasia, A.S. (2004). Heat Transfer Kinetics in the Pyrolysis of Shrinking Biomass Particle. *Chemical Engineering Science;* 59: 1999 – 2012.

Baharuddin, A. and Sohif, M. Combustion of Rice Husk for Electrical Power Generation. In: *Proceedings of National Seminar on Management and Utilization of Industrial Wastes;* 13 - 14 September 1984: Universiti Pertanian Malaysia.

Baharuddin, A. and Sohif, M. Design Characteristics of a Vertical Rice Husk Cyclone Combustor. In: *Proceedings of Asean Conference on Energy from Biomass;* 13 - 15 October 1986: Penang, Malaysia: 89 - 93.

Banerjee, H.D., Charaverty, A., Mahapatra, A.K. and Nishra, P. (1985). Combustion Process of Rice Husk for Amorphous Silica Production. *Agricultural Mechanisation in Asia, Africa and Latin America;* 16 (2): 67 - 71.

Beagle, E.C. (1978). Rice Husk: Conversion to Energy. *FAO Agricultural Service Bulletin:* 31.

Becker, H.A. (1961). An Investigation of Laws Governing the Spouting of Course Particles. *Chemical Engineering Science.;* 13: 245.

BERAS NASIONAL (BERNAS). (2003). A Briefing on Rice Husk Management by BERNAS.

Berruti, F., Muir, J.R. and Behie, L.A. (1988). Solid Circulation in a Spout-Fluid Bed with Draft Tube. *Canadian Journal of Chemical Engineering;* 66: 919 - 923.

Bhattacharya, S.C. (1998). State of the Art of Biomass Combustion. *Energy Sources;* 20: 113 - 135.

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

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

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

Bhattacharya, S.P. and Harttig, M. (2003). Control of Agglomeration and Defluidisation Burning High-Alkali, High-Sulphur Lignites in a Small Fluidized Bed Combustor - Effect of Additive Size and Type, and the Role of of Calcium. *Energy and Fuels;* 17: 1014 - 1021.

Boateng, A.A. and Skeete, D.A. (1990). Incineration of Rice Hull for Use as a Cementitious Material: The Guyana Experience. *Cement Concrete Research;* 20: 795 - 802.

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

Borman, G.L. and Ragland, K.W. (1998). *Combustion Engineering*. United States of America: McGraw-Hill. 463 - 474.

Botterill, J.S.M., Teoman, Y. and Yuregir, K.R. (1982). The Effect of Operating Temperature on the Velocity of Minimum Fluidisation, Bed Voidage and General Behaviour. *Powder Technology;* 31: 101 - 110.

Brereton, C.M.H., Epstein, N. and Grace, J.R. (1996). Side-Outlet Spouted Bed with Draft Tube: Effect of varying the Position of the Outlet. *Canadian Journal of Chemical Engineering;* 74 (4): 542 - 546.

Briens, C. L., Bergougnou, M. A. and Baron, T. (1988). Prediction of Entrainment from Gas-Solid Fluidised Beds. *Powder Technology;* 54: pp 186 - 196.

Brown, G.G. (1950). Unit Operations. John Wiley and Sons Publishers, New York.

Brunner, C.R. (1991). Rotary Kiln Technology. In: "*Handbook of Incineration Systems*", McGraw-Hill Incorporated, New York; 12.1 - 12.13.

Chakraborty, R.K. and Howard, J.R. (1981). Combustion of Char in Shallow Fluidised Bed Combustors: Influence of Some Design and Operating Parameters. *Journal of Institute of Fuel;* 51: 220 - 224.

Chakraverty, A., Banerjee, H.D. and Mishra, P. (1990). Production of Amorphous Silica from Rice Husk in a Vertical Furnace. *Agricultural Mechanisation in Asia, Africa and Latin America;* 21 (4): 69 - 75.

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. *Journal of Materials Science;* 23: 21 - 24.

Chakraverty, A., Mishra, P. and Banerjee, H.D. (1985). Investigation of Thermal Decomposition of Rice Husk. *Thermochimica Acta;* 94: 267 - 275.

Chandnani, P.P. and Epstein, N. Spoutability and Spout Destabilization of Fine Particles with a Gas. In: *Fluidisation, Proceedings of Fluidisation,* V.K. Ostergaard and A. Sorensen, Eds., Engineering Foundation, New York (1986); 233 - 240.

Chen, K.S., Hsu, W.T., Lin, Y.C., Ho, Y.T. and Wu, C.H. (2001). Combustion Modeling and Performance Evaluation in a Full-Scale Rotary Kiln Incinerator. *Journal of Air and Waste Mangement Association;* 51: 885 - 894.

Chen, G.Y., Fang, M.X., Luo, Z.Y., Yu, C.J., Li, X.T., Ni, M.J. and Cen, K.F. (1998). Study on Combustion Characteristics of Rice Husk-Fired Fluidised Bed Boiler. *RanShao Kexue Yu Jishu;* 4 (2): 193 - 198.

