

**EVALUATION ON THE PRESENCE OF
HAZARDOUS MATERIAL FROM
MEDIUM DENSITY FIBREBOARD**

by

SITI HAZNEZA BT. ABDUL HAMID

**Thesis submitted in fulfillment of the
requirements for the degree of
Master of Science**

MEI 2008

ACKNOWLEDGEMENTS

Alhamdulillah.

My sincere gratitude goes out to:

First and foremost my parents Salmah bt. Ahmad and Abdul Hamid b. Hamad and my sister Siti Hazlini bt. Abdul Hamid for their undying support and confidence in me.

My supervisor, Associate Professor Dr.Rokiah Hashim and Associate Professor Dr.Othman Sulaiman for their patience and courageous advices. Thank you for always being there every step of this research and for helping me to see this research from a different point of view and not merely to get a degree per se.

I would like to thank Associate Professor Dr. Mahamad Hakimi Ibrahim, Dr. Norli Ismail and Dr. Hasnah Md. Jais for their collaboration in making this research more beneficial.

To my program chairman Associate Professor Abdul Khalil H.P. Shawkataly for his timely advice and motivation.

To Dr. Issam Ahmed al-Salihiy, Pn. Lily Hanum Mohd Yusuf and Dr. Tay Guan Seng for all the lively discussion we had had.

To my former Dean, Prof. Wan Rosli Wan Daud and my present Dean Prof. Rozman Hj. Din for their support.

To all lab assistants who had been kind throughout the research. They were En. Azizan Che Nun, En. Azhar Md Noor, Pn. Noorhasni Othman, En. Maarof Salleh, En. Mohd Farim Mahassan, En. Abu Mangsor Mat Sari, En. Shamsul Zoolkifli, Pn. Noraida Bukhari, En. Azlisufryzal Bunizar, En. Joseph, En. Zainoddin

Osman, En. Sadali Othman, En. Yahaya Mohd. Ismail, En. Shabudin, En. Muthu, Cik Jamilah and the list goes on. Your help had helped in my research progress.

Thank you to my colleagues, all my brothers and sisters and best friends that keep reminding me why I must finish what I have started when giving up seem the easy way out. All the prayers and words of courage are very much appreciated.

Thank you to Guthrie MDF Sdn. Bhd. for their samples and USM for the financial support and facilities that made the research more smooth running.

Each and every individual who had lent helpful hands throughout this research and in a way or another made its result more fruitful.

So, verily, with every difficulty, there is relief: verily, with every difficulty there is relief. Therefore, when thou art free (from thine immediate task), still labour hard, and to thy Lord turn (all) thy attention (al-Sharh: 5-8).

Siti Hazneza bt. Abdul Hamid

Universiti Sains Malaysia
11800 Minden, Pulau Pinang
28 Mei 2008

TABLE OF CONTENTS

	Page
ACKNOWLEDGEMENTS	ii
TABLE OF CONTENTS	iv
LIST OF TABLES	ix
LIST OF FIGURES	xi
LIST OF ABBREVIATION	xvi
LIST OF APPENDICES	xix
ABSTRAK	xxi
ABSTRACT	xxiii
CHAPTER ONE: INTRODUCTION	1
1.1 Wood Based Composites in Malaysia	1
1.2 Current Recycle Awareness	2
1.3 Problem Definition and Justification of the Study	6
1.4 Objectives of Study	8
CHAPTER TWO: LITERATURE REVIEW	9
2.1. Landfill situation in Malaysia	9
2.2. Wood waste	11
2.3. Wood Based Composites	12
2.4. Background on Medium Density Fibreboard (MDF)	15
2.5 Manufacturing of Medium Density Fibreboard (MDF)	18
2.5.1 Rubberwood	19
2.5.2 Availability of rubberwood	22
2.5.3 Urea Formaldehyde Resin	33
2.5.4 The Production Process of Medium Density Fibreboard	40

2.5.5	Use and disposal of MDF products	44
2.6	Characteristics of formaldehyde	44
2.6.1	Formaldehyde Emission	45
2.6.2	Formaldehyde as Carcinogen	49
2.6.3	Formaldehyde Emission Test	51
2.6.4	Tollens' test	52
2.6.5	Desiccators method	52
2.6.6	Flask method	54
2.7	Water analysis	54
2.7.1	Turbidity test	55
2.7.2	pH test	55
2.7.3	Biological oxygen demand (BOD)	56
2.7.4	Chemical oxygen demand (COD)	57
2.7.5	Fourier transform infra-red (FTIR) analysis	58
2.8	Biological test	59
2.8.1	Vermiculture	59
2.8.2	Soil burial study	60
a.	Soil microbes	60
b.	Soil as natural degrader	60
c.	Soil burial test	61
2.8.3	Fungal treatment	63
a.	Fungal as degrader	63
b.	Soft rot and brown rot	64
	CHAPTER THREE: MATERIALS AND METHODS	67
3.1	Materials	67

3.2.3.2c Exposing samples to fungal	86
3.2.4 Water Analysis	87
3.2.4a Thickness swelling and water absorption	87
3.2.4b Turbidity test	88
3.2.4c pH Value of water	88
3.2.4d Biological Oxygen Demand (BOD) of water	89
3.2.4e Chemical Oxygen Demand (COD) of water	90
3.2.4f FTIR analysis	91
CHAPTER FOUR: RESULTS AND DISCUSSIONS	92
4.1 Preliminary Results	92
4.1.1 Tollens' Test	92
4.1.2 Vermiculture	93
4.2 Formaldehyde Emission Value	94
4.3 Biological Test	97
4.3.1 Soil Burial	97
4.3.2 Fungal Treatment	120
4.4 Water Analysis	122
4.4.1 Thickness swelling and water absorption	122
4.4.2 Turbidity	124
4.4.3 pH Value	126
4.4.4 Biological Oxygen Demand (BOD)	127
4.4.5 Chemical Oxygen Demand (COD)	128
4.4.6 The BOD: COD ratio	129
4.4.7 FTIR analysis of water	130
CHAPTER FIVE: CONCLUSION	137

CHAPTER SIX: RECOMMENDATION FOR FUTURE RESEARCH	138
REFERENCE	139
APPENDICES	

LIST OF TABLES

	Page
Table 1.1 List of materials found in landfills and their respected time to biodegrade	5
Table 2.1 Projected total wood production from rubber plantations in Peninsular Malaysia from 1996-2012	27
Table 2.2 Projected log and sawnwood production from rubber plantations in Peninsular Malaysia from 1996-2012	28
Table 2.3 Supply and demand of rubberwood sawlogs in Malaysia in 1996-2012	31
Table 2.4 Supply and demand of rubberwood chip logs in Malaysia in 1996-2012	31
Table 2.5 Japanese imports of wooden furniture by source (Million yen)	32
Table 3.1 Standard specifications of urea formaldehyde rubberwood MDF	67
Table 3.2 Details of samples taken for research study	68
Table 3.3 The cutting of board according to the methods used.	70
Table 4.1 Percentage of thickness swelling and water absorption of 6 mm MDF samples	122
Table 4.2 Percentage of thickness swelling and water absorption of 18 mm MDF samples	123
Table 4.3 The BOD: COD ratio of the water after being soaked with MDF samples for four weeks	129

