DEVELOPMENT OF COATING FOR FORMALDEHYDE SCAVENGERS IN WOOD COMPOSITE

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DEVELOPMENT OF COATING FOR FORMALDEHYDE SCAVENGERS IN WOOD COMPOSITE

JEEVAN NAIR A/L VASUDEVAN

Thesis submitted in partial fulfilment of the requirements
for the award of the degree of
Bachelor of Chemical Engineering

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JUNE 2015

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Bachelor of Chemical Engineering.

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Date	: 30 JUNE 2015

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is my own except for quotations and summaries which have been duly acknowledged. The thesis has not been accepted for any degree and is not concurrently submitted for award of other degree.

Signature	:
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ID Number	: KA11168
Date	: JUNE 2015

Dedication

To my two cute dogs which I will always cherish,

to my parents whom I will forever be grateful,

to my siblings whom I will eternally love,

thank you all for believing in me

as you all are the light in my darkest nights.

Special thanks to AP Dr. Arun Gupta for his excellent guidance and support,

my roommate, Teh Kwo Wei, for his support,

my best friends for their undying love,

the Chemical and Natural Resources Engineering Faculty and Universiti Malaysia Pahang.

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ABSTRACT

Wood composite is also known as wood engineering. This field is available due to its ability to overcome the current limitation faced by applying natural lumber wood. The many advantage that wood-composite have over natural lumber makes it more desirable in long-term usage. In the production of wood-composite, the agent use to bind wood together is urea formaldehyde. The issue faced when urea formaldehyde is used, that it will produce free formaldehyde which is rather cancerous to human beings. Hence, steps have to be taken to reduce the emission of urea formaldehyde. The step proposed in this research is utilizing formaldehyde scavengers. But if scavengers are applied directly during the production of wood composite, it will affect the credibility of the product and also react will the urea formaldehyde. Thus, a study on developing a typical wax or polymer coating for these scavengers could solve the problem. Once, the coating is developed, it is incorporated to the preparation of the medium density fibreboard and after that, tests are conducted to characterize its properties. To study the feasibility of success of this research, the parameter studied is mechanical properties of the wood and the formaldehyde emission of the finished product. The focus of mechanical properties is the internal bonding, modulus of elasticity and modulus of rupture to determine effect of scavengers to the wood panel. In formaldehyde emission, perforator and desiccator methods are applied to determine the concentration of formaldehyde liberated. From the proposed scavengers used, sodium metabisulfite and ammonium bisulfite, sodium metabisulfite shows great effectivity in reducing the formaldehyde liberation followed by ammonium bisulfite. However, ammonium bisulfite affected the mechanical properties of the board greatly, where else, sodium metabisulfite did not affect adversely. With this study, it could provide the wood-composite industry an alternative to open new market with this method of producing wood-composite products.

ABSTRAK

Kayu komposit dalam erti kata lain adalah kejuruteraan kayu. Bidang ini wujud kerana keupayaannya untuk mengatasi kekurangan-kekurangan yang dihadapi oleh kayu semula jadi. Kelebihan-kelebihan menggunakan kayu komposit membuatkannya diingini dalam jangka panjang. Dalam pembuatan kayu komposit, agen pengikat yang digunakan adalah urea formaldehid. Masalah yang dihadapi apabile urea formaldehid digunakan adalah pelepasan formaldehid yang juga boleh menyebabkan pertumbuhan barah dalam kalangan manusia. Oleh sebab itu, langkah pencegahan harus diambil untuk menggurangkan pelepasan formaldehid. Langkah yang dicadangkan adalah penggunaan pemungut formaldehid dalam proses pembuatan kayu komposit. Tetapi, jikalau pemungut ini digunakan di masa pembuatan kayu komposit, pemungut ini boleh merosakkan kualiti produk atau bertindak balas dengan urea formaldehid. Jadi, suatu salutan atas pemungut dikaji dan dibangunkan. Selepas salutan ini dicipta, pemungut ini akan digabungkan dalam proses pembuatan kayu komposit. Untuk menyimpulkan penyelidikan ini, ciri-ciri mekanikal akan dikaji dan pelepasan formaldehid ditentukan. Dalam kajian ciri-ciri mekanikal, ikatan dalaman, modulus keanjalan dan modulus pecah akan ditentukan dalam papan serat kepadatan sederhana (MDF). Dalam kajian pelepasan formaldehid pula, beberapa kaedah akan diambil dalam menentukan kadar pelepasan formaldehid. Antaranya, kaedah "perforator" dan kaedah "desiccator". Dengan pemungut yang dicadangakan adalah natrium metabisulfite dan ammonium bisulfite, pelepasana formaldehid adalah lebih rendah apabila natrium metabisulfite digunakan daripada ammonium bisulfite. Walau bagaimanapun, ammonium bisulfite telah menjejaskan ciri-ciri mekanikal terlalu rendah tetapi natrium metabisulfite hanya menjejaskan sikit ciri-ciri mekanikal kayu komposit. Dengan kajian ini, adalah dengan harapan boleh memberi industri kayu komposit suatu alternatif dalam perwujudan pasar baru dengan kaedah baru pembuatan produk kayu komposit.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

ANSI	American National Standards Institute
ASTM	American Standard of Testing & Materials
CARB	California Air Resources Board
EN	European Nation (standard)
F/U	Formaldehyde to Urea
FRIM	Forest Research Institute of Malaysia
IARC	International Agency for Research on Cancer
IB	Internal Bonding
JAS	Japanese Agricultural Standard
JIS	Japanese Industrial Standard
MDF	Medium Density Fibreboard
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
NPA	Notice of Proposed Amendment
RH	Relative humidity
UF	Urea Formaldehyde
UTM	Universal Testing Machine
WPC	Wood Plastic Composite

1 INTRODUCTION

1.1 Motivation and statement of problem

With strict laws and policies like Malaysia's very own National Forestry Act 1984, to protect natural wood from illegal logging and harvesting, it has been difficult for avid natural wood-lover to purchase or satisfy their passion. Hence, wood-composite makes a suitable and the most promising alternative to solve this issue.