Choi, J. H., Choi, K. B., Peter K., Shun D. W., Kim S. D. (1997a). The Effect of Temperature on Particle Entrainment Rate in a Gas Fluidised Bed. *Powder Technology;* 92: 127 - 133.

Chungsangunsit, T., Gheewala, S.H. and Patumsawad, S. (2004). Environmnetal Assessment of Electricity Production from Rice Husk: A Case Study in Thailand. In: *Electricity Supply Industry in Transaction: Issues and Porpects for Asia.* 14 – 16th January, Bangkok, Thailand.

Concha, R., Maria, D.A. and Jose, M.C. (1996). Preparation of Silica from Rice Husk. *Journal of American Ceramic Society;* 79 (8): 2012 - 2016.

Cook, H.H. and Bridgwater, J. (1985). Particle Residence Times in the Continuous Spouting of Mixtures. *Canadian Journal of Chemical Engineering;* 63: 326 - 331.

Cooke, R.B., Goodson, M.J. and Hayhurst, A.N. (2003). The Combustion of Solid Wastes as Studied in a Fluidised Bed. *Transactions of Institution of Chemical Engineers Part B;* 81: 156 - 165.

Cooper, C.D. and Alley, F.C. Cyclones. In: *Air Pollution Control: A Design Approach*, PWS Publishers, Boston: 1986.

Davis, L. and Cornwell, D. A. (1998). Introduction to Environmental Engineering. McGraw-Hill Series in Water Resources and Environmental Engineering.

Della, V.P., Kuhn, I. and Hotza, D. (2002). Rice Husk Ash as an Alternate Source for Active Silica Production. *Materials Letters;* 57: 818 - 821.

Di Blasi, C., Buonanno, F. and Branca, C. (1999). Reactivities of Some Biomass Chars in Air. *Carbon;* 37: 1227 – 1238.

Doheim, M.A. and Collinge, C.N. (1978). Effect of Temperature on Incipient Fluidisation and Study of Bed Expansion. *Powder Technology;* 21: 289 - 293.

Errgun, S. (1952). Fluid Flow through Packed Bed Column. *Chemical Engineering Progress;* 48: 89 - 94.

Fane, A.G. and Mitchell, R.A. (1984). Minimum Spouting Velocity of Scale-up Beds. *Canadian Journal of Chemical Engineering;* 62: 437 - 439.

Fang, M., Wang, Q., Chen, G., Zhi, Z., Yu, C., Zhou, J., Luo, Z. and Cen, K. (2003). Experimental Study on Rice Husk Combustion in a Circulating Fluidised Bed. *Fuel Processing Technology;* 85 (11): 1273 - 1282.

Fiorentino, M., Marzocchella, A. and Salatino, P. (1997). Segreagation of Fuel Particles and Volatile Matter During Devolatilisation in a Fluidised Bed Reactor - I: Model Development. *Chemical Engineering Science;* 52: 1893 - 1908.

Freitas, L.A.P. and Freire, J.T. (2001). Heat Transfer in a Draft Tube Spouted Bed with Bottom Solids Feed. *Powder Technology;* 114: 152 - 162.

Geankoplis, C.J. (1995). Chapter 3: Principles of momentum transfer and apllications. In: *Transport Process and Unit Operations (Third Edition).* Prentice Hall Inc., New Jersey: 114 - 213.

Geldart, D. (1972). The Effect of Particle Size and Size Distribution on the Behaviour of Gas-fluidised Beds. *Powder Technology;* 6: 201 - 215.

Geldart, D. (1973). Type of Gas Fluidisation. *Powder Technology;* 7: 285 - 292.

Geldart, D. (1986). Chapter 6: Particle Entrainment and Carryover. In: *Gas Fluidisation Technology*. Great Britain: A Wiley-Interscience Publication. 123 - 153.

Grover, P.D. (1991). Pyrolysis Cum Steam Gasification of rice Husk for Co-generation of Power and Amorphous Silica – A Case for Agro Based Decentralised Rural Energy System. In: *Third Asian Conference on Technology for Rural Development;* 12 – 14 August; Kuala Lumpur; 132 – 148.

Guedes de Carvalho, J.R.F., Pinto, A.M.F.R. and Pinho, C.M.C.T. (1991). Mass Transfer around Carbon Particles Burining in Fluidised Beds. *Transactions International Chemical Engineering;* 69: 63 – 70.

Guo, Q., Yue, G., Suda, T. and Sato, J. (2003). Flow Characteristics in a Bubbling Fluidised Bed at Elevated Temperatures. *Chemical Process Engineering;* 42: 439 - 447.

Haider, A. and O, Levelspiel. (1989). Drag Coefficient and Terminal Velocity of Spherical and Non-spherical Particles. *Powder Technology;* 58: 1: 63 - 70.

Halimaton, H., Mohd Nazlan, M.M., Salasiah, E., Endang, L. and Zainab, R. (1997). ^{29}Si MAS NMR, XRD and FESEM Studies of Rice Husk Silica for the Synthesis of Zeolites. *Journal Non-Crystalline Solids;* 211: 126 - 131.

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.