LIST OF FIGURES

	Page	
Figure 2.1	An illustration of open loop waste cycle in Malaysia	10
Figure 2.2	Types of composites based on reinforcement shape	15
Figure 2.3	Rubber tree	20
Figure 2.4	The microscopic view of (a) cross section, (b) radial and (c) tangential of a rubberwood	21
Figure 2.5	Flow of rubberwood logs and primary products in Malaysia in 1992	25
Figure 2.6	Adjusted outlook to 2016 for rubberwood log availability in Malaysia.	29
Figure 2.7	Adjusted outlook to 2016 for rubberwood sawnwood availability in Malaysia.	30
Figure 2.8	Production of urea formaldehyde resin based on Dunky (1998).	34
Figure 2.9	The MDF production process	40
Figure 3.1	Initial removal of the perimeter of the board before cutting.	69
Figure 3.2	Test apparatus where test pieces are fixed with rubber band	75
Figure 3.3	The calibration curve with the slope f , 0.014.	78

Figure 3.4	Planted test specimens for soil burial study. (a) specimen in laboratory environment, (b) 20 mm of specimen protruding from soil surface and each specimen distant 20 mm from each other in laboratory, (c) ground stake test and (d) 20 mm of specimen protruding from soil surface and each specimen distant 20 mm from each other for ground stake test.	80
Figure 3.5	Inoculation of fungal using monoculture technique	85
Figure 3.6	Arrangement of samples on fungal in a Petri dish	86
Figure 4.1	Influence of weathering on the extractable formaldehyde from MDF	94
Figure 4.2	The relationship between moisture content to the extractable formaldehyde value of 6 mm MDF	95
Figure 4.3	The relationship between moisture content to the extractable formaldehyde value of 18 mm MDF	95
Figure 4.4	Test specimens of 6 mm MDF in comparison of control (C), laboratory environment (L) and ground stake test (N). (a) after four weeks, (b) after eight weeks, (c) after twelve weeks and (d) after sixteen weeks	98
Figure 4.5	Test specimens of 18 mm MDF in comparison of control (C), laboratory environment (L) and ground stake test (N). (a) after four weeks and (b) after eight weeks	99
Figure 4.6	The percent of weight loss of samples within 16 weeks of the ground stake test	99

Figure 4.7	Scanning electron Micrographs (SEM) of MDF samples after soil burial test for eight weeks viewed at 500x magnification for 6 mm MDF control sample.	101
Figure 4.8	Scanning electron Micrographs (SEM) of MDF samples after soil burial test for eight weeks viewed at 500x magnification for 6 mm laboratory unsterile soil burial sample.	102
Figure 4.9	Scanning electron Micrographs (SEM) of MDF samples after soil burial test for eight weeks viewed at 500x magnification for 6 mm ground stake test sample.	103
Figure 4.10	Scanning electron Micrographs (SEM) of MDF samples after soil burial test for eight weeks viewed at 500x magnification for 18 mm control sample	104
Figure 4.11	Scanning electron Micrographs (SEM) of MDF samples after soil burial test for eight weeks viewed at 500x magnification for 18 mm laboratory unsterile soil burial sample.	105
Figure 4.12	Scanning electron Micrographs (SEM) of MDF samples after soil burial test for eight weeks viewed at 500x magnification for 18 mm ground stake test sample.	106
Figure 4.13	The pH_{H_2O} and pH_{KCl} values of soil within 16 weeks of laboratory unsterile soil burial study and ground stake test	108
Figure 4.14	Cation exchange capacity (CEC) and exchangeable cations in soil within 16 weeks of the laboratory unsterile soil burial	111
Figure 4.15	Cation exchange capacity (CEC) and exchangeable cations in soil within 16 weeks of the ground stake test	112

Figure 4.16	The nitrogen content in soil within 16 weeks of the laboratory unsterile soil burial	116
Figure 4.17	The nitrogen content in soil within 16 weeks of the ground stake test	116
Figure 4.18	The soluble phosphorus content in soil within 16 weeks of the laboratory unsterile soil burial	118
Figure 4.19	The soluble phosphorus in soil within 16 weeks of the ground stake test	118
Figure 4.20	The percentage of weight loss of the samples after 16 weeks exposure to fungal	120
Figure 4.21	Turbidity value of water after being soaked with MDF samples for four weeks using the APHA 2130 standard method for water analysis	125
Figure 4.22	The pH of water after being soaked with MDF samples for four weeks using the APHA 4500-H ⁺ standard method for water analysis	126
Figure 4.23	The BOD of water after being soaked with MDF samples for four weeks using the APHA 5210 standard method for water analysis	127
Figure 4.24	The COD of water after being soaked with MDF samples for four weeks using the APHA 5220 standard method for water analysis	128

Figure 4.25	FTIR spectra for the 6 mm MDF sample in comparison of the initial sample dust, the sample dust after being soaked in water for four weeks, the water after being soaked with 6 mm MDF samples for four weeks, rubberwood dust, UF resin and distilled water	131
Figure 4.26	FTIR spectra of water after being soaked with MDF 6 mm samples for four weeks	132
Figure 4.27	FTIR spectra for the 18 mm MDF sample in comparison of the initial sample dust, the sample dust after being soaked in water for four weeks, the water after being soaked with 18 mm MDF samples for four weeks, rubberwood dust, UF resin and distilled water.	133
Figure 4.28	FTIR spectra of water after being soaked with MDF 18 mm samples for four weeks	134

LIST OF ABBREVIATION

$(\text{NH}_4)_2\text{SO}_4$	Ammonium sulphate
A	absorbance
Ag_2SO_4	Argentum sulphate
APHA	American Public Health Association
AWWA	American Water Works Association
BOD	Biological oxygen demand
c	concentration
Ca	Calcium
$\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$	Calcium chloride anhydrous
COD	Chemical oxygen demand
CV	<i>Coriolus Versicolor</i>
DIY	Do-it-yourself
$\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$	Ferum chloride anhydrous
FSP	Fibre saturation point
FTIR	Fourier Transmittance Infra Red
F_v	Flask value
G.tra	<i>Gleophyllum trabeum</i>
H	Humidity or moisture
H_2O	Water
H_2SO_4	Sulphuric acid
HCHO	formaldehyde

I ₂	Iodine
K	Potassium
K ₂ Cr ₂ O ₇	Potassium dichromate
KBr	Potassium bromide
KCl	Potassium chloride
KH ₂ PO ₄	Potassium dihydrogen phosphate
L.saj	<i>Lentinus sajor-caju</i>
LCA	Life Cycle Assessment
m	mass
mc	Moisture content
MDF	Medium density fibreboard
MF	Melamine formaldehyde
Mg	Magnesium
MgSO ₄ .7H ₂ O	Magnesium sulphate anhydrous
MOE	Modulus of elasticity
MOR	Modulus of rupture
MUF	Melamine urea formaldehyde
N	Nitrogen
Na ₂ S ₂ O ₃	Sodium thiosulphate
NaOH	Sodium hydroxide
OSB	Oriented strand board
P	Phosphorus
PDA	Potato dextrose agar
S.com	<i>Shizophyllum commune</i>
UF	Urea formaldehyde

V	volume
VOC	Volatile organic compound
WEF	Water Environment Federation
WHC	Water Holding Capacity

LIST OF APPENDICES

Appendix A: Oral Presentation

A1 Oral Presentation at the 3rd Colloquium on Postgraduate Research National Postgraduate Colloquium on Materials, Minerals and Polymers (MAMIP) 2007 at Vistana Hotel, Penang on April 10-11 2007.