Wood-composite is viable in the form of medium-density fibreboard (MDF), particleboard, oriented strand board, plywood, etc. The manufacture of composite wood-based products occurs when various sources of wood particles are bind with a thermosetting binding agent which is usually a type of resin. This will eventually form into compacted mats which are rather loose. These wood-particles are also varied in many different forms. Such examples are like flakes, fibres, strands, and particulate forms. Different wood-particles yield different type of boards. The generic end products are fibreboard, hardboard, flakeboard, strandboard, particleboard, and waterboard to name a few. Unlike hardboard and medium-density fibreboard, these boards are characterised in terms of their density. Back to production or preparation of wood composite, the mats are then placed in mould and pressed until it reaches a suitable or preferred thickness using a hot-press machine. Then, it is left to cool down until the adhesive or resin is cured. (Taylor & Reid, 1984).

The resin which is usually utilised is urea formaldehyde resin. Approximately, urea formaldehyde resin is responsible for at least 90% or more in the world's wood-composite board production (Maloney, 1993). Moreover, urea formaldehyde is the most popular amino resins (William, 1991). From the amino resins manufacturing in the industry, urea formaldehyde comprises of 80% of the amino resins produced worldwide and the rest belongs to the rest of the amino resin group, primarily melamine-formaldehyde (Conner, 1996). The properties which make urea formaldehyde very much desired in the wood-composite industry as the main adhesive are as follow:

- Cheap and low in production cost,
- Solubility towards water,
- Low curing temperature,
- Resistive to abrasion and microorganisms,
- Fast reaction time under hot press,
- Excellent thermal stability,
- Lack of colour, and
- Its adaptability properties to wide array of curing conditions (Maloney, 1993, Dunky, 1998 & Conner, 1996).

Unfortunately, the ultimate drawback for utilising urea formaldehyde in wood-composite is the emission of free formaldehyde to the surrounding. Formaldehyde is labelled as a carcinogenic toward humans, which makes it very much cancerous. The International Agency for Research on Cancer (IARC, Monograpgh on the evaluation of carcinogenic risk to human, 2006) classified formaldehyde as "carcinogenic to human (Group 1). On top of that, a policy imposed by the California Air Resources Board (CARB) imposes restriction which limits formaldehyde emission. This resulted in greatly on the wood-based panel industry (Costa, et al., Scavengers for achieving zero formaldehyde emission of wood-based panels, 2013).

Hence, to overcome this major issue, many research have been done to reduce or eliminate if all, the emission of urea formaldehyde. Some methods which are currently being research and practiced in the industry are reduction of formaldehyde to urea (F/U) ratio, substitution of urea formaldehyde resin, and usage of urea formaldehyde scavengers (Costa, et al., 2013).

1.1.1 Reduction in formaldehyde to urea (F/U) ratio

Myers has studied on the F/U ratio and concluded the contradicting standards set by respective responsible agencies in different countries do not match up (Myers, 1984).

- F/U < 1.2 or < 1.1 to meet German standard
- F/U < 1.3 or < 1.22 to meet NPA emission standards for U.S. mobile homes
- F/U ≥ 1.2 for bending strength and modulus of rupture

- F/U ≥ 1.1 or possibly ≥ 1.2 for internal bond
- F/U ≥ 1.2 or ≥ 1.3 for 24-hours thickness swell.

Eventually, based on Myers extensive study, he found out that the bending strength and modulus of rupture was thoroughly affected when the F/U dropped to 1.2. Internal bond however, are at an acceptable manner but started deteriorating when the F/U ratio increase to 1.4 or 1.5. Besides that, the thickness swell begins rapidly as F/U falls to 1.3 onwards. Most importantly, the reactivity of urea formaldehyde decreases as the F/U ratio reduces.

1.1.2 Substitution of Urea Formaldehyde

Substitution of urea formaldehyde adhesive with a formaldehyde-free compound could be very promising. Unfortunately, due its higher price and lower reactivity, industrial producers are not convinced (Amazio, et al., 2011). A research done (Despres, et al., 2010) suggested that substituting dangerous urea formaldehyde with alternative, non-toxic, non-volatile aldehydes to produce urea-based resins. Unfortunately, these aldehydes have a significant problem, it is coloured (Pizzi, 1983). Besides that, they are also toxic to some level and are have reactivity issues with other compounds present in the binding agent (Mansouri & Pizzi, 2006) (Wang & Pizzi, 1997).

1.1.3 Usage of urea formaldehyde scavengers

Usages of urea formaldehyde scavengers are relatively new in the industry. Scavengers are compound utilized to extract or remove a certain substance by either reacting with it or being adsorbing it. Many researches have been done to signify the gain in benefits by using scavengers to reduce urea formaldehyde emission. The usage of natural or biological-based urea formaldehyde scavengers is very common in the industry to reduce urea formaldehyde emission (Kim, et al., 2006). Studies have shown that scavengers like sodium metabisulfite ($Na_2S_2O_5$) is very efficient in particleboards produced with urea formaldehyde and melamine-formaldehyde (MF) resin and yielded successful results (Costa, et al., 2012).

1.2 Objectives

The following are the objectives of this research:

- To develop a coating for urea formaldehyde scavengers either with a suitable wax or a type of polymer.
- To analyse the mechanical properties of the medium-density fibreboard which are; internal bonding, modulus of rupture, and modulus of elasticity.
- To investigate the free formaldehyde emission rate of the wood composite board fabricated.

1.3 Scope of this research

The following are the scope of this research:

i) Perform a study on the affectability of wax and polymer for a coating used in the preparation of scavengers. This coating is via trial and error method.

ii) Emission of formaldehyde is to be studied after the completion of the fibreboard.

iii) The mechanical properties like internal bonding, modulus of rupture, and modulus of elasticity of the board are to be studied via utilizing the universal testing machine (UTM)

1.4 Organisation of this thesis

The structure of the reminder of the thesis is outlined as follow:

Chapter 2 provides a detailed description of this research literature review. It comprises of three main parts, which is wood composite, urea formaldehyde, and scavengers. A general description about the economic point of view is also discussed. Lastly, a summary of predicted parameters are identified to give an overview on the variation by manipulating each parameters.

Chapter 3 gives an overview on the characterization efforts in the process of investigating the efficiency of scavengers in formaldehyde emission, the mechanical properties of the board and the coating of scavengers. Moreover, this chapter will portray the experimental methodology of this research.

Chapter 4 is devoted to a comparative study on the predicted experimental results with the future expected results. Further discussion and justification regarding possible deviation of data are hypothesized.