Hammad, H., Zurigat, Y., Khzai, S., Hammad, Z. and Mobydeen, O. (1998). Fluidised Bed Combustion Unit for Oil Shale. *Energy Conversion Management;* 39 (3 - 4): 269 - 272.

Hanafi, S., Abo-El-Enein, S.A., Ibrahim, D.M. and El-Hemaly, S.A. (1980). Surface Properties of Silicas Produced by Thermal Treatment of Rice-husk Ash. *Thermochimica Acta;* 37: 137 - 143.

Hartiniati, Soemardjo, A. and Youvial, M. (1989). Performance of a Pilot Scale Fluidised Bed Gasifier Fueled by Rice Husk. In: *Pyrolysis and Gasifiaction,* Ferreto *et. al.* Eds, Elsevier Applied Science, London: 257 - 263.

Hatate, Y., Uemura, Y., Tanaka, S., Tokumasu, Y., Tanaka, Y., King, D.F. and Ijichi, K. (1994). Development of a Spouted Bed - Type Coal Gasifier with Cycling Thermal Medium Particles. *Kagaku Kogaku Ronbunshu;* 20: 758 - 765.

Hattori, H. and Nagai, T. (1996). Spouted Bed with a Draft-Tube Without Gas Inlet Nozzle or Orifice. *Journal of Chemical Engineering of Japan;* Vol 28: 484 – 487.

Hilal, N., Ghannam, M.T. and Anabtawi, M.Z. (2001). Effect of Bed Diameter, Distributor and Inserts on Minimum Fluidization Velocity. *Chemical Engineering Technology;* 24 (2): 161 – 165.

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

Hoi, W.K. Smokeless Combustion: An Environmentally Clean Waste Disposal System by Incineration. In: *Asia Pacific Conference on Suitable Energy and Environmental Technology,* Singapore, 1996.

Hoque, M.M. and Bhattacharya, S.C. (2001). Fuel Characteristics of Gasified Coconut Shell in a Fluidised and a Spouted Bed Reactor. *Energy;* 26: 101 - 110.

Hossain, M. and Metzger, J. (1987). Effect of Temperature, Particle Average Diameter and Bed height on Minimum Fluidization Velocity. Particulate and Multiphase Processes, Vol 1: *General Particulate Phenomena;* 633 – 644.

Howard, J.R. *Fluidised Beds: Combustion and Applications.* Applied Science Publishers, London : 1989a.

Howard, J.R. *Fluidised Bed Technology: Principles and Applications.* Adam Hilger Publishers, Bristol: 1989b.

Huang, G.W. and Scaroni, A.W. (1992). Prediction and Measurement of the Combustion Time of Single Coal Particles. *Fuel;* 71: 159 - 164.

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

Hunt, C.H. and Brennan, D. (1965). Estimation of Spout Diameter in a Spouted Bed. *Australian Chemical Engineering;* 5: 9.

Hunt, L.P., Dismukes, J.P. and Amick, J.A. (1984). Rice Hull as a Raw Material for Producing Silicon. *Journal of Electrochemistry Society;* 131 (7): 1683 – 1686.

Ijichi, K., Tanaka, Y., Uemura, Y., Hatate, Y. and Yoshida, K. (1994). Solids Circulation Rate and Holdup in the Draft Tube of a Spouted Bed. *International Chemical Engineering;* 34 (3): 370 - 376.

Islam, M.N. and Nasir, F.A. (1999a). Pyrolytic Oil from Fluidised Bed Pyrolysis of Oil Palm Shell and Its Characterisation. *Renewable Energy;* 17: 73 - 84.

Islam, M.N. and Nasir, F.A. (1999b). Thermal Characteristics of Malaysian Rice Husk. *Jurnal Teknologi;* 30 (A): 39 - 50.

Islam, M.R., Ahmed, R., Shameem Ahsan, S.M. and Islam, M.M. (2002). Hydrodynamic Studies of Fludised Bed Colod Model Reactor for Thermal Conversion of Biomass Solid Waste. *BSME-ASME International Conference on Thermal Engineering;* Dhaka, Bangladesh: 592 – 598.

Ismail, M.S. and Waliuddin, A.M. (1996). Effect of Rice Husk Ash on High Strength Concrete. *Construction Building Materials;* 10: 7: 521 - 526.

Jain, A., Rao, T.J., Sambi, S.S. and Grover, P.D. (1995). Energy and Chemicals from Rice Husk. *Biomass and Bioenergy;* 7: 1 - 6: 285 - 289.

Jatuporn, W., Kanokorn, H., Wilasinee, K. and Nurak, G. (2001). Silica Production from Rice Husk and Rice Husk Ash. In: *Proceedings of Regional Symposium on Chemical Engineering*, Bandung, October 29 - 31: BM4-1 - 4-6.

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

Ji, H.S., Tsutsumi, A. and Yoshida, K. (1997). Characteristics of Particle Circulation in a Spouted Bed with a Draft Tube. *AIChE Symposium Series;* 317 (93): 131 - 135.

Ji, H.S., Tsutsumi, A. and Yoshida, K. (1998). Solid Circulation in a Spouted Bed with a Draft Tube. *Journal of Chemical Engineering of Japan;* 31 (5): 842 - 845.

