# DEVELOPMENT OF A FLUIDIZED BED SOLID STATE FERMENTER FOR THE CONVERSION OF PALM KERNEL CAKE AS POULTRY FEED

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**BIOTECHNOLOGY RESEARCH INSTITUTE**
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**2007**

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THESIS SUBMITTED IN FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE

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2007

**UNIVERSITI MALAYSIA SABAH**

**BORANG PENGESAHAN STATUS TESIS@**

**JUDUL: DEVELOPMENT OF A FLUIDIZED BED SOLID STATE FERMENTER FOR THE CONVERSION OF PALM KERNEL CAKE AS POULTRY FEED**

**IJAZAH: SARJANA SAINS (KEJURUTERAAN KIMIA)**

**SESI PENGAJIAN: 2004-2007**

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# DECLARATION

The materials in this thesis are original except for quotations, accepts, summaries and references, which have been duly acknowledged.

FOONG CHEE WOH

PS04-008-010

5 APRIL 2007

# ACKNOWLEDGEMENT

First of all, I would like to express my heartiest and sincere gratitude to my supervisors Professor Kamatam Krishnaiah, Associate Professor Auti Prabhakar, and Mr. Jidon Janaun for their invaluable supervision, guidance, and suggestions throughout the period of this project.

Special thanks to Professor Duvvuri Subbarao who has given me a lot of constructive suggestions and guidance in my work. I would like to take this opportunity to express my genuine appreciation to Mr. Panjiman, Mr. Abdullah Tarikim, Cik Noridah Abbas, and Cik Aemy who have facilitated me in all my lab works.

I would like to express my deepest gratitude to Professor Datin Ann Anton as our project leader for giving us all kind of supports along the way. Besides, I would like to thank Korea Research Institute of Bioscience and Biotechnology (KRIBB) especially Dr. Kim Chul Ho and Dr. Choi Ho Min for providing us training.

The financial assistance granted by UMS Fundamental Research Grant B-0101-13/PRU037 is highly acknowledged. In between, I would like to thank IOI Edible Oils Sdn. Bhd. for providing us palm kernel cake in this research.

Last but not least, I would like to thank my project partners; Chin Hooi Chuan, Wong Yoke Phooi, Saw Horng Yuan, and all the people who have given me support and encouragement all the time.

# ABSTRACT

Solid state fermentation (SSF) which involves growth of microorganism on moist solid substrates in the absence of free flowing water, has gained renewed attention over submerged fermentation for specific applications. During the SSF process in fermenter, there are three main engineering problems encountered such as the removal of metabolic heat from the substrate, diffusion of $O_2$ and moisture through the substrate, and heterogeneity of the substrate and inoculum. A fluidized bed fermenter in which the particles move independently like a fluid was proposed to conduct SSF of PKC. Hydrodynamic studies showed that the experimental $U_{mf}$ for 855µm, 655µm and 363µm PKC particles were 0.340 m/s, 0.205 m/s and 0.080 m/s, respectively, where as the $U_{mf}$ calculated using Wen and Yu correlation was 0.206 m/s, 0.131 m/s, and 0.043 m/s. The discrepancy between experimental and theoretical values most probably due to the breakage of the PKC particles and the presence of shells with different density. Heat transfer studies have also been carried out. The results showed that the heat loss from PKC to air was very fast and increased with increase of air velocity. In contrary, heat loss from PKC to air was increased with decrease in air relative humidity and bed height. Throughout the study, rapid heat transfer from PKC to air was experimentally observed within the first 150 seconds with a temperature drop of $30^0$C. This indicated that the excellent heat transfer between palm kernel cake and air allows solid state fermentation of PKC without accumulation of metabolic heat in the fermenter. A mathematical model for heat transfer between PKC and fluidizing medium was proposed which can predict the experimental data quite satisfactorily within an average error of ± 15%. Apart from heat removal, water adsorption on PKC from air to bed was carried out. It showed that the increase of adsorbed water in PKC was proportional to air relative humidity and inversely proportional to superficial air velocity. The maximum moisture content adsorbed by PKC under fluidization conditions was around 10% (on dry basis). For SSF operation, 10% moisture content was too low for microbial growth. Therefore, a water dropping system was installed to add water on PKC to maintain the moisture content at required level. A mathematical model for mass transfer between PKC particle and fluidizing air was proposed which can predict the experimental data quite satisfactorily. Finally, the effect of superficial air velocity on SSF of PKC was studied in the prototype fermenter, which can be operated as fluidized bed and packed bed, using fungal strain *Aspergillus flavus*. The strain was isolated from PKC sample. The maximum increase of reducing sugar concentration was at 0.17 m/s. It increased about 28%, from 14.55 mg mannose/g dry PKC to 18.63 mg mannose/g dry PKC. Meanwhile, the hemicellulose content reduced about 10%.