2 LITERATURE REVIEW

2.1 Overview

This paper presents the experimental studies mainly on the development of coating for scavengers, the effectivity of scavengers toward formaldehyde and also the mechanical properties of the board utilizing coated scavengers. This chapter will subdivided into three different parts which each plays an important role. The subchapters which will be included in this chapter are as follow:

- Wood composite,
- Urea formaldehyde, and
- Scavengers.

A detailed insight will be presented regarding each subchapter. Lastly, a summary of predicted parameters are identified and explained further.

2.2 Wood composite

Wood composite is also known as wood engineering. This field is developed to overcome the limitations faced by general wood. Some of the advantages of using wood composite over actual wood lumber are as follow:

- It is less likely to split,
- It is lighter for easier handling,
- It is scratch and stain resistant,
- Low cost,
- Low CO_2 emission,
- Biodegradable and renewable, and
- Mould resistant this makes its interaction with microorganism relatively impossible (Ashori, 2008).

With that in mind, this gives wood composite a longer lifespan than actual wood lumber. This concludes that wood composite overcomes the disadvantages faced by actual wood lumber in every possible manner. As the name goes, it is a composite material which is a mixture of wood or plant fibres and binding agent (Ashori, 2008). Moreover, waster wood materials can be utilised in the production of wood composite. This will be very beneficial to the environment and cost-saving which could maximize the use of raw materials and reduction of waste creation (Trost, 2002). What makes wood composite unique and different with each other is the composition of binding agent. Some wood composite can are added with wax to promote its water resistive properties and some are added with certain dense compound to make it stronger, heavier or tougher.

In economic perspective, wood composite or wood-plastic composite has a large market in the industry worldwide. Globally, there are four main factors that make use of naturals fibres and wood in plastic attractive:

- Enhanced specific properties,
- Reduction of price of materials,
- Improve the bio-based share, and
- More easily recyclable when compared to other composites.

The wood-composite production reached 1.5 million extruded tonnes after more than 30 years in the marker. This makes about 750,000 tonnes of wood which only a small fragment of the total timber market. (Eder & Carus, 2013). This shows that wood-composite is does not harm the environments as much as the other activities since only a small amount of wood is being utilized in this industry. Wood composite is a growing market (Haider & Eder, 2010) as in Europe and with that arguably throughout the whole world.

Application of wood plastic composite (WPC) varies from furniture to consumer goods. Even it can be broken down into three different components and each components are exampled as follow:

- Outdoor applications
    - Noise barrier in street construction and sheet piling for landscaping
    - Garden furniture and fences
    - Construction and safety sector, especially in decking, railings, window frame, porches and docks
    - Piping, core pipes

- Indoor applications
    - Automotive engineering (interior)
    - Trucks and containers
    - Doors, furniture parts, kitchen cupboard frames, furniture
- Consumer goods and niche products
    - Musical instruments
    - Toys
    - Household electronics
    - Frames (Eder & Carus, 2013).

2.3 Urea Formaldehyde

Urea formaldehyde is the most well-known amino resin in the wood composite industry (Boran, et al, 2011 & Dunky, 1998). As stated before, urea formaldehyde is used as a binding agent in the wood composite industry because of it unlimited array of benefits. To recap, urea formaldehyde is chosen to be the prominent thermosetting plastic resin r binding agent in wood composite for its financial benefits, able to adapt to many curing conditions, faster reaction time, solubility towards water, low curing temperature, resistive properties towards microorganisms, and its colourless qualities (Pizzi, 1983 & Conner, 1996).

2.3.1 Chemistry of urea-formaldehyde resin formation

Generally, urea formaldehyde is formed in a two stage reaction. In general, these reaction main reactants are urea and formaldehyde. Initially, urea is hydroxymethylotated by the addition of formaldehyde into the amino resin group.

Mono-, di-, and trimethylolurcas are yielded from this reaction, as shown in Figure 2.3.3.1-1. This reaction rate is very dependent on the pH range (de Jong & de Jonge, 1953). For the exact ratio of formaldehyde to urea, F/U is affected by the operation conditions in the addition reaction.

The second stage for urea formaldehyde preparation is condensation. Likewise, the rate of condensation reaction is also very dependent on the pH range of the operation. Practically, condensation occurs only during acidic pHs. The range of pH values and rate of reaction is shown in Figure 2.3.3.1-2.

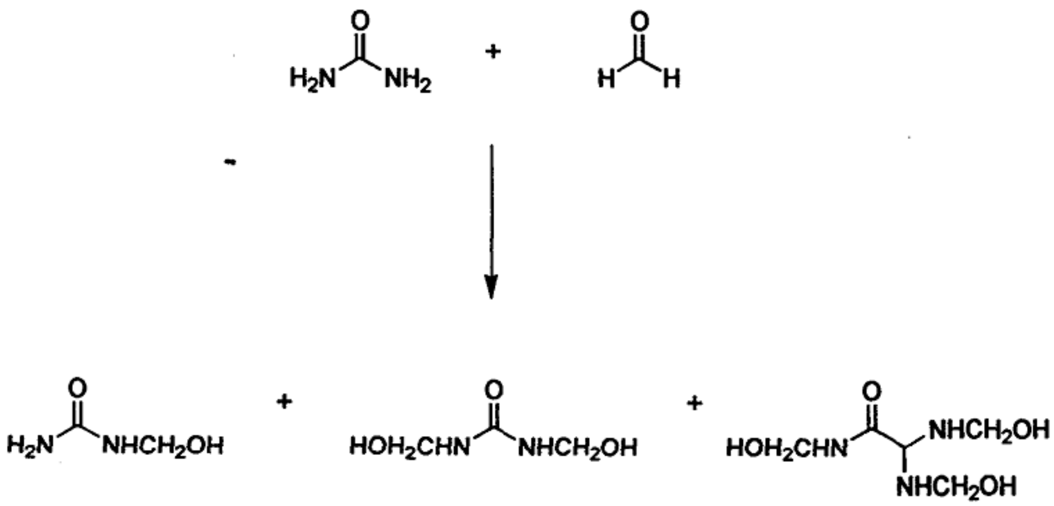

Figure 2.3.3.1-1: Formation of mono-, di-, and trimethylolurcas by addition of formaldehyde to urea (Conner, 1996).