Jiang, H., Zhu, X., Guo, Q. and Zhu, Q. (2003). Gasification of Rice Husk in a Fluidised Bed Gasifier without Inert Additives. *Industrial and Engineering Chemistry Research;* 42 (23): 5745 - 5750.

Jones, J.M., Pourkashanian, M, Williams, A. and Hainsworth, D. (2000). A Comprehensive Biomass Combustion Model. *Renewable Energy;* 19: 229 - 234.

Kamath, S.R.and Proctor, A. (1998). Silica Gel from Rice Hull Ash: Preparation and Characterisation. *Cereal Chemistry;* 75: 484 - 493.

Kanury, A.M. (1994). Combustion Characteristics of Biomass Fuels. *Combustion Science and Technology;* 97: 469 - 491.

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.

Keating, E.L. (1993). Chapter 2: Solid Fuels. In: *Applied Combustion*, Marcel Dekker Inc., New York: 105 - 154.

Khosnoodi, M. and Weinberg, F.J. (1978). Combustion in Spouted Beds. *Combustion and Flame;* 33: 11 - 21.

Khosnoodi, M. (1991). Heat Generation in Spouted Bed Combustor. *Iranian Journal of Science and Technology;* 15: 1: 87 - 95.

Khosnoodi, M. (1993). Spouted Bed: A Novel Combustor. *Bulletin FKKKSA;* 7: 1: 10 - 26.

Khosnoodi, M. and Rozana, Z.A. Combustion of Malaysian Peat in Fluidised and Spouted Bed Furnaces. In: *Proceeedings of International Conference and Exhibition on Environment and Development,* Kuala Lumpur; 19 - 21 October 1994.

Konduri, R., Altwicker, E. and Morganii, M. (1994). Combustion of Propane in a Spouted Bed: Surface Effects. *Combustion Science and Technology;* 101: 461 - 481.

Khraisha, Y.H. (2005). Batch Combustion of Oil Shale Particles in a Fluidised Bed. *Fuel Procesing Technology;* 86: 691 - 706.

Khraisha, Y.H., Hamdan, M.A. and Qalalweh, H.S. (1998). Direct Combustion of Olive Cake Using Fluidised Bed Combustor. *Energy Sources;* 21: 319 - 327.

Krishnarao, R.V., and Subrahmanyam, J. (1996). Formation of SiC from Rice Husk Silica-Carbon Black Mixture: Effect of Rapid Heating. *Ceramics International;* 22: 489 - 492.

Kulwiec, R.A. Materials Handling Handbook, John Wiley and Sons, New York, 1985.

Kunii,D. and Levenspiel, O. (1991). Fluidisation and Mapping Regimes. In: *Second Edition: Fluidisation Engineering,* Butterworth-Heinemann Publishers, Boston: 61 - 94.

Kutz, M. Liquid Fossil Fuels from Petroleum. In: *Mechanical Engineering Handbook,* A Wiley-Interscience Publications, New York, 1986.

La Nuaze, R.D. A Review on the Fluidised Bed Combustion of Biomass. In: *Proceedings of Asean Conference on Energy from Biomass;* 13 - 15 October 1986: Penang, Malaysia: 22 - 49.

La Nauze, R.D. (1987). A Review of the Fluidised Bed Combustion of Biomass. *Journal of the Institute Energy;* June: 66 - 77.

Lapple, C.E. (1951). Processes Use Many Collector Types. *Chemical Engineering;* 58: 5.

Lawrence, A.D., Bu, J. and Gokulakrishnan, P. (1999). The Interactions Between SO_2, NO_x, HCl and Ca in a Bench-scale Fluidised Combustor. *Journal of the Institute of Energy;* 72: 34 - 40.

Lee, J.K., Gu, J.H., Kim, M.R. and Chun, H.S. (2001). Incineration Characteristics of Dye Sludge in a Fluidised Bed Incinerator. *Journal Chemical Engineering of Japan;* 34 (2): 171 - 175.

Licht, W. (1980). Chapter 6: Centrifugal Collectors. In: *Air Pollution Control Engineering: Basic Calculations for Particulate Collection,* Marcel Dekker Incorporated; New York.

Lim, C.J. and Grace, J.R. (1987). Spouted Bed Hydrodynamics in a 0.91 m Diameter Vessel. *Canadian Journal of Chemical Engineering;* 65: 366 - 372.

Lim, C.J., Barua, S.K., Epstein, N., Grace, J.R. and Watkinson, A.P. Spouted Bed and Spout-fluid Bed Combustion of Solid Fuels. In: *Proceedings of Institute of Energy Symposium on Fluidised Bed Combustion*, 1984, England: 72 - 79.

Lim, C.J., Watkinson, A.P., Khoe, G.K., Low, S., Epstein, N. and Grace, J.R. (1988). Spouted, Fluidised and Spout-Fluid Bed Combustion of Bituminous Coals. *Fuel;* 67: 1211 - 1217.

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

Lin, Z.J., Liu, H., Huang, L. and Liu, D.C. (1994). Combustion Characteristics of a Rice Husk Fluidised Bed. *Journal of Huazhong University Science and Technology;* 22: 21 - 24.