A2 Oral Presentation at the Conference on Forestry and Forest Products Research 2007 (CFFPR 2007) at The Legend Hotel, Kuala Lumpur on November 27-29 2007.

Appendix B: Publications

B1 Full research paper accepted by the Journal of Tropical Forest Science

Appendix C: Data and Calculations

C1 Formaldehyde Emission Determination

C1a Determination of moisture content

C1b Determination of flask volume

C1c The absorbance values from UV-vis spectrophotometer in determination of formaldehyde emission according to Flask Method for 6 mm and 18 mm MDF samples for 16 weeks

C1d. Expression of result.

- C1e. An example of calculation taking the initial flask value of 6 mm MDF samples
- C1f. Data table for MDF moisture content
- C1g. Data table for flask value in 16 weeks of weathering for MDF samples
- C2 Water holding capacity (WHC) determination
- C3 Thickness swelling and water absorption
 - C3a. Thickness swelling and water absorption of 6 mm and 18 mm MDF samples
 - C3b. Thickness swelling and weight gained by 6mm and 18mm samples for 4 weeks

Appendix D: Apparatus

- D1 The Hach 2100 p Turbidimeter
- D2 The Hach sensION3 pH meter
- D3 The Hach BOD Incubator
- D4 The YSI 5000 Dissolved Oxygen Meter
- D5 The Hach COD reactor
- D6 The Hach Odyssey COD meter.

**PENILAIAN KEHADIRAN BAHAN BERBAHAYA DARIPADA PAPAN GENTIAN
BERKETUMPATAN SEDERHANA**

ABSTRAK

Industri komposit berasaskan kayu di Malaysia sedang berkembang dengan pesat. Kini Malaysia adalah satu daripada pengeluar utama papan gentian berketumpatan sederhana (MDF) di rantau Asia Pasifik. Kayu getah ialah bahan mentah utama yang digunakan dalam MDF dengan komponen-komponen lain termasuk perekat dan aditif. Perekat yang utama adalah perekat berasaskan formaldehid. Perekat-perekat jenis ini membebaskan formaldehid selepas dibuang mengakibatkan masalah kepada alam sekitar apabila papan gentian merosot. Kajian ini bertujuan melakukan simulasi kemerosotan MDF, mengkaji kesan sisa MDF pada tanah, menganalisa kesan sisa MDF pada air dan melakukan simulasi pembebasan formaldehid jangka panjang melalui kajian jangka pendek. MDF daripada kayu getah dengan perekat resin urea formaldehid (UF) dengan dua ketebalan, 6mm dan 18 mm telah digunakan. Pembebasan formaldehid dikaji menggunakan piawaian EN717-3:1996 E *flask method*. Penanaman dalam tanah tanpa steril dilakukan mengikut piawaian BS 1982 : 1990. Kulat monokultur yang digunakan ialah kulat reput putih, *Coriolus versicolor*, *Lentinus sajor-caju* dan *Shizophyllum commune* dan kulat reput perang, *Gloeophyllum trabeum*. Daripada kajian dapat disimpulkan bahawa jumlah formaldehid terbebas berkurangan dengan masa, selepas minggu ke-10 dan 13 pembebasan formaldehid adalah sifar untuk sampel MDF 6mm dan 18 mm, kehilangan berat daripada penanaman dalam tanah dan pendedahan kulat adalah besar, kemerosotan MDF telah mengganggu keupayaan penukaran kation (CEC) tanah begitu juga kation tertukarganti tanah dan kehilangan berat oleh *Lentinus sajor-caju* adalah lebih tinggi dibandingkan dengan *Coriolus versicolor*, *Shizophyllum commune* dan *Gloeophyllum trabeum*. Kesan MDF pada air dapat didimpulkan telah memberikan Impak negatif pada ciri-ciri air yang dikaji selepas merendam sampel selama empat minggu

kerana meningkatnya kekeruhan, nilai pH, nilai BOD dan nilai COD. Nisbah BOD: COD memberikan gambaran bahawa air tercemar teruk dan mengandungi banyak bahan tak terbiodegradasi. Analisis FTIR bagaimanapun tidak menunjukkan kehadiran aldehid dalam air sampel. Kesimpulannya sisa MDF memberikan kesan yang buruk apabila direndam dalam air namun dapat diterima oleh tanah dan kawasan terbuka.

EVALUATION ON THE PRESENCE OF HAZARDOUS MATERIAL FROM MEDIUM DENSITY FIBREBOARD

ABSTRACT

The wood-based composites industry in Malaysia is increasing rapidly. Currently Malaysia is one of the main producers of medium density fibreboard (MDF) in Asia Pacific Region. Rubberwood is the main raw materials used in medium density fibreboard with other components include adhesives and additives. The adhesives used are mainly formaldehyde based adhesive such as urea and melamine formaldehyde. These types of adhesives produced formaldehyde emission that poses waste disposal problems to the environment when the boards degraded. This study aimed to simulate the MDF decomposition, to study the effect of waste MDF on soil, to analyze the contamination caused by MDF waste in water and to simulate long term formaldehyde emission through short term study. Medium density fibreboard from rubberwood with urea formaldehyde (UF) resin of two thicknesses: 6mm and 18 mm were used. The extractable formaldehyde was determined in accordance to EN717-3:1996 E flask method. The unsterile soil burial and monoculture fungal were carried out in accordance with BS 1982: 1990. The monoculture fungi used include white rot fungi, *Coriolus versicolor*, *Lentinus sajor-caju* and *Shizophyllum commune* and brown rot fungus, *Gloeophyllum trabeum*. From the study, as a conclusion it found that the amount of extractable formaldehyde decreased with time, in the 10th and 13th week the extractable formaldehyde was zero for 6 mm and 18 mm MDF samples respectively, the weight loss of soil burial and monoculture were substantial, the degradation of waste MDF had affected the cation exchange capacity (CEC) of soils and fluctuate the exchangeable cations content in the soil and the weight loss by *Lentinus sajor-caju* was higher compared to the weight loss by *Coriolus versicolor*, *Shizophyllum commune* and *Gloeophyllum trabeum*. This study also concluded that the

impact MDF had on water characteristics were negative as after the samples were soaked in water for four weeks it had increased the turbidity, pH, BOD and COD. The BOD:COD ratio values reflected that the water was highly polluted and contained more unbiodegradable organic matter in it. The FTIR analysis however found no aldehyde in the water samples. In short, MDF waste post more hazard when immersed in water but the hazardous material especially formaldehyde was better coped by soil and open environment.