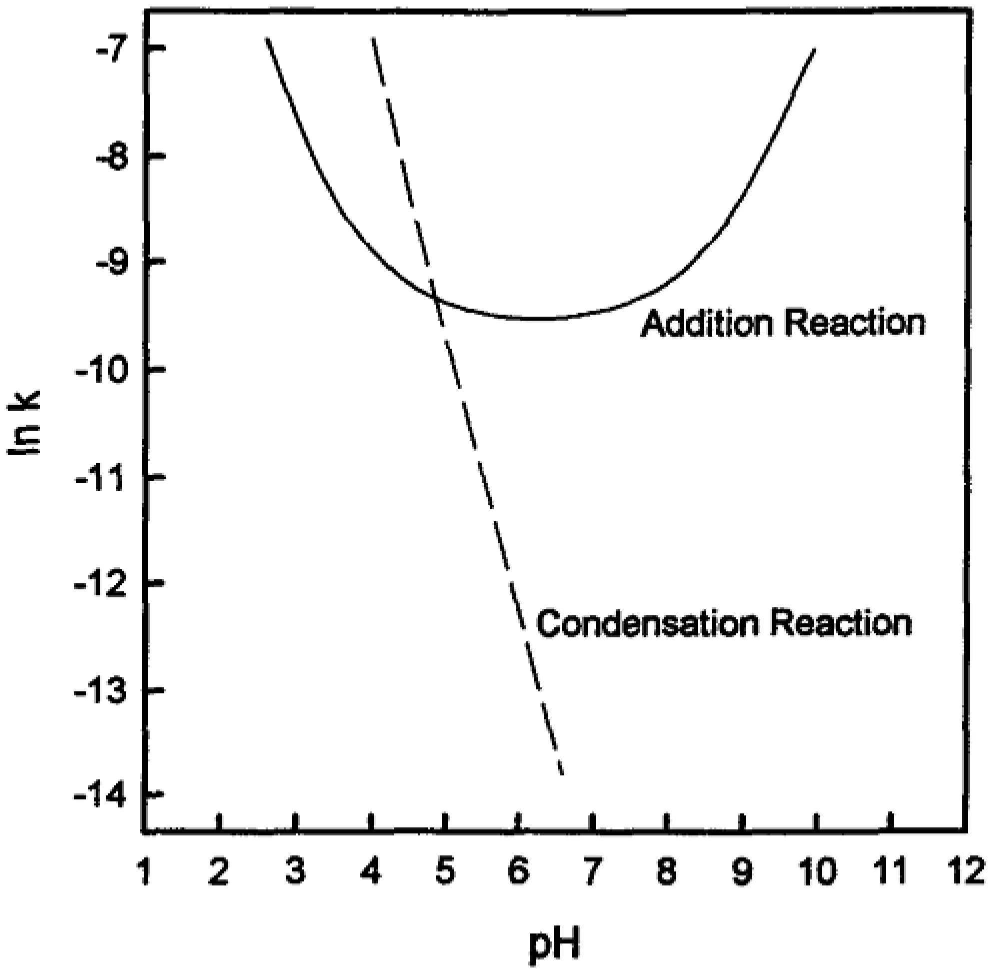

Figure 2.3.3.1-2: Influence of pH on the rate constant (k) for addition and condensation reaction in urea formaldehyde production (de Jong & de Jonge, 1953).

Similarly, in the case for urea formaldehyde resin production, it involves two major steps, addition of formaldehyde to urea and condensation method. The first step is formation of methylolurcas under basic condition of around 8.9 in the pH value. In this step also, the range of formaldehyde to urea, F/U ratio is determined and defined. Secondly, condensation process occurs under acidic condition of about 5 in the pH value. Once, the reaction is completed, the mixture is cooled and neutralized. Water, a by-product is then removed via vacuum distillation until desired viscosity. If it solidifies, formaldehyde makes excellent thermal insulator and it is also light weight (Meyer L. S., 1951). In the second step however, the F/U ratio can also be altered. In the second step, usually urea is added to lower the final F/U ratio (Conner, 1996).

The resin outcome from this process usually cures around the temperature of 120 ^{o}C in a very acidic condition (pH < 5). For curing time however, it is assumed to be similar to acid condensation of methylolurcas. The formation of a cross-linked polymeric network for the hardened, cured resin gave rise to this traditional viewpoint. Research has also shown that curing also occurs in colloidal phase (Pratt, et al., 1985).

2.3.2 Formaldehyde emission for UF resins

All good things do have certain drawbacks and for the case of urea formaldehyde, it has one major issue which affects living things adversely. Using urea formaldehyde seems to be the most suitable binding agent in the wood composite industry, but unfortunately urea formaldehyde release free formaldehyde to the surrounding. Roffael studied on this matter and found out that it is affected by exogenous factors like air humidity, air exchange and temperature. Besides that also, it is also affected by endogenous factors like raw material species, type of resins used and production conditions (Roffael E. , 1993) This emission is an important factor in the evaluation of the environment and health effects of this industry (Risholm-Sundman, et al., 2007). Moreover, formaldehyde-based wood composite products emits these free formaldehyde has cause many customers to portray discomfort and dissatisfaction towards the industry. Cause of health problems among customers can be traced back to these products, outcome from this industry (Boran, et al., 2011). Research has shown that the common health problems faced by customers who come in contact with the emitted free formaldehyde are irritation in the eyes and respority issues (Kim & Kim, 2004).

Also, as stated before, exposure to low concentration of formaldehyde causes minor health problems like irritation in the eyes and respiratory issue, but prolonged exposure could lead to risk of serios poisoning, chronic toxicity and eventually cancer (IARC, 2006 & Tang, et al., 2009). With health risks imposed on living being, regulations and steps have to be taken to overcome these serious issues. Also, standards and policies set by agencies worldwide affected the wood composite industry to reduce or eliminate if all the formaldehyde emission from wood products on a world-wide scale. In response to the standards and policies, companies pioneering in wood composite has taken major stride to reducing the formaldehyde emission level as shown in Figure 2.3.3.1-1 .