Lin, C.L., Wey, M.Y. and You, S.D. (2004). Effect of Concentration of Bed Materials on Combustion Efficiency During Incineration. *Energy;* 29: 125 - 136.

Liou, T.H., Chang, F.W. and Lo, J.J. (1997). Pyrolysis Kinetics of Acid-leached Rice Husk. *Industrial and Engineering Chemistry Research;* 36: 568 - 573.

Liu, H., Lin, Z.J., Liu, D.C. and Wu, W.H. Combustion Characteristics of Rice Husk in Fluidised Beds. In: *Proceedings 13th. International Conference Fluidised Bed Combustion,* 1, 1995: 615 - 618.

Lu, S.H. and Woo, S.K. Rice Husk Burner and Other Rice Husk Uses in Malaysia. In: *Workshop on Appropriate Technologies on Farm and Village Level Postharvest Grain Handling,* Kuala Lumpur, 1986.

Lyngfelt, A., Amand, L.E., Gustavsson, L. and Leckner, B. (1996). Methods for Reducing the Emission of Nitrous Oxide from Fluidised Bed Combustion. *Energy Conversion Management.;* 37: 6 - 8: 1297 - 1302.

Ma., A.N., Choo, Y.M. and Yusof, B. (1994). Renewabale Energy from the Palm Oil Industry. *ELAIS:* 6: 2:

McNab, G.S. and Bridgwater, J. Spouted Beds: Estimation of Spouted Pressure Drop and the Particle Size for Deepest Bed. In: *Proceedings of European Congress on Particle Technology,* Nuremberg; 1977.

Malek, M.A. and Lu, B.C.Y. (1965). Pressure Drop and Spoutable Bed Height in Spouted Beds. *Industrial Engineering, Chemistry, Process Design and Development;* 4: 123.

Manee, S. and Paisan, K. (2003). Synthesis of Silica from Rice Husk by One-Step Combustion, Fluidised Bed Combustion and Alkaline Extraction. *KKU Engineeering Journal;* 30 (2): 162 - 172.

Mansaray, K.G. and Ghaly, A.E. (1997a). Agglomeration Characteristics of Alumina Sand-Rice Husk Ash Mixtures at Elevated Temperatures. *Energy Sources;* 19: 1005 - 1025.

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

Mansaray, K.G. and Ghaly, A.E. (1998). Thermogravimetric Analysis of Rice Husks in an Air Atmosphere. *Energy Sources;* 20: 653 - 663.

Manurung, F. (1964). Studies in the Spouted Bed Technique with Particualr Reference to Low Temperature Coal Carbonization. *University of New South Wales, Kensington, Australia, PhD Thesis*.

Mathur, K.B. and Epstein, N. *Spouted Beds*. Academic Press, New York, 1974.

Mathur, K.B. and Gishler, P.E. (1955). A Technique for Contacting Gases with Coarse Solid Particles. *AIChE Journal;* 1: 157.

Mathur, A., Saxena, S.C. and Zhang, Z.F. (1986). Hydrodynamic Characteristics of Gas-Fluidised Beds Over a Broad Temperature Range. *Powder Technology;* 47: 247 - 256

Mazrulhisam, M. (2003). Kesan Nikel dan Abu Sekam Padi Terhadap Penghidratan Simen. *Universiti Teknologi Malaysia: Bacherlor of Science Thesis*.

Miccio, F., Scala, F. and Chirone, R. Fluidised Bed Combustion of a Biomass Fuel: Comparison between Pilot Scale Experiments and Model Simulations. In: *Proceedings 17th International Conference on Fluidized Bed Combustion, 2003*: 745 - 752.

Milioli, F.E. and Foster, P.J. (1995). Entrainment and Elutriation Modelling in Bubbling Fluidised Beds. *Powder Technology;* 83: 233 - 243.

Mohd Nazlan, M.M., Halimanton, H., Salasiah, E. and Zainab, R. (1997). Morphology of Zeolite A from Rice Husk and Local Sand by Field Emission Scanning Electron Spectroscopy. *Buletin Kimia;* 12 (1): 61 – 65.

Mokhtar, H., Rashid, A.R.A., Salleh, M. S. and Ujang, Z. Malaysian Experience on Fluidised Bed Combustor for Agricultural Waste. In: *Proceedings of Asean Conference on Energy from Biomass;* 13 - 15 October 1986: Penang, Malaysia: 62 - 75.

Morris, A.S. (1988). *Principles of Measurement and Instrumentation.* Prentice and Hall International, Hertfordshire, England.

Mujumdar, A.S. Spouted Bed Drying. In: *Industrial Drying,* Marcel Dekker Incorporated, New York, 1987: 419 - 474.

Natarajan E. and Nordin, A. (1998). Experimental Determination of Bed Agglomeration Tendencies of Some Common Agricultural Residues in Fluidised Bed Combustion and Gasification. *Biomass and Bioenergy;* 15 : 2: 163 - 169.