CHAPTER 1 : INTRODUCTION

1.1 Wood Based Composites In Malaysia

Wood is a hygroscopic material and has the ability to exchange its moisture content with air. Many mechanical properties are affected by changes in moisture content below the fibre saturation point (FSP) of wood. In a time of conservation and public awareness of the environment's limitations, the wood composite industry has gained wide acceptance because of its economic use of woodworking residues and generally under-utilized tree species (Aydin *et al.*, 2006).

The wood based composites in Malaysia varies from plywood, particleboard, fibreboards such as insulation boards, hardboards and medium density fibreboards (MDF) and other engineered wood products namely glue laminated lumber, laminated veneer lumber, laminated strand lumber and parallel strand lumber.

MDF is a wood based composite material used for the production of architectural mouldings such as skirting boards, dado rails, moulding etc for construction and do-it-yourself (DIY) industries. The total annual waste generated by five major UK and Ireland producers was approximately 23 000 m³ (15 000 tons) in 2000 and the volume is rising rapidly due to the growing popularity of MDF architectural mouldings (Gan *et al.*, 2004).

The manufacturing of medium density fibreboard had started in the forties in order to better exploit and utilize wood (Roffael 1993). Malaysia had taken the same step in improving the downstream product of its plantations and agro residues with the total export of fibreboard in 2005 was 1 183 454 m³ that translated into RM 1.1 billion (Malaysian Timber Council 2006). Another data obtained from the Malaysia Timber Industry Board showed that for 2007 from January until February alone, Malaysia had exported 181 222 m³ of fibreboard amounting to RM 1.8 billion.

To date there is no comprehensive information on the effects of long storage in months or years on the formaldehyde emission from medium density fibreboard. But it is

a known fact that the formaldehyde emission from UF bonded particleboard decreases during storage and ageing and can be considered reduced (Que *et al.*, 2005; Que *et al.*, 2007).

Most of the waste MDF is currently disposed of by combustion on site whilst a small proportion goes to landfill at a cost to the manufacturers (Gan *et al.*, 2004).

If the waste is in form of dust, the dust is too fine and voluminous to be easily handled, stored and transported. It also contains free formaldehyde residue rendering it hazardous through inhalation. It is suspected that the presence of nearly 10% of binding agents (UF resins) in the MDF material may have prevented a proper development of porous structure under the charring and activation conditions. On the other hand acid treatment at low concentrations may be ineffective as the degree of chemical penetration would have been too low. The high presence of UF in the MDF sawdust and the strong chemical bonding between the binding agent and the carbonaceous material could have been another important factor associated with the ineffective development of a microporous structure in the MDF sawdust particles (Gan *et al.*, 2004).

1.2 Current Recycle Awareness

Currently Malaysia has 230 landfills with each covering 20 to 150 ha of land (Chia 2005). By the year 2003, 80% of these landfills will expire (Hasnah 2003). Many waste ended up at landfills which in turns are burned or piled up. Uncontrolled open burning can result in air pollution while piling up needs to face challenges from animals, diseases, water contamination and odour pollution (Azlinariah 2007). Among potential problems in a landfill are contamination of soil, ground water and surface water (Fatta *et al.*, 1999).

Besides economic advantages, landfilling enables the organic part and the refuse to be decomposed to inert and stabilized materials under controlled conditions. The organic part of the refuse within landfills is gradually decomposed by the activity of aerobic

and anaerobic bacteria. Anaerobic decomposition of solid waste in conventional landfills is a slow process; the decomposition rate depends on many factors such as the age and composition of landfilled refuse, its moisture content, the geology of the site, the leachate level, the temperature distribution; within the landfill and the effectiveness of capping of the site (Bilgili *et al.*, 2006).

Malaysian produced averagely 15 million kg of waste per day or 0.8-1.2 kg per person as reported by ENSEARCH, a non government organization (NGO) in Malaysia. With this amount of waste everyday, the Twin Tower that is 452 m height will be filled within 9 days. In 2005, 19 000 metric tons of waste are thrown consisting of 45% food waste, 24% plastic, 7% paper, 6% metal and 3% glass. This did not really have to happen because 55% of the waste was recyclable save food waste (Lee 2004 ; Azlinariah 2007). By recycling, 1000 kg/ year of carbon dioxide (CO₂) can be reduced (Hata 2007).

Basically recycle means reusing a material or item or reprocessing it to make it into its former form, alike its former form or others. In short recycle mean not simply throwing away. Recycle works hand in hand with 'reduce' that is to use items with less packaging materials or to use items with reusable materials and 'reuse' that is to avoid throwing away but try to use again as many times as possible. This process not only can reduce our waste up to 2 million metric tons but also save water usage and energy. Recycle glass can reduce 50% of water usage while recycle paper save 70% of energy. Recycled aluminum, paper and glass reduce pollution 95%, 50% and 14% respectively (Azlinariah 2007).

The Europeans and other citizens in the world have taken and adapted to the recycling culture because they see it as a demand to promote the quality and professionalism of life be it to oneself, family, society or environment. In Germany for instance, Avoidance of Packaging Waste (Packaging Ordinance) had been passed in 1991 to put a legislative force on recycling culture towards factories, wholesaler, retailer

and manufacturer. The Germans were known as avid and passionate recyclers. They were able to achieve 90% recycle per capita per year (Esqander 2007).

Current rate of recycle in Malaysia is 5% compared to Denmark, Germany, Singapore and Korea that have reached 45-50% rate of recycle. Though they had taken 20-25 years to achieve it, we are not on the safe side. The campaign for recycle in Malaysia had started 15 years back. First recycle campaign in Malaysia was in 1993, regenerated in 2000 and touched with some colours: orange for plastics and aluminum, brown for glass and bottle and blue for papers. We had 80-90% of citizens who had the knowledge about recycle meaning that they know what can be recycled, how to manage recycles and where to send them (Azrina 2007; Azlinariah 2007) yet the practicing citizens are much far less.

Alkaline of soil indicated the biochemical activity in the landfill body was in its final stage and the organic load was biologically stabilized while low pH values indicated acid formation (Fatta *et al.*, 1999).

Incineration and burial methods cannot avoid any wastage or destruction in waste material treatment by far. Incineration particularly should not be seen as a wise choice since incinerators had been found to aggravate city air pollution markedly and it was a waste of energy because the heat produced from incineration was usually lost and it caused a total destruction. Take cellulose for example. This main structural material of a plant life took many years to produce involving time consuming and intricate chemical process in its natural synthesis but through incineration, this raw material will be burnt and thus destroyed within seconds (Hunt & Terpstra 1974).

No matter how advanced or whatever name is given to an incinerator, it is unavoidable that incineration produced toxic, toxic ash and waste or residues that caused environmental pollution thus exposed animal as well as human beings to hazardous pollutant (Idris 2007).

Many products that were naturally biodegradable in soil such as tree trimmings, food wastes and paper will not biodegrade when placed in landfills because the artificial landfill environment lacks the light, water and bacterial activity required for the decay process to begin (Anonymus B 2007).