# ABSTRAK

## PEMBANGUNAN LAPISAN TERBENDALIR SEBAGAI BIOREAKTOR SUBSTRAT PEPEJAL UNTUK PENUKARAN SISA KELAPA SAWIT SEBAGAI MAKANAN TERNAKAN

*Penapaian pepejal telah menjadi satu alternatif yang menarik untuk menggantikan penapaian cecair walaupun penapaian pepejal mempunyai beberapa masalah kejuruteraan seperti penyingkiran haba metabolisma, penghantaran oksigen dan kelembapan ke jarah, dan pencampuran jarah yang seragam. Bioreaktor lapisan terbendalir adalah salah satu pilihan yang boleh mengatasi masalah tersebut. Dalam kertas penyelidikan ini, satu bioreaktor lapisan terbendalir telah direka. Kajian hydrodinamik telah dijalankan dan keputusannya menunjukkan $U_{mf}$ eksperimen untuk 855μm, 655μm and 363μm saiz partikel PKC adalah 0.340 m/s, 0.205 m/s and 0.080 m/s manakala $U_{mf}$ teori dari persamaan Wen and Yu adalah 0.206 m/s, 0.131 m/s, and 0.043 m/s. Perbezaan antara nilai eksperimen dan teori kemungkinan besar disebabkan oleh pemecahan PKC partikel dan kehadiran tempurung kelapa sawit yang lain ketumpatan. Selain daripada kajian hydrodinamik, kajian penyingkiran haba dari substrat ke gas telah dijalankan. PKC telah digunakan sebagai substrat dalam kajian ini. Diameter purata untuk PKC yang digunakan adalah 855μm. Kesan halaju gas, kelembapan gas dan ketinggian lapisan telah dikaji. Keputusan menunjukkan bahawa penyingkiran haba dari PKC ke gas adalah berkadar langsung dengan halaju gas dan berkadar songsang dengan kelembapan gas serta ketinggian lapisan. Penyingkiran haba yang cepat telah diperhatikan dalam 150 saat pertama dengan penurunan suhu sebanyak $30^0$C. Satu model matematik telah dihasilkan untuk menjangka data eksperimen. Di samping itu, kajian penyerapan air dari gas ke PKC telah dijalankan. Keputusan menunjukkan bahawa penyerapan air di PKC adalah berkadar terus dengan kelembapan gas dan berkadar songsang dengan halaju gas. Maximum kandungan air yang boleh diserap oleh PKC dalam keadaan eksperimen adalah 10% (w/w). Untuk operasi SSF, 10% kandungan air adalah terlalu rendah untuk aktiviti microorganisma. Maka, satu sistem penyiraman air telah dipasang untuk menambah air ke PKC. Satu model matematik telah dihasilkan untuk menjangka data eksperimen. Akhirnya, kesan halaju gas bagi penapaian pepejal PKC telah dikaji dengan menggunakan satu prototaip bioreaktor, di mana bioreaktor itu boleh digunakan sebagai bioreaktor lapisan terbendalir dan bioreaktor lapisan terpegun. Peningkatan tertinggi kepekatan gula penurunan adalah pada 0.17 m/s. Ia meningkat sebanyak 28%, daripada 14.55 mg mannose/g dry PKC pada mulanya ke 18.63 mg mannose/g dry PKC. Manakala kandungan hemicelulosa pula menurun sebanyak 10%.*