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

Natarajan, E., Ohman, M., Gabra, M., Nordin, A., Liliedahl, T. and Rao, A.N. (1998b). Experimental Determination of Bed Agglomeration Tendencies of Some Common Agricultural Residues in Fluidised Bed Combustion and Gasification. *Biomass and Bioenergy;* 15 : 2: 163 - 169.

Nur, H. (2001). Direct Synthesis of NaA Zeolite from Rice Husk and Carbonaceous Rice Husk Ash. *Indonesian Journal of Agricultural Science;* 1: 40 - 45.

Ohtake, K., Sawyer, F. and Hart, J.R. Combustion and Flow in a Two Dimensional Spouted Bed. In: *18th Symposium International Conference on Combustion: The Combustion Institute, 1984*: 1427 - 1433.

Olazar, M., Aguado, R. Sanchez, J.L., Bilbao, R. and Arauzo, J. (2002). Thermal Processing of Straw Black Liquor in Fluidised Bed and Spouted Bed. *Energy and Fuels;* 16: 1417 - 1424.

Olazar, M., San Jose, M.J., Llamosas, R. and Bilbao, J. (1994). Hydrodynamics of Sawdust and Mixtures of Wood Residues in Conical Spouted Beds. *Industrial and Engineering Chemistry Research;* 33: 993 – 1000.

Paddy Statistics of Malaysia, Department of Agriculture, Peninsular Malaysia; 1996.

Padhi, B.K. and Patnaik, C. (1995). Developmentof Si_2N_2O, Si_3N_4 and SiC Ceramic Materials Using Rice Husk. *Ceramics International;* 21: 213 - 220.

Patel, M., Karera, A. and Prasanna, P. (1987). Effect of Thermal and Chemical Treatments on Carbon and Silica Contents in Rice Husk. *Journal of Materials Science;* 22: 2457 - 2464.

Peel, R.B. and Santos, F.J. Fluidised Bed Combustion of Vegetable Fuels. In: *Proceedings of Institute of Energy's International Conference, Volume III Fluidised Bed Combustion: Systems and Application,* London 1980: II-B-2.1 - II-B-2.9.

Perry, R.H. and Chilton, C.H. *Chemical Engineers' Handbook 5th Edition*. McGraw-Hill Kogakusha Limited, Tokyo, 1973.

Perry, R.H., Green, D.W. and Maloney, J.O. *Perry's Chemical Engineers' Handbook, 6th Edition.* McGraw-Hill Book Company, New York; 1984.

Pillai, K.K. (1981). The Influence of Coal Type on Devolatilisation and Combustion in Fluidised Beds. *Journal of the Institute of Energy;* 54: 142 – 150.

Preto, F., Anthony, E.J., Desai, D.L. and Friedrich, F.D. Combustion Trials of Rice Hulls in a Pilot-Scale Fluidised Bed. In: *Proceedings 9th. International Conference Fluidized Bed Combustion,* 1987: 2: 1123 - 1127.

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

Rashid, A.R.A. and Mokhtar, H. Potential of the Spouted/Fluidised Bed Combustor for Waste Utilization. In: *Proceedings of the 3rd ASEAN Fluidised Bed Combustion Workshop;* 6 - 9 November 1991: Bangkok and Chiang Rai.

Raveendran, K. and Anuradda, G. (1996). Heating Value of Biomass and Biomass Pyrolysis Products. *Fuel;* 75: 15: 1715 - 1720.

Raveendran, K., Anuradda, G. and Kartic, C.K. (1995). Influence of Mineral Matter on Biomass Pyrolysis Characteristics. *Fuel;* 74: 12: 1812 - 1822.

Raveendran, K., Anuradda, G. and Kartic, C.K. (1996). Pyrolysis Characteristics of Biomass and Biomass Components. *Fuel;* 75: 8: 987 - 998.

Reddy Karri, S.B. and Knowlton, T. M. (1999). *Gas distributor and plenum design in fluidized beds* in *Fluidisation Solids Handling and Processing,* Editors Yang, W.C. New Jersey: Noyes Publication.

Rozainee, M.T. (1998). Incineration of Sluge Waste in a Novel Rotating Fluidised Bed. *University of Sheffield, PhD Thesis*.

Rozainee, M.T., Lim, S.Y., Simon, L.Y.S. and Ngo, S.P. Initial Study on the Combustion of Palm Waste in a Spouted Bed. In: *Proceedings of 15th Symposium of Malaysia Chemical Engineers;* September 11-12, 2001, Johor Bahru: 378 - 383.

Saenger, M., Hatge, E.U., Werther, J., Ogada, T. and Siagi, Z. (2001). Combustion of Coffee Husks. *Renewable Energy;* 23: 103 - 121.

Sanchez, C. G. and Lora, E. S. (1994). "Biomass fluidized bed gasification research in the State University of Campinas". *Energy for Sustainable Development;* Vol 1 (Issue 4): 31 - 33.

San Jose, M.J., Olazar, M, Llamosas, R., Isquierdo, M.A. and Bilbao, J. (1996). Study of Dead Zone and Spout Diameter in a Shallow Spouted Beds of Cyclindrical Geometry. *Chemical Engineering Journal;* 64: 353 - 359.