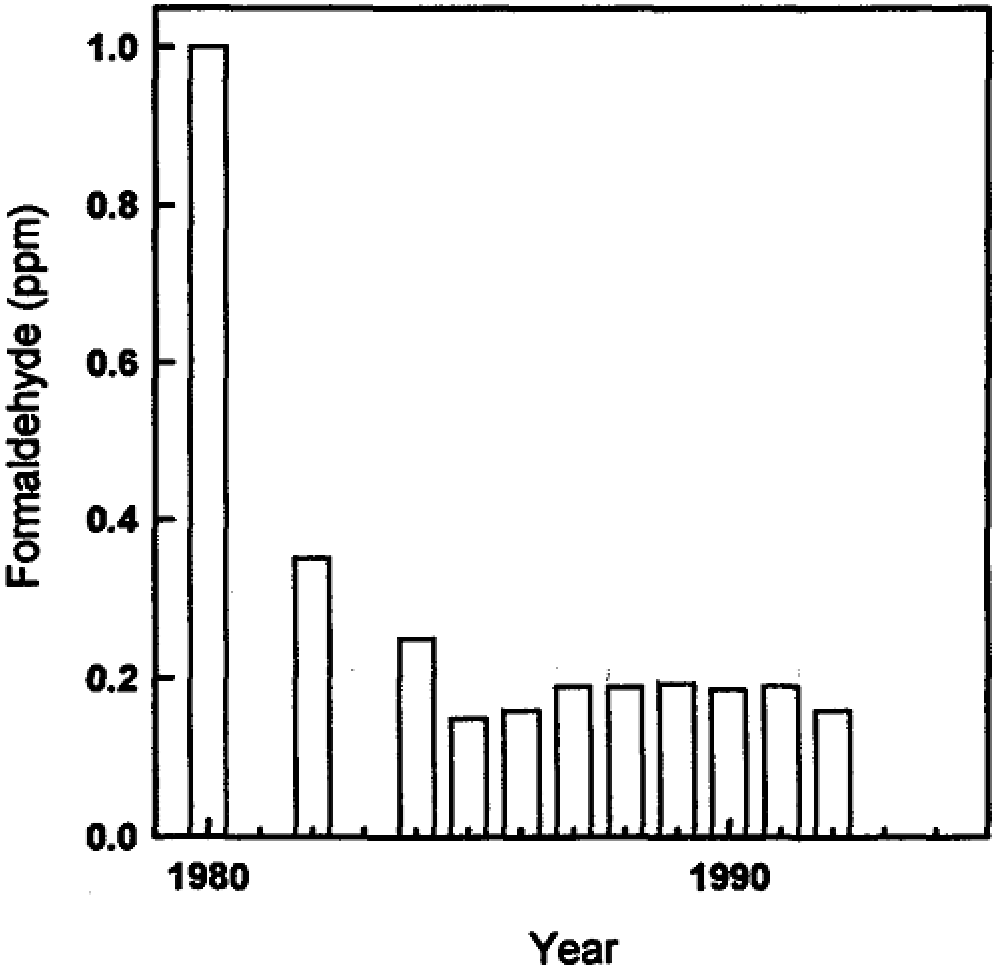

Figure 2.3.3.1-1: Average formaldehyde emission levels from particleboard manufactured in the year indicated. The levels were determined by the large chamber test method (National Particleboard Association & Conner, 1996).

In short, compulsory steps have to be taken to reduce the formaldehyde emission. One of the methods proposed by Myers, stated that reduction of formaldehyde to urea, F/U ratio seems promising (Myers, 1984). In his study, he found out that reduction of F/U ratio affected both the physical and mechanical properties of the wood composite board. With the credibility of these boards on the balance, the marketability of these products are also affected.

On top of that, a research done by Conner in 1996, he proposed several worthy methods to reduce formaldehyde emission. Besides reducing F/U ratio, he proposed for adding of formaldehyde-scavenging materials directly to urea formaldehyde adhesive resins, adding formaldehyde-scavenging material seperately to finished wood products, treating wood panels with formaldehyde-scavenging by the application of coating or laminates, and utilization of a completely different adhesive resin system in production of wood composite (Conner, 1996). However, replacing urea formaldehyde could affect the quality of the wood product. For example, in a research, it was found thar replacing urea formaldehyde with amine adhesives affected its physical and mechanical properties (Boran, et al, 2011).However, replacing urea formaldehyde with acrylic resins showed better results in mechanical properties like lower water absorption, and lesser thickness swelling but did not effect its thermal insulation properties (Amazio, et al., 2011).

2.3.3 Test for formaldehyde emission

Risholm-Sundman, et al, studied upon the different tests carried out for formaldehyde emission in different countries. The study shown a significance importance being placed in order to compare products with formaldehyde emission classes like E1 in Europe and F*** and F**** in Japan (Risholm-Sundman, et al, 2007)

2.3.3.1 Standard test methods

There are five standard tests for formaldehyde emission determination. This determination is in accordance to reference methods stated in Europe and on Japan. Some of the methods characteristics are discussed by Yu and Crump in 1999 as shown in Figure 2.3.3.1-1 (Yu & Crump, 1999).

There are many differences between the European standard and the Japanese standards. The main reason why the results from each method differ is because of the testing conditions. The test conditions like temperature, relative humidity and air exchange rate varies (Que & Furuno, 2007). Besides that, type of resin, type of wood panels, thickness plays a role (Salem, Bohm, et al, 2011).

Another factor why the results differ is due to sample treatment (Risholm-Sundman, et al., 2007). Such examples are as follow:

- Edge and back sealed off, and
    - Some European flask method and Japanese desiccator method had its sample sealed at some placed to meet certain criteria.

- Conditioning prior to measurement.
    - Some samples are taken for results testing after probation period and some have to being conditioned to certain humidity level and temperature.