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# NOMENCLATURE

| | |
|---|---|
| $A$ | column cross section area, $m^2$ |
| $Ar$ | Archemedies number |
| $Cp_g$ | specific heat of gas, J/kg.K |
| $Cp_s$ | specific heat of solid, J/kg.K |
| $C_f$ | correction factor |
| $C_g$ | concentration of absorbate in fluid, $kmol/m^3$ |
| $C_{gp}$ | concentration of absorbate on particle, $kmol/m^3$ |
| $D_{AB}$ | diffusivity of water vapor in air, $m^2/s$ |
| $D$ | diameter of the column, cm |
| $D_p$ | average diameter of the particle, m |
| $g$ | acceleration due to gravity, $m/s^2$ |
| $H$ | height of bed, cm |
| $H$ | humidity, kg water vapor per kg dry air |
| $H_s$ | saturation humidity, kg water vapor per kg dry air |
| $K_a$ | adsorption coefficient |
| $K_g$ | air to particle mass transfer coefficient, m/s |
| $L$ | length of bed, m |
| $L_f$ | height of bubbling fluidized bed, m |
| $L_m$ | height of fixed bed, m |
| $Mw$ | weight of water, kg |
| $M_{wt}$ | molecular weight of water, kg/kmol |
| $Mw_{eq}$ | weight of water at equilibrium, kg |
| $M_p$ | weight of particle, kg |
| $(\Delta P)_b$ | bed pressure drop, $mmH_2O$ |
| $(\Delta P)_{DP}$ | pressure drop across the distributor, $mmH_2O$ |
| $(\Delta P)_t$ | total pressure drop across the bed, $mmH_2O$ |
| $Re$ | particle Reynold's number |
| $Re_{mf}$ | particle Reynold's number at minimum fluidization velocity |
| $RH$ | relative humidity, % |
| $Sh$ | Sherwood Number |
| $s_p$ | surface area of a single particle, $m^2$ |
| $T_b$ | bed temperature, $^0C$ |

| | |
|---|---|
| $T_{bo}$ | initial bed temperature, $^0C$ |
| $T_{gi}$ | inlet air temperature, $^0C$ |
| t | time, sec |
| $\upsilon_p$ | volume of a single particle, $m^3$ |
| $u_g$ | superficial air velocity, m/s |
| $u_{mf}$ | minimum fluidization velocity, m/s |
| W | weight of the particles, kg |
| $\varepsilon$ | fractional voidage |
| $\varepsilon_f$ | void fraction in a fluidized bed as a whole |
| $\varepsilon_m$ | void fraction in a fixed bed |
| $\mu_g$ | viscosity of fluidizing medium, kg/m.s |
| $\rho_p$ | density of particle, $kg/m^3$ |
| $\rho_b$ | bulk density, $kg/m^3$ |
| $\rho_g$ | density of fluidizing medium, $kg/m^3$ |
| kg | kilogram |
| g | gram |
| mg | milligram |
| hr | hour |
| min | minute |
| s | second |
| m | meter |
| mm | millimeter |
| µm | micron |
| L | litre |
| ml | milliliter |
| $^0C$ | degree Celsius |
| % | percent |
| H/D | ratio of bed height to column diameter |
| $H/H_s$ | ratio of humidity to saturation humidity |
| W/A | ratio of PKC weight to column cross section area |
| v/w | volume per weight |
| w/w | weight per weight |
| DF | dilution factor |
| gds | gram dry substrate |
| $O_2$ | gas oxygen |

| | |
|---|---|
| PDA | potato dextrose agar |
| PKC | Palm kernel cake |
| SSF | solid state fermentation |
| SmF | submerged fermentation |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Solid state fermentation (SSF) which involves growth of microorganism on moist solid substrates in the absence of free flowing water, has gained renewed attention over submerged fermentation for specific applications (Raghavarao, 2003). In recent years, some bioprocesses using SSF have been developed for the production of bulk chemicals and value-added products such as ethanol, single-cell protein (SCP), mushrooms, enzymes, organic acids, amino acids, and biologically active secondary metabolites (Soccol and Vandenberghe, 2003). There are many parameters that affect the quality of bio-products such as the particle characteristics of the substrate, contact between the substrate and the microbes, removal of metabolic heat from the substrate, diffusion of $O_2$ through the substrate, removal of byproduct gases, and maintenance of desired moisture in the substrate (Krishnaiah *et al.*, 2005).