Santana, D., Rodríguez, J. M., Macías, M. A. (1999). Modeling Fluidised Bed Elutriation of Fine Particles. *Powder Technology*; 106: 110 - 118.

Sami, M., Annamalai, K. and Wooldridge, M. (2001). Co-firing of Coal and Biomass Fuel Blends. *Progress in Energy and Combustion Science;* 27: 171 - 214.

Satyanarayana, K. and Rao, P.G. (1989). Minimum Fluidisation Velocity at Elevated Temperatures. *Indian Chemical Engineer;* Vol 31 (1): 79 - 81.

Scala, F. and Chirone, R. (2004). Fluidised Bed Combustion of Alternative Solid Fuels. *Experimental, Thermal and Fluid Science;* 28 (7): 691 - 699.

Schenkel, Y., Pennington, M. and Gonzales, A.D. Biomass Residues for Energy and Environment in Asean Countries. In: *European-Asean Conference on Combustion of Solids and Treatment of Products;* 16 - 17 February 1995: Bangkok, Thailand:139 - 161.

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

Sharma, A. and Rao, T.R. (1999). Kinetics Pyrolysis of Rice Husk. *Bioresource Technology;* 67: 53 - 59.

Sharma, N.K., Williams, W.S. and Zangvil, A. (1984). Formation and Structure of Silicon Carbide Whiskers from Rice Hulls. *Journal of American Ceramic Society;* 67 (11): 715.

Shizukuishi, S. (1999). Natural Gas Utilization for Industrial User. Tokyo Gas Asia Sendirian Berhad and Gas Malaysia Sendirian Berhad.

Singh, R., Maheshwari, R. C. and Ojha, T.P. (1980). Efficient Use of Agricultural Wastes for Energy Production. *Journal of Agriculture Mechanics;* Autumn: 31 - 37.

Soponronnarit, S., Swasdisevi, T., Thepent, V., Shujinda, A. and Srisawat, B. (2000). Cyclonic Rice Husk Furnace and Its Application in Paddy Drying. *International Energy Journal;* 1 (2): 67 - 75.

Singh, S.K., Mohanty, B.C. and Basu, S. (2002). Synthesis of SiC from Rice Husk in a Plasma Reactor. *Bulletin of Material Science;* 25 (6): 561 - 563.

Sugita, S. (1993). Method of Producing Active Rice Husk Ash. *US Patent 5,329,867.*

Surjosatyo, A., Farid, N.H.A. and Abdullah, M.Z. (1999). A Study of Oil Sludge Combustion in a Bubbling Fluidised Bed Incinerator. *RERIC International Energy Journal;* 21 (2): 121 - 131.

Susanto, H. Experimental Study on the Combustion of Sawdust in a Laboratory Spouted Bed Combustor. In: *Proceedings of the 3rd ASEAN Fluidised Bed Combustion Workshop;* 6 - 9 November 1991: Bangkok and Chiang Rai.

Swift, P. (1969). Dust Control Industry. *Steam Heating Engineering;* 38.

Szafran, R.G. and Kmiec, A. (2004). CFD Modelling of Heat and Mass Transfer in a Spouted Bed. *Industrial and Engineering Chemistry Research;* 43 (4): 1113 - 1124.

Tasirin, S.M. and Geldart, D. (1998). Entrainment of FCC from Fluidised Beds – A New Correlation for the Elutriation Rate Constants $K^{*}_{i\infty}$. *Powder Technology;* 95: 240 - 247.

The Star. (January 26, 2004). 21-Vehicle Pile-up on Highway.

Thomas, M.G., Griffiths, A.J. and Syred, N. Biomass Combustion and Gasification – The 4th Energy Source. In: *European-Asean Conference on Combustion of Solids and Treatment of Products;* 16-17 February 1995: Bangkok, Thailand: 70 - 89.

Thorley, B., Saunby, J.B., Marthr, K.B. and Osberg, G.L. (1959). An Analysis of Air and Solid Flow in a Spouted Wheat Bed. *Canadian Journal of Chemical Engineering;* 37 - 84.

Tia, S., Bhattacharya, S.S. and Wibulswas, P. (1991a). Spout and Spout-fluid Bed Combustors 1: Devolatilisation and Combustion of Coal Particles. *International Journal of Energy Research;* 15: 185 - 201.

Tia, S., Bhattacharya, S.S. and Wibulswas, P. (1991b). Spout and Spout-fluid Bed Combustors 2: Batch Combustion of Carbon. *International Journal of Energy Research;* 15: 203 - 221.

Twoomy, R.D. and Johnstone, H.F. (1952). Gaseous Fluidisation of Solid Particles. *Chemical Engineering Progress;* 48: 220 - 226.

Unciano, H., Briones, L. and Pulmano, D. Differential Fluidised Bed boiler for Waste Biomass and Low-Grade Coal. In: *Proceedings of the 3rd ASEAN Fluidised Bed Combustion Workshop;* 6 - 9 November 1991: Bangkok and Chiang Rai.