To say a product had a sustainable disposal the waste must return to the earth and be able to biodegrade. In fact any material that came from nature will return to nature as long as it was still in a relatively natural form. Therefore any plant-based, animal-based or natural mineral-based product had the capability to biodegrade (Anonymus B 2007).

To be truly biodegradable, a substance or material should broke down into carbon dioxide (CO₂) which was a nutrient for plants, water and naturally occurring minerals such as salt or baking soda that did not cause harm to the ecosystem (Anonymus B 2007).

Table 1.1 shows the estimated time for materials found in a landfill to degrade.

Table 1.1: List of materials found in landfills and their respected time to biodegrade.

Materials	Time to degrade
Cotton rags	1-5 months
Paper	2-5 months
Rope	3-14 months
Orange peels	6 months
Wool socks	1-5 years
Cigarette butts	1-12 years
Plastic coated paper milk cartons	5 years
Leather shoes	25-40 years
Nylon fabrics	30-40 years

Tin cans	50-100 years
Aluminum cans	80-100 years
Plastic 6-pack holder rings	450 years
Glass bottles	1 million years
Plastic bottles	Forever

Source: Anonymus B 2007

1.3 Problem Definition and Justification of the Study

Malaysian produced 15 million kg waste per day. From these wastes 25-30% is industrial waste and 75% are municipal waste. 60% waste generated from urban sector, 20% from agro-industrial and 20% from industrial sector and construction. 55% from these wastes are actually recyclable while currently the recycle rate in Malaysia is only 3%. In Penang alone every day Penangites on average throw 1.1 kg of waste per person. The rate of recycle is 15% on the island and 11% on the mainland. With this increasing trend of waste production, more landfills are demanded and to date we have 230 landfills with each covering 60ha of land (Chia, 2005).

The negligence to recycle or to reduce waste will result in exhausting land resources in the country since an expired landfill cannot be used for residence purposes until after 20 years. It can only be considered to be used as park or farm. The latter however needs a deeper deliberation because due to unclassified landfills, chemicals from waste will absorb into the underground water source thus jeopardizing public health either when the water is drunk or through nutrient intake from soil by any plants on it.

As technology develops through better understanding of science, MDF has been widely used primarily for the manufacturing of household and office furniture, kitchen and bath cabinetry, millwork, moldings and do-it-yourself (DIY) products. It is anticipated that

these products will eventually be replaced with a newer products. Unfortunately there was very little information on MDF life cycle analysis (LCA) although there were LCA studies on particleboard but not on MDF specifically. Hence these products of MDF will add to the already existing waste. The pressing issue regarding MDF is the use of formaldehyde resin and in industry of board manufacturing; no resin has yet better replaced formaldehyde resin. One widely used formaldehyde resin is urea formaldehyde. Urea formaldehyde is highly soluble in water and the increased of relative humidity (30-70%) and temperature (5-6°C) result in increased rate, nearly double, of formaldehyde emission and this situation can easily occur in any landfill.

Presuming that if the MDF product is channeled into the environment it will have contact with soil, water and its emission will interact with the air thus this study aims not just to stimulate the degradation of waste MDF but also to evaluate the potential hazard it may cause to the environment so as to take better precautions in handling waste MDF. Besides this study aims to see if there is anyway in particular that degrades MDF without risking the environment too severely.

The government is showing great interest in environment protection and welcomes initiatives to preserve or control natural resources consumption as long as it is economic. Thus the study focuses on accessing the long term effects of waste MDF on environment through short term study.

If this study is a success it will help at the least to decrease the amount of waste or its bulkiness in landfills.

1.4 Objectives Of Study

As it is anticipated that the used MDF products would be cast away in the environment thus this study simulated the decomposition of the MDF on soil, in water and free weather exposure. Paying attention to the lignocellulosic fibres in the MDF that can serve as food source to other microorganisms thus this study aims:

- To simulate Medium Density Fibreboard (MDF) decomposition.
- To study the effects of waste MDF on soil.
- To analyze the contamination caused by MDF waste in water.
- To simulate long term formaldehyde emission through short term study.

CHAPTER 2: LITERATURE REVIEW

2.1 Landfill situation in Malaysia

From a personal communication with Dato' Dr. Ong Han Tee (2007), the Chairman of Penang Environment Working Group (PEWOG) it is important to first define waste from rubbish. Waste is the things that people do not want to use any longer while rubbish is referring to the things that cannot be used. Thus any persons' waste can actually be useful to another.

The second thing that should be given attention is the different of dumpsite from a landfill. A dumpsite is where all rubbish and waste are simply thrown away. While in landfill the rubbish and waste are carefully monitored and managed. The rubbish and waste will be covered with soil at the first level. In the second level there will be two layers; one of soil and another of plastic. In the third level the leachate will be removed from the landfill. Malaysia has two types of landfill. The sanitary landfill such as in Pulau Burung, Penang and another is a secured landfill for chemical waste in Bukit Nanas, Negeri Sembilan.

The waste can be classified into safe waste which is non-toxic that normally goes into the sanitary landfills such as domestic waste and unsafe toxic waste. The unsafe toxic waste requires further classification because this type of waste not only pollutes the environment; soil, water and air which eventually go into the human system but also have a disastrous effect on human beings. It can cause cancer, damage body parts or organ, interfere the hormonal equilibrium and jeopardize the reproduction system.

The strategy that seems approachable to handle the situation is by taking up the three steps of clean production, zero waste management and resource recovery.

A clean production means either producing green product that facilitate environment reuse and recycle, reduce hazardous substances in a product or reduce waste from electrical and electric equipment.

Zero waste management looks into reducing packaging, promote biodegradable material, use the reduce, reuse and recycle (3R) concept and having a close loop system that collect and dispose the product produced. Figure 2.1 gives an illustration of a closed loop system which is aimed and the open looped system Malaysia is currently using.

The final, resource recovery is by segregating waste thus only rubbish is thrown.