	Method	Test sample		Conditioning	Test conditions	
		Size loading factor	Edge sealing (m open edge m^{-2})	Temp/RH	Temp/RH	Air exchange/ hour
Europe	EN 717-1 0.225, 1 or $>12\,m^3$ chamber	$1\,m^2\,m^{-3}$	Partly ($1.5\,m\,m^{-2}$)	23 °C/45%[a]	23 °C/45%	1
	EN 717-2 gas analysis 41 chamber	$0.4 \times 0.05\,m$	Yes	Not stated	60 °C/⩽ 3%	15
	EN 717-3 500 mL flask	$0.025 \times 0.025\,m$, 20 g	No ($80\,m\,m^{-2}$)	Not stated	40 °C/~100%	No
	EN 120 perforator	$0.025 \times 0.025\,m$, 110 g	No	Not stated	Toluene extraction at 110 °C	No
Japan	JIS A 1901 201 – $1\,m^3$ chamber	$2.2\,m^2\,m^{-3}$	Yes	28 °C/50%	28 °C/50%	0.5
	JIS A 1460 9–111 desiccator	$0.18\,m^2$	No ($27\,m\,m^{-2}$)	20 °C/65%	20 °C/0–80%[b]	No
	JAS 233 9–111 desiccator	$0.18\,m^2$	No ($27\,m\,m^{-2}$)	No[c]		No
Global	ISO/CD 12460 $1\,m^3$ chamber	$1\,m^2\,m^{-3}$	Partly ($1.5\,m\,m^{-2}$)	23 °C/50%[a]	23 °C/50%	1

[a]Conditioning in the chamber, the values reported are steady-state values.
[b]See Fig. 4.
[c]Stored at 20 °C for 1 day wrapped in plastic before testing.

Figure 2.3.3.1-1: Table of Comparison between standard methods for the determination of formaldehyde emission (Yu & Crump, 1999).

The five methods which are the standard method are as follow:

- Chamber methods,
- Gas analysis,
- Flask method,
- Perforator method, and
- Desiccator method.

2.3.3.1.1 Chamber method

In chamber method, the standard that guards its place is EN 717-1 and JIS A 1901. Under the European standard, the sample is placed in a chamber the size of 1 m^3 or 0.255 m^3 in volume. The temperature of the chamber is kept constant at 300.15 K and its relative humidity (RH) is at 45%. The air exchange rate is per an hour, 1 h^{-1} and loading factor is 1 m^2m^{-3}. The mechanism that follows is the formaldehyde released from the test samples mixes with the air in the chamber, and a specific volume of mixed air is drawn from the chamber twice a day. This formaldehyde is absorbed in impringer flask containing water and the concentration is determined photometrically (EN 717-1, European Standard, 2004).

In Japanese standards, a chamber of 20L is preferred. The loading factor is 2.2 m^2m^{-3} and the air exchange rate is 0.5 h^{-1}. The RH is at 50% with the temperature is at 28 ^oC. The results from this standard are measured as specific emission rate (EF) in µg $m^{-2}h^{-1}$. When the loading factor and air exchange rate is 1 in European chamber, the concentration result in mg m^{-3} is equal to EF results in mg $m^{-2}h^{-1}$ (same as Japanese standard).

2.3.3.1.2 Gas analysis

Gas analysis however is only specific to European standard, EN 717-2. In this method, determination of accelerated formaldehyde release from wood-panels is the focus. Similarly to the chamber method (EN 717-1), the sample is place in a controlled temperature, RH, airflow and pressure. Air is then drawn into a container and absorbed in water and immediately, the concentration of formaldehyde is determined photometrically (EN 717-1, 1994).

Usually, the temperature stated 60 ^oC and RH of ≤ 3% with air exchange rate of 15 h^{-1}.

2.3.3.1.3 Flask method

Likewise the gas analysis, flask method is also guided under European standards. Flask method, or in other terms, EN 717-3 have the same purpose as chamber method, to determine the formaldehyde emission from wood panel. However, the method carried out to execute this test is by placing a sample piece over water in an enclosed chamber or container for a period of time at constant pressure and temperature. After that period of time, the concentration of formaldehyde in water is determined photometrically. In particular, the small piece of sample wood is placed in a large, air-tight container situated under immense temperature of 40 ^{o}C and high HR (EN 717-3, 1996).

2.3.3.1.4 Perforator method

EN 120 is the standard for perforator method. In this standard, the emission of formaldehyde in wood composite is determined using a perforator. First, the formaldehyde from the sample is extracted with boiling toluene and then transferred into water. The formaldehyde solution in the aqueous is determined photometrically and expressed in weight per 100g of dry board. The results are then correlated to standards due to its dependence to type of board as shown Figure 2.3.3.1-2. This method is still widely used but often questioned due to environment point of view (Risholm-Sundman, et al, 2007).

Formaldehyde emission measured according to different standard methods

Material		Thickness	Chamber	Gas analysis	Flask	Perforator	Chamber	Desiccator	
		(mm)	EN 717-1 ($mg\,m^{-3}$)	EN 717-2 ($mg\,m^{-2}\,h^{-1}$)	EN 717-3 ($mg\,kg^{-1}$)	EN 120 (mg per 100 g)	JIS A 1901 ($\mu g\,m^{-2}\,h^{-1}$)	JIS A 1460 ($mg\,l^{-1}$)	JAS 233 ($mg\,l^{-1}$)
Solid wood	Oak MC = 8%	20	0.005[a]	0.05[a]	0.06[a]	0.19[a]		<0.1 (0.00)[c]	<0.1 (0.03)[c]
	Pine MC = 8%	20	0.006[a]	0.3[b] 0.09[a]	0.16[a]	0.23[a]		<0.1 (0.05)[c]	0.18
Particle board	E0 MC = 6.8%	12	0.03	0.8	2	2–3		0.2	
	E1 MC = 6.0%	12	0.07	2	4	4.6		0.5	
Plywood	Interior MC = 8.6%	9.5	0.20	5.5	32				4.7
	Exterior MC = 6.2%	15	0.01	0.2	1.4				0.3
MDF	MC = 5.9%	12	0.10	4.4	3.5	7.5	74 (43 at 23 °C)	0.6	

[a]Value from Meyer and Boehme (1997).
[b]No conditioning.
[c]Analysed value, below the determination limit of 0.1 $mg\,l^{-1}$.

Figure 2.3.3.1-2: Formaldehyde emission measure according to different standard method to respect its type of board (EN 717-3, 1996 & Meyer & Boehme, 1997)

2.3.3.1.5 Desiccator method

This method is utilised as Japanese standard known as JIS A 1460 and JAS MAFF 233. The two methods have a similar purpose which is determination of formaldehyde emission. The methodology to perform this test is by placing a sample into a desiccator. In the desiccator, a valid amount of water in a vessel is placed. The condition is set at 20 ^{o}C during a 24-hours period. After the 24-hours period, the water in the vessel, in the desiccator is checked for formaldehyde photometrically. Since the water is in an enclosed space, the RH is relatively high (JAS 233, 2003 & JIS A 1460, 2001).