Van Den Broek, R., Faaij, A. and Van Wijk, A. (1996). Biomass Combustion for Power Generation. *Biomass and Bioenergy;* 11: 4: 271 - 281.

Vuthaluru, H. B. and Zhang D. K. (2001). Effect of Ca-Mg Bearing Minerals on Particle Agglomeration Defluidisation during Fluidized Bed Combustion of South Australian Lignite. *Fuel Processing Technology*. 69: 13 - 27.

Wang, S.N., Xu, J., Wei, W.S., Shi, G., Bao, X.J., Bi, H.T. and Lim. C.J. (2000). Gas Spouting Hydrodynamics of Fine Particles. *Canadian Journal of Chemical Engineering;* 78: 156 - 160.

Wang, W. Y., Lu, Y., Nasserzadeh, V. S., Swithenbank, J., Shaw, T. and Madden, M. (2000). Experimental Investigation into the Incineration of Wool Scouring Sludges in a Novel Rotating Fluidised Bed. *Journal of Hazardous Materials;* 73: 143 - 160.

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

Werther, J. and Ogada, T. (1999). Sewage Sludge Combustion. *Progress in Energy and Combustion Science;* 25: 55 - 116.

Werther, J., Ogada, T., Borodulya, V.A. and Dikalenko, V.I. (1995). Devolatilization and Combustion Kinetic Parameters of Wet Sewage Sludge in a Bubbling Fluidised Bed Furnace. In: *Proceedings of the Institute of Energy's 2 nd International Conference on Combustion and Emission Control;* London, UK.: 1995: 149 - 158.

Werther, J., Saenger, M, Hartge, E.U., Ogada, T and Siagi, Z. (2000). Combustion of Agricultural Residues. *Progress in Energy and Combustion Science:* 26: 1 - 27.

Wu, S.Y. and Baeyens, J. (1991). Effect of Operating Temperature on Minimum Fluidisation Velocity. *Powder Technology;* 67: 217 - 220.

Wu, C.H., Lee, C.P. and Dai, C.Y. (2003). Prediction of the Performance of a Rotary Kiln Incinerator in Treating Rice Hulls. *Transactions of ASAE;* 46 (2): 367 - 381.

Wu, W.M., Lim, C.J. and Epstein, N. (1987). Hydrodynamics of Spouted Beds at Elevated Temperatures. *Chemical Engineering Communication;* 62: 252 - 268.

Wu, W.Y. and Saxena, S.C. (1997). Mixing Characteristics of Light Paper Pellets in a Sand Fluidised Bed. *Energy;* 22 (6): 615 - 619.

Wu, W.Z. (1986). Fluidised Bed Combustion of Rice Husk for Energy and Pozzolana. *Asian Institute of Technology, Bangkok, Thailand; Master Thesis*.

Xu, B.Y., Huang, W.C., Flanigan, V.J. and Sitton, O.C. Design and operation of a 6 inch fluidized bed gasifier for rice hulls. In: *Symposium on Energy from Biomass and Waste IX*. Organised by IGT, Chicago, U. S. A, 1985.: 595 - 614.

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

Yates, J.G. (1983). Chapter 1: Some Fundamental Aspects of Fluidisation. In: *Fundamentals of Fluidsed-bed Chemical Process*, Butterworths Publishers, London: 4 - 71.

Ye, B., Lim, C.J. and Grace, J.R. (1992). Hydrodynamics of Spouted and Spout-Fluidised Beds at High Temperatures. *Canadian Journal of Chemical Engineering;* 70: 840 - 847.

Yeoh, A.K. and Ong, K.S. (1989). Rice Husk Ash Utilization in Malaysia - SIRIM's Experience. In: *Workshop on Appropriate Technologies on Farm and Village Level Postharvest Grain Handling,* Kuala Lumpur.

Yeoh, A.K., Rahim, B., Chong, C.N. and Tay, C.Y. (1979). The Relationship between Temperature and Duration of Burning of Rice Husk in the Development of Amorphous Rice Husk Ash Silica. Paper presented at *ESCAP/RCTT Rice Husk Follow-up Meeting.* Alor Setar, Kedah.

Zhang, J.Q., Becker, H.A. and Code, R.K. (1990). Devolatilisation and Combustion of Large Coal Particles in a Fluidised Bed. *Canadian Journal of Chemical Engineering;* 68: 1010 - 1017.

Zhang, M.H., Lastra, R. and Malhotra, V.M. (1996). Rice-Husk Ash Paste and Concrete: Some Aspects of Hydration and the Microstructure of the Interfacial Zone Between the Aggregate and Paste. *Cement Concrete Research;* 26 (6): 963 - 977.

Zhao, J., Lim, C.J. and Grace, J.R. (1987). Flow Regimes and Combustion Behaviour in Coal-Burning Spouted and Spout-fluidised Beds. *Chemical Engineering Science;* 42 (10): 2865 - 2875.

Zu, C.M., Zhao, Z.N. and Yang, H.P. (1992). Fluidisation Characteristics and Heat Transfer in a Rice Husk Fluidised Bed. *Journal of Huazhong University of Science and Technology;* 20 (6): 81 - 85.