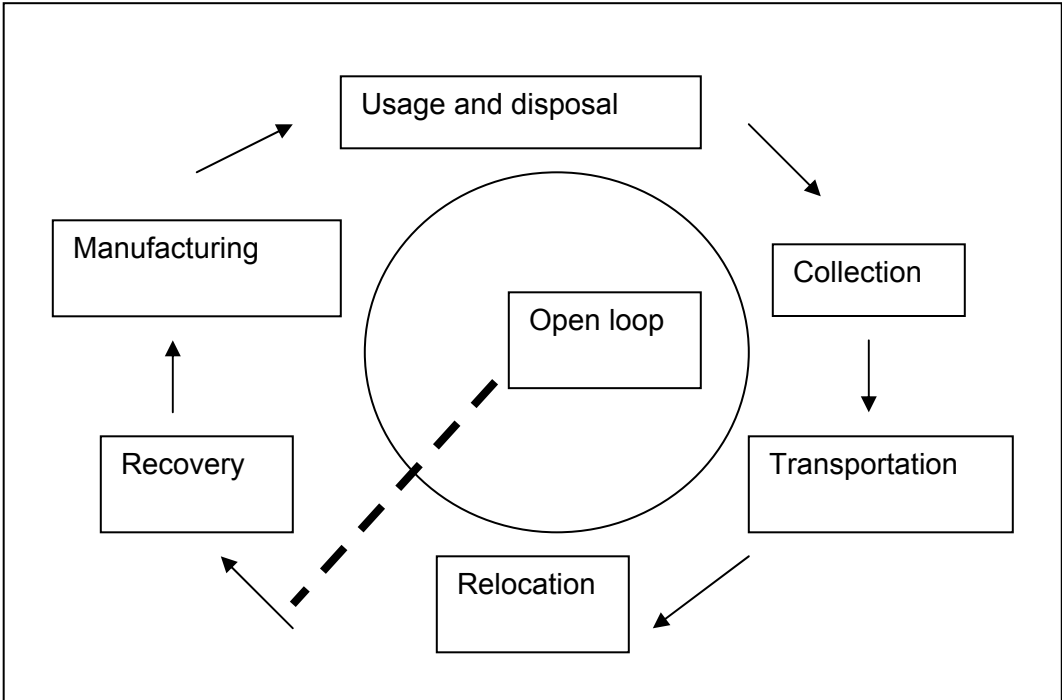


Figure 2.1: An illustration of open loop waste cycle in Malaysia

2.2 Wood waste

The classification of wood waste made by FRIM (1999) divided wood waste into nine types that were considered significant. They were bark, slabs, long off-cuts (trimmings), short off-cuts (short ends), peeler cores, sawdust, shavings, sander dust and rejects. These types were then further categorized into two groups. The bulk wastes included all the larger size wastes and were easy to segregate like bark, slabs, long off-cuts, short off cuts, peeler cores and rejects. The particle wastes or silo wastes were the mixture of small and fine wood particles like sawdust and shavings. These wastes were more difficult and costly to segregate.

In handling wood wastes, there were six dominant aspects that needed consideration before deciding on how the wood wastes could be utilized. The six attributes were wood species; either it was hardwood or rubberwood, segregation; did it stand alone or as a mixture, purity; was the waste clean or contaminated, moisture; the waste had been kiln dried, air dried or green, storage; had it been stored in silos, bins or left on the ground and finally size; did the waste required size reduction or did it not. Hence forth the wood waste could be used in two general areas. They can be utilized either as energy production resource or as a secondary raw material (FRIM 1999).

As an energy production resource, wood wastes were used as boiler fuel for kilns drying, lacquer-curing etc, as co-generation plant fuel and as industrial firewood that is for brick baking, noodle production, tobacco curing and steam generation.

On the other hand as a secondary raw material wood wastes were used within the wood based industry such as MDF, particleboard, block board, laminated board, charcoal briquettes, parquet and pallet manufacturing while outside the wood based industry wood wastes as a secondary raw material were used as fertilizer and mushroom growing media, livestock litter or bedding, small scale wood products that was cottage industry and in paper pulp industry (FRIM 1999).

Sawdust can be used as animal beddings. If this dust was mixed with chicken manure it can be used as fertilizer. It should be noted that immature sawdust was harmful to plants. Sawdust on its own cannot do much as soil mulch because the layer would be too compact. To reduce the density tea growers in Taiwan mixed sawdust with wood shavings before using it as soil mulch. The mulch decayed very slowly improving the soil for as long as five years (Nan 1982).

Bark residues made good composting material for fruit growers and some sugarcane plantations. Pulp factory had been using bark residues as fuel (Nan 1982).

2.3 Wood Based Composites

The Malaysia timber industry has successfully developed and diversified into downstream activities with strong support from the government and the implementation of the first and second Industrial Master Plans (IMPs) for 1986-1995 and 1996-2005 (Malaysian Timber Council 2007b).

Over the past 40-50 years the timber industry has developed from a primary processing industry to a much more sophisticated infrastructure today which consists of a significant number of downstream value-adding industries that include furniture and BCJ mills as well as engineered wood products such as MDF and plywood besides the traditional sawmills and plywood mills (Malaysian Timber Council 2007b).

Kaw (2006) defined composite as “a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the *reinforcing phase* and the one in which it is embedded is called the *matrix*. The reinforcing phase material may be in the form of fibres, particles or flakes. The matrix phase materials are generally continuous. Example of composites systems include concrete reinforced with steel and epoxy reinforced with graphite fibres, etc.”

On the other hand Abdul Khalil & Rozman (2004) defined composites as a solid material consisting two or more materials in which each material preserved its individual characteristics. They had given five general classes of composites such as fibre composites, flake composites, specialized composites, filled or frame composites and laminate composites. Examples of composites classification were as such: wood, bones, bamboo and muscles were a few examples of natural composites. Metal, reinforced thermoplastic and pieces moulded compound were micro composites and reinforced concrete beam was an example of a macro composite that was an engineered product.

This is agreeable with Kaw (2006) that points out wood and bones as natural composites. In wood lignin served as the matrix while the cellulose fibres as the reinforcing phase materials. On the other hand bone-salt plates made of calcium and phosphate ions reinforce soft collagen.

In fact the beginning of composites usage had started long ago when the Israelites used bricks made of clay and straw when as individual neither clay nor straw can serve the function. The people then believe the straw either kept the clay from cracking or blunted the sharp cracks in the dry clay (Kaw 2006).

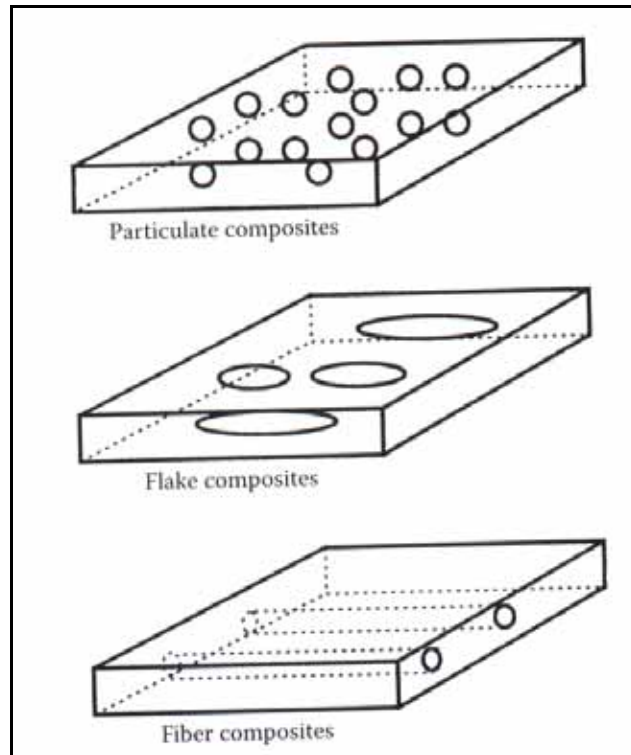
Then there were reinforcement of mud wall with bamboo shoots and glued laminated wood for house walls as in Egypt back in 1500 B.C., laminated forging swords in A.D. 1800 and in the 20th century in the 1930s the breaking through of glass fibres reinforced resins known as fibre glass used in making boats and aircrafts (Kaw 2006).