2.4 Scavengers

Out of the many methods to reduce the formaldehyde emission from wood composite, application of addition of additives called scavengers. Scavengers in this context are a compound or substance that will reduce, remove or extract certain chemical either by reacting with it or by having the chemical or compound adsorbed to it. This procedure is feasible in limiting the liberation of free formaldehyde from wood composite products (Boran, et al., 2011).

Some common known formaldehyde scavengers are primary or secondary amine compound. For example, urea, ammonia, melamine, dicyandiamide, etc. (Dupre, et al., 2002). For non-amine compound, other formaldehyde scavengers like tannin, resorcinol, peroxides, and ammonia treatment also exist (Coppock, 1996). Unfortunately, these scavengers are rather expensive and at the same time, not that effective (Roffael, et al., 2000). Again, though utilizing scavengers in the production of wood composite seems to be beneficial, unfortunately, it has to be used carefully or it will adversely affect the properties of the end-wood-product (Ebewele, et al., 1991).

Commonly, in the industry, natural or bio-based scavengers are utilised to reduce free formaldehyde emission (Costa, et al., 2013). Other compound with good affinity to capture formaldehyde is also applied.

In a study by Costa et al., the work examines the performace of several scavengers in wood composite. The scavengers under their study was sodium metabislufite, ammonium bisulfite and urea. It is found that sodium metabisulfite seems to be the best scavenger, while urea, the worst. With different test methods taken into consideration, still sodium metabilsulfite seems to excel. Prior to that conclusion, it was hypothesised that the performance of the scavengers is deeply affected by analysis method (Costa, et al., 2013).

Hence, the scavengers applied in this research is sodium metabisulfite and ammonium bisulfite and not urea due to it poor performance led by previous research.

2.4.1 Sodium metabisulfite

Costa, et al. did a research on particleboards made from urea formaldehyde and melamine formaldehyde resins using sodium metabisulfite (Na2S2O5) as a scavenger. The results were as expected and successful. Water reacts with sodium metabisulfite to form sodium bisulfite. The reaction between formaldehyde and sodium bisulfite forms a bisulfite adduct (complex) (Barberá, et al., 2000).

$$Na_2S_2O_5 + H_2O \rightarrow 2NaHSO_3$$

$$NaHSO_3 + HCHO \rightarrow NaSO_3CH_2OH \text{ (adduct)}$$

To quantidy formaldehyde, sodium sulfite is measured. To gain sodium sulfite, sodium bisulfite is neatralised with sodium hydroxide, as shown in the equation below:

$$NaHSO_3 + NaOH \rightarrow H_2O + Na_2SO_3$$

Sodium sulfite is used to quantify formaldehyde by titrating sodium sulfite wuth sodium hydroxide formed as by product.

$$HCHO + Na_2SO_3 \rightarrow NaOH + NaSO_3CH_2OH$$

2.4.2 Ammonium bisulfite

For ammonium bisulfite however, Under aqueous condition, ammonium and sulfite ions are at equilibrium.

$$NH_4HSO_3 \leftrightarrow NH_4^+ + HSO_3^-$$

Adduct is formed when the sodium ion present in urea formaldehyde reacts with sulfite ions, as shown in the chemical equation below;

$$Na^+ + HSO_3^- + HCNO \rightarrow NaSO_3CH_2OH \text{ (adduct)}$$

To calculate the amount of adduct formed, ammonia in aqueous reacts with formaldehyde to form hexamine.

$$NH_3 + H_2O \leftrightarrow NH_4^+ + HO^-$$

$$4NH_3 + 6HCHO \rightarrow (CH_2)_6N_4$$

Table 2.3.3.1-1: Table of comparison between sodium metabisulfite and ammonium bisulfite (Compound Summary for CID 656671, 2014 & Ammonium bisulfite, 2010)

Scavengers	*Sodium metabisulfite*	*Ammonium bisulfite*
Molar mass (g/mol)	190.107	115.11
Density (g/cm^3)	1.48	1.78
Melting point (^{o}C)	170	147

2.5 Summary

To summarise this chapter, the crucial component that makes this research interesting is wood composite, urea formaldehyde and scavengers. At a glance, these three words are rather difficult to interpret simultaneously. The driven importance of wood composite in the industry plays a valid role in sustaining one’s economy. For countries rich with source of lumber, provide a huge market and enhance mutual economic benefit, advancement in research of wood–based products and services and also sustain environment importance.

Secondly, urea formaldehyde is an important binding agent in the wood composite industry. Though it provides many benefits to this industry, it also imposes health risks. Hence, preventive steps have to be taken to overcome drawbacks from utilizing.

Lastly, scavengers provide a promising future for reducing the facilitation of free formaldehyde emission. Developing scavengers helps in its performance as a scavenger and successfully reducing this dangerous emission. With the proposed research, effectivity of scavengers are to be improved in order to reduce this emission and also provide a better market to suffering wood-composite industries.

3 MATERIALS AND METHODS

3.1 Overview

This paper presents a different point-of-view also into three different sections like the previous chapter. The first part will be the development of coating or polymer for urea formaldehyde or more specifically, free formaldehyde scavengers, and studying on the mechanical properties of the board prepared. With three parts successfully completed one way or another, the effectivity of the scavenger will be analyzed hypothetically. Due to lack of information regarding this research, some of the methods discussed are needs referral in the future. The first part, a type of coating is developed using certain types of wax or polymer. Several chemicals are proposed to be utilized in this stage of research. Once complete, research will move to part two. Part two is whereby; wood composite is prepared or manufactured using all the scavengers as well. Lastly, mechanical properties will be studied, and the emission of free formaldehyde is analyzed with different methods to meet the most suitable standard.

3.2 Introduction

This paper presents a noval method of preparation of coating for free formaldehyde scavengers in wood composite, and more specifically in medium density fibreboard (MDF).