While handling the SSF process in fermenter, there are three main engineering problems which include the removal of metabolic heat from the substrate, diffusion of $O_2$ and moisture content through the substrate, and heterogeneity of the substrate and inoculum. Heat accumulation in bioreactor during SSF is one of the major problems particularly in scale-up of bioreactor. In general, during SSF, a large amount of metabolic heat is evolved and its rate is directly proportional to the level of metabolic activity in the system (Robinson and Nigam, 2003). Usually the solid substrate used for SSF has low thermal conductivities. Hence, heat removal from the process could be very slow. Sometimes accumulation of heat may reach as high as 60 to 70 $^{0}C$ in the innermost region which affect the growth of microorganism (Hayes, 1977). The transfer of heat out of SSF system is closely related with the aeration which also supplies the $O_2$ and moisture content to the microorganism.

In order to overcome these mass and heat transfer problems of SSF process, fluidized bed solid state bioreactor was proposed to be used for SSF of PKC in which the particles move independently like a fluid and the heat and mass transfer coefficients are very high between particle to gas, bed to surface and surface to bed (Kunii and Levenspiel, 1991). Even though fluidized bed is one of the established reactors, the studies mentioned above are not available for the natural material like palm kernel cake (PKC).



## 1.2 Research Aim

The aim of this research is to develop a lab-scale fluidized bed bioreactor for the bioconversion of palm kernel cake (PKC) as poultry feed.

## 1.3 Research Objectives

The objectives of this research are:

i. To develop a lab-scale fluidized bed fermenter.
ii. To characterize PKC.
iii. To determine the hydrodynamic parameters of fluidized bed.
iv. To study mass and heat transfer operations of PKC in fluidized bed.
v. To evaluate the performance of fluidized bed fermenter operated at different air velocity.

## 1.4 Scope of Research



The scopes of the research are:

i. To fabricate a lab-scale fluidized bed fermenter.
ii. To measure the bulk density, moisture content and particle size distribution of PKC.
iii. To determine experimentally the operating parameters such as distributor plate pressure drop, pressure drop across the bed and minimum fluidization velocity, and to calculate minimum fluidization velocity from model equation.
iv. To study the effect of superficial air velocity, air relative humidity and bed height on water adsorption from air to PKC and to develop its mathematical model.

v. To study the effect of superficial air velocity, air relative humidity and bed height on heat loss from PKC to fluidizing medium, air and to develop its mathematical model.

vi. To evaluate the effect of superficial air velocity on SSF of PKC in the fluidized bed fermenter using fungal strain *Aspergillus flavus* in term of biomass growth, pH, moisture content, and food and feed analysis such as reducing sugar concentration and hemicelluloses content.

## 1.5 Significance of Research

Large scale process of SSF is limited by engineering problems as mentioned in the earlier section. Basic understanding of these limitations at laboratory level improves the design of reactor and enhances the efficiency of any SSF process. Systematic studies of the effect of various parameters on quality of SSF in the laboratory build up a data bank for handling industrial processes more efficiently. This research is an attempt in this direction.



This research is also important to produce a value-added local agro-industry residues, PKC for the potential bioconversion to poultry feed. From the economy point of view, it will save cost through reduction of import of feedstuffs at a cost of a billion Ringgits every year, by substituting the components of feedstuffs with treated PKC. In fact, the attempt to do SSF of PKC using fluidized bed fermenter is the first in SSF world. Hence, this research will become a pioneer and reference to future SSF work in fluidized bed fermenter using PKC as substrate.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

This chapter reviews all the literature, data, theories that have been published, referred or applied in this research. First of all, introduction about PKC is given in Section 2.2. Secondly, the usages or applications of PKC are discussed in section 2.3. SSF and selection of β-mannanase producing microorganism are discussed in Section 2.4 and Section 2.5 respectively. Besides that, Section 2.6 discusses about the general engineering aspects of SSF bioreactor such as heat and mass transfer problem while handling SSF process. The advantages of fluidized bed fermenter are discussed in Section 2.7 and finally an overview of bioreactor for SSF of PKC is given in Section 2.8.



## 2.2 Palm Kernel Cake

Malaysia currently produces an annual quantity of 1.4 million tones of PKC as by-product in the milling of palm kernel oil. The potential of PKC as feed for livestock have long been known. PKC can be fed to ruminant animals like cattle (Camoens, 1979), sheep (Hair-Bejo and Alimon, 1995) and also monogastric animal like pig (Rhule, 1996). And, for the last few years many researchers are interested to study on the possibility to feed PKC to poultry (Onwudlike, 1986) and also aquaculture (Ng,