Composites are classified by Kaw (2006), as illustrated in Figure 2.2, according to the geometry of the reinforcement phase materials or the type of the matrix as such:

- i. Particulate composites made from particles immersed in matrices such as alloys and ceramics. They are usually isotropic as being added at random. The advantages of these types of composites are that they

have improved strength, increased operating temperature, oxidation resistance, etc.

- ii. Flake composites from flat reinforcements of matrices. Examples of flake materials are glass, mica, aluminum and silver. The advantages of flake composites are high out-of-plane flexural modulus, higher strength and low cost.
- iii. Fibre composites made from matrices reinforced by short (discontinuous) or long (continuous) fibres. Fibres are generally anisotropic like carbon and aramids. Examples of matrices are resins such as epoxy.
- iv. Nanocomposites are made from materials that are of the scale of nanometers (10^{-9} m). To be classified as nanocomposites, one of the constituents in making the composites must be less than 100 nm.



Source: Kaw 2006

Figure 2.2: Types of composites based on reinforcement shape

2.4 Background on Medium Density Fibreboard (MDF)

Problem faced in panels or wood-based composites industries such as OSB, plywood or sawn timber are:

- i. decreasing raw material supply
- ii. reduced availability of large-sized timber
- iii. increasing responsiveness to environmental pressures
- iv. government policies to develop domestic wood-based industries (Forestry Department 2007b)

The first three factors explain why the traditional sawnwood sector has lagged behind other sectors and the declining importance of the plywood sector which has been

significantly affected by a reduction in wood supplies as well as competition with MDF whose production costs are considerably lower (Forestry Department 2007b).

When plywood was produced as a response to government policies in promoting domestic wood-based industries, MDF is more a reaction to decreasing raw material sources that was becoming more evident and opportunity of using formerly untapped resources (Forestry Department 2007b).

The first MDF was produced in Malaysia in the 1960s. The board was very much like hardboard and particleboard yet very different from the two. The MDF produced has the density of 500-800 kgm⁻³. Like the hardboard, MDF was made of wood that has been reduced in size to become individual or accumulation of fibres. The bond in the product was through synthetic adhesives or artificial binders as a replacement to lignin bond (Haygreen & Bowyer 2003)

The number of MDF plants using rubberwood has increased rapidly since 1992 and started to grow rapidly in 1993 by producing 1.1 million m³ of MDF a year (Forestry Department 2007a; Forestry Department 2007d). MDF production technologies had been in use, tested and refined for more than 25 years before they featured more prominently in the Region. At the end of 1996, Asia-Pacific Region became the leader in MDF production with an installed capacity of well over 5 million m³ per year (Forestry Department 2007b).

In 2001 there were a total of 1 099 sawmills, 156 veneer and plywood mills, 14 MDF mills, 15 particleboard factories and over 2300 furniture, joinery, molding and other woodworking plants. Of the 14 MDF plants in the country, all of them were using rubberwood as the raw material except for two companies in Sarawak which used mixed tropical hardwoods and one each in Sabah and Peninsular Malaysia utilizing oil palm empty fruit bunches (EFB). Total annual production capacity of these plants is 1.2 million m³ (Malaysian Timber Council 2007b).

Tsoumis (1991) as well as Haygreen & Bowyer (2003) stated that MDF had tight edges and a practically homogenous texture, can be machined like solid wood and suitable for carving since it have a smooth surface that can be directly coated, painted or grain-printed thus can reduce the need for face veneer or other layers. It is also manufactured in textured surfaces simulating rough sawn wood or raised latewood grain and is available finished with plastic films.

There were many advantages in using wood composites. They were unlike solid wood that was not predictable. Solid wood varies inter and intra species, even within the same tree. A composite had the advantages of having controlled characteristics which made it possible to tailor to more desired values (Abdul Khalil & Hashim 2004).

According to Kartal & Green (2003) MDF is a wood based panel that is composed of wood fibres bonded together with resin under heat and pressure. MDFs have a specific gravity ranging from 0.50 to 0.88 and have a wide application for both structural and non-structural uses. Production of MDF products has increased dramatically and new plants are planned worldwide.

The Forest Department (2007b) has outlined the advantages of MDF that draws massive investment in its production as:

- i. price competitive alternatives than plywood, particleboard and hardboard.
- ii. similar characteristics as plywood
- iii. turning low quality and low value raw material (including non wood fibres) into high value and high quality wood panels. This explains why the production costs are about 50% lower.
- iv. desirable and user friendly physical properties.
- v. favorable machining properties.
- vi. has a variety of end uses.
- vii. can replace tropical hardwood timbers for furniture.

- viii. the production process can virtually use all wood species of minimum log diameter down to 5 cm.
- ix. it is marketed as an environmentally friendly product which relies on sustainable resources such as rubberwood, radiata pine and non-wood fibres.

2.5 Manufacturing of Medium Density Fibreboard (MDF)

The basic materials for MDF are fibres either wood or non-wood, binding matrix such as resin and additives to improve certain characteristics of the product such as strength, moisture resistant, improve resistant to microorganisms attack or fire retardant. The materials may also include paraffin, asphalt, alum, insecticides, fungicides, fire retardants, starch, synthetic resins and drying oils. Both hardwoods and softwoods are used in the manufacturing of fibreboard. The preferred species are those with thin walled fibres for easy collapse, present a larger area of contact and contribute to development of more and stronger hydrogen bonds (Tsoumis 1991).

Important raw material for MDF include radiata pine (New Zealand), mixed tropical species (Japan), rubberwood (Thailand), bagasse (Pakistan, China and Thailand) and cotton stalks (India). At the beginning the only raw material used in Malaysia was rubberwood (Forestry Department 2007b).

The growth in the MDF sector in Malaysia is also the direct consequence of rubberwood abundance. Amongst the advantages of rubberwood were its low price, availability in large volumes, it was a homogenous raw material and a renewable resource (Forestry Department 2007b).

Since rubberwood is readily attacked by fungi and insects as well as the wood chips are easily discolored during storage. The manufacture of MDF with UF resin

requires that chips be used within four weeks, preferably fresh, in order to maintain the expected strength properties of MDF (Forestry Department 2007a).

Boards made from fresh chips and UF have been found to attain the minimum bending strength requirement of JIS A-5909-1983 type 200. However the internal bond in MDF tests has exceptionally high at about 16 kg/cm² (Forestry Department 2007a).

The colour of the boards varied from yellowish-cream to dark gray depending on the age of the raw material. MDF to acceptable quality could be made from rubberwood that has been stored up to three months with different treatments of fungicide and insecticide (Forestry Department 2007a).

2.5.1 Rubberwood

Rubber wood, *Hevea brasiliensis* as in Figure 2.3 is classified as a light weight hardwood according to Malaysia Grading Regulations (MGR) 1994 (Menon 1997) thus the density of the wood is less than 720 kg/m³ and the moisture around 15 %. This wood was introduced from its native South America and rubber industry was established in South and Southeast Asia at the end of the 19th century. Three largest producer countries for rubberwood are Indonesia, Thailand and Malaysia (Forestry Department 2007d).



Figure 2.3: Rubber tree

The colour of the sap wood and the heart wood of rubber wood does not differ much; they are white or light cream in colour; sometime with pink spots. When exposed to weather the colour change to hay brown or light brown. Shaved surface of rubber wood is not shiny. The tangent surface might have zigzag mark due to wood parenchyma. The texture of rubber wood varies from medium rough to rough and even. On the other hand the grain orientation is straight to slightly spiral. Air dried density of rubber wood range from 560-640 kg/m³. This wood is not durable in contact with soil or exposed to moisture (Menon 1997).

Rubber wood has no growth ring. The presence of parenchyma bands might imitate growth ring. The vessels have simple perforation plate (Nair 1998) medium to large (Menon 1997). Some of them are singles while the majority are radially coupled or multiplied up to 4 vessels. Sometimes they are radially multiplied that 5-8 vessels are found. Scattered clustered vessels are usually found in rubber wood and they often

contain tyloses. Vessels lines are obvious and visible as scars on radial surface (Menon 1997).

Apotracheal wood parenchyma in rubberwood was predominant and visible with naked eyes. This parenchyma looked like inconsistent, close and fine bands connecting rays forming a net pattern. Paratracheal parenchyma was found like small borders around vessels (Menon 1997). The microscopic view of rubberwood is shown in Figure 2.4.

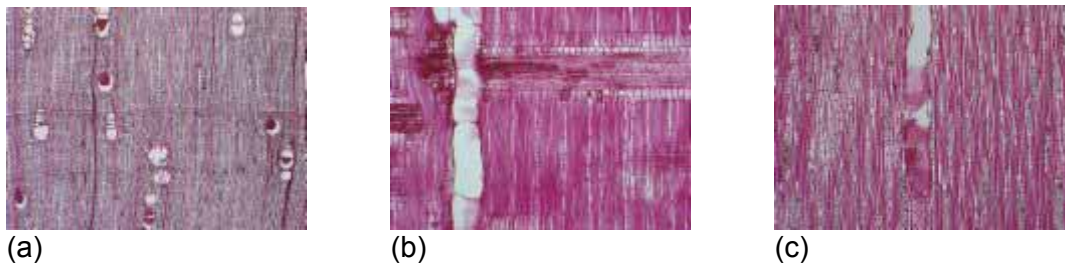


Figure 2.4: The microscopic view of (a) cross section, (b) radial and (c) tangential of a rubberwood. Figures shown are at 100x magnification.

The physical characteristics of rubberwood enable it to be used extensively in the manufacture of chairs, stools, benches, tables and bed legs. It is also suitable for joint works, cabinetry, furniture, decorative panels, flooring and tableware. Rubberwood's good working qualities for machining, acceptable durability, light natural colour that allows it to be stained, uniform texture (that make it ideal fibre source for MDF production) and adaptability in accepting paints and other finishes makes it an ideal wood for furniture. Thus rubberwood has begun to make inroads in traditional domains. These advantages however compensate for the recognized problems of variations in colour and density but the need remains for preservation and drying treatment in order to avoid problems of discoloration or bowing and twisting of the wood when the moisture content of the wood rises above 10-12%. Rubberwood biodegrades rapidly due to high sugar content and was

very susceptible to insect infestations and fungal attack after felling. Another major factor which influences the extent to which rubberwood utilization becomes a success will be the price of the raw material itself (Forestry Department 2007a; Forestry Department 2007b; Forestry Department 2007d).

2.5.2 Availability of rubberwood

Generally rubberwood is not durable in natural tropical climate but quite durable in temperate climate (Menon 1997). Before rubberwood found a use in timber and timber products, felled trees were almost exclusively used as fuelwood and charcoal in many countries. Rubberwood charcoal has been commercially produced in Malaysia for many years. Unprocessed rubberwood is also sold in local markets for household use (Forestry Department 2007a).

More than twenty five years ago, the commercial value of rubberwood as a raw material for the wood processing industry was negligible (Forestry Department 2007b). Significant utilization of rubberwood can be attributed to the combination of research and development by the FRIM and the development of marketing strategies by private companies and related government agencies (Forestry Department 2007b).

Historically, a substantial share of harvested rubberwood was either burned at the site or used for fuelwood or charcoal. The increasing used of rubberwood in furniture, furniture parts and panel products suggested that a growing share of available rubberwood had found its way to primary and secondary processing industries. This momentum had been created by Malaysia and Thailand to promote more rubberwood utilization (Forest Department 2007c).

Malaysia was the first country to utilize rubberwood at an industrial scale, starting with the production of sawnwood that were mainly for exports, which stimulated the development of the larger rubberwood industry. The peak of rubberwood sawnwood

exports from Malaysia was reached in 1989 with 221 000 m³ exported (Forest Department 2007c).

Since the 1980s, rubberwood has gradually established itself as a major wood product in several countries, particularly for the production of furniture components and wood panels. Rubberwood plywood is used for both construction and decorative end uses. More recently, MDF, particleboard and oriented strand board (OSB) have also joined the list of products derived from rubberwood and sawmill waste (Forestry Department 2007a).

The rubberwood processing industry of Malaysia is recognized to be a world leader because of the strength of its secondary processing sector. Rubberwood in Malaysia is the main wood used by the furniture industry. It is estimated that exports of rubberwood furniture from Peninsular Malaysia accounted for 70% of all wooden furniture exported in 1994. Rubberwood could also be used for the production of semi-chemical pulp. One Malaysian company is exporting rubberwood chips to Japan for the production of corrugated paper medium. However apart from this small amount of trade, there is no other recorded use of rubberwood for pulping (Forestry Department 2007a).

In the wood based composites industry, rubberwood plywood has proved to be a potential high value end use, provided that appropriate technology is used. The rubber tree is also extremely well suited as a raw material for the production of particleboard and MDF (Forestry Department 2007a).

In 1990 furniture industry has sustained its foreign exchange earnings at RM 215 million (Malaysian Timber Council 2007). In 1992 an estimated of 85% rubberwood sawnwood produced in Malaysia was processed further into furniture. A tentative estimate based on previous studies indicates a figure of 1.6 million m³ of rubberwood logs were used for sawnwood production in Malaysia in 1995. Assuming a 33% average sawnwood yield, this would give 520 000 m³ of rubberwood sawnwood production (6% of

total production in Malaysia) and using a yield of 50% of sawnwood to finished products, some 220 000 m³ of secondary products production from rubberwood (Forestry Department 2007a).

In 2004 the furniture foreign earnings had increased to RM 6.3 billion. In 2005 it was expected to be RM 7 billion. Of this amount, 80% of the furniture exported was made of rubberwood (Malaysian Timber Council 2007). In Malaysia, rubberwood has outperformed many of the traditional light-coloured species used in the production of furniture due to its low price and availability. Of the approximate USD 600 million for furniture export values in Malaysia in 1995, around 70% is from rubberwood (Forestry Department 2007b).

Figure 2.5 illustrates the flow of rubberwood logs and primary products in Malaysia in the year 1992.