3.3 Chemicals

The chemicals proposed to be used are urea formaldehyde, sodium metabisulfite, ammonium bisulfite, paraffin, thermostat waxes, and some polymer will be used. Most of these chemicals are readily available in the Faculty of Chemical and Natural Resources Engineering lab. The main chemicals to be used to proceed with this research are sodium metabisulfite and ammonium bisulfite. These chemicals are not available in the lab due to poor demand. Hence, these chemicals are purchased from a local vendor; Permula Chemicals Sdn. Bhd. Polymers suggested to be used in this research is polyurethane and polypropylene. These two chemicals are readily available from the lab which is the leftovers from previous research done by a post-graduate recently prior to beginning this research. Besides that, the thermostat wax proposed to be utilised in this research is Astorstat 95. Before beginning with the experiment proper training to handle the chemicals are learned, proper material safety data sheets (MSDS) are revised, and occupational safety and health briefing was participated thoroughly.

3.4 Sample handling

The sample in this experiment or research is wood fibres; these fibres are also readily available in the lab. The wood fibres found to be very delicate, very minute, particle like, almost like powder. Thus, a face-mask is needed to protect the individual performing the experiment. Moreover, gloves are also needed to be worn at all times while near the wood fibres and using it. The density of the wood fibres is also found to be very light, which in turn will require a large amount to produce fibreboard with a substantial thickness. These wood fibres is utilised in the fabrication of medium density fibreboard, after the preparation of scavengers. To the glue blender it will go to evenly distribute the binding agent and scavengers throughout the wood fibres. One problem that will arise is when transferring the wood composite from the source, in a basin, to the glue blender. Due to the wood fibres being very light and almost particle like as shown in Figure 2.3.3.1-1 and Figure 2.3.3.1-2, it can easily mess the place around the location of experiment execution. In short, proper care has to be taken to maintain the hygiene of the location and not contaminate any other chemical around it.

Figure 2.3.3.1-1: Image of wood fibres or particles that is utilised as part of the research (personal)

Figure 2.3.3.1-2: Image of wood fibres or particles that is utilised as part of the research (personal)

3.5 Methodology of the experiment

3.5.1 Preparation of scavengers

This step is a prerequisite step prior to moving to producing MDF. In this step, the coating for the scavengers is developed. Initially, the wax proposed is melted using water bath for safety purposes. Once the wax is melted, solid scavengers are added to it which makes it a heterogeneous mixture of solid scavengers and liquid wax. The temperature of wax is made sure to not go beyond 120 ^{o}C which is the curing temperature for the MDF fabrication. Besides that, the temperature is maintained below that temperature stated so that the free formaldehyde scavengers do not melt as well. Once when sufficient scavengers are added to the melted wax, the scavengers are separated from the wax using a metal sieve. This will result the scavenger to be coated with a layer of wax. These wax-coated scavengers are left to cool and hardened before proceeding to the next step. After the whole experiment complete, another batch of scavenger are prepared, but with different coating material and another for the second scavenger. With that, the experiment proceeds like normal.

3.5.2 Fabrication of medium density fibreboard (MDF)

First, 200g of wood fibres are weighed and place into the rotatory drum or glue-blender. Next, these wood fibres are sprayed with a substantial amount of urea formaldehyde, which is 7 wt% of the mass of wood fibres (Boran, et al., 2011). The glue-blender is switch on and the wood fibres are left to mix around with the urea formaldehyde for even distribution throughout the wood fibres. After a period of time, the mixture of wood composite and urea formaldehyde is taken out and placed in a basin. Slowly while transferring the mixture, the prepared scavengers are spread randomly and evenly across the mixture. This will lead to a mixture of wood fibres, urea formaldehyde and scavengers. The new mixture is then again transferred to a square mould, dimensioned at 25 cm × 25 cm, placed above a peel-looking, thick and flat metal sheet which also looks like a pizza shovel. Next, once the mixture is in the mould, the mould is then removed. Then, another similar metal sheet is placed above mixture of wood fibres, urea formaldehyde and scavengers. The two flat metals and the mixture in between are moved carefully to the hot and cold press machine. The mixture is then pressed at 120 ^{o}C to 180 ^{o}C for 4 minutes. Once that is done, the board is removed and left to cool. The board is then weighed to find its density. The experiment is repeated again for a different type of coating and the second scavengers.

Figure 2.3.3.1-1: Picture of the glue blender or the rotatory drum that is used in the preparation of wood fibres for MDF (personal)

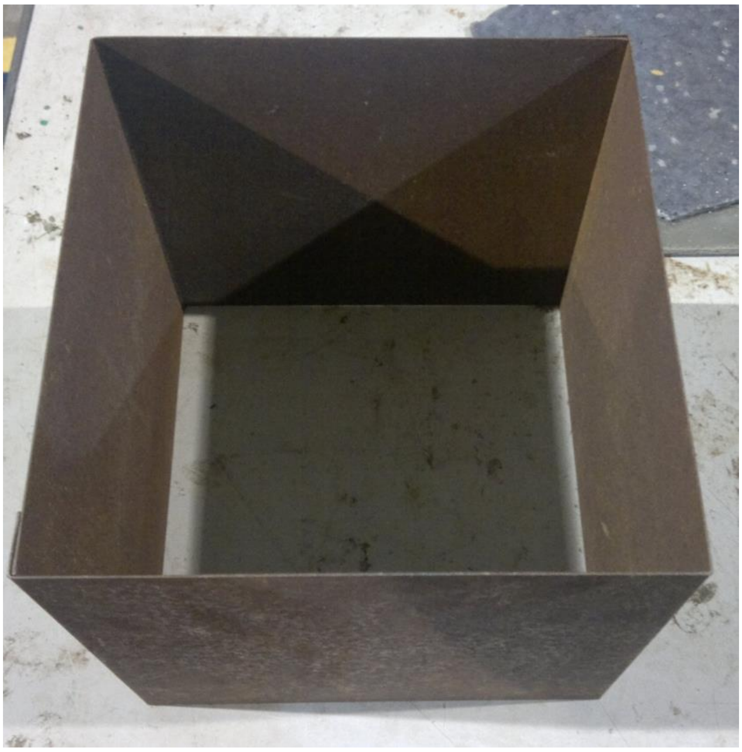

Figure 2.3.3.1-2: Mould that will be utilized in the fabrication of MDF (personal)

Figure 2.3.3.1-3: The hot and cold press machine which is responsible for the fabrication of MDF (personal)

3.5.3 *Characterization of MDFs*

Once the MDFs are ready, it is then characterized to two different parts. The first part is the determination of its mechanical properties and the second part is the free formaldehyde emission.

3.5.3.1 Determination of mechanical properties

The characterization will be done by using the universal testing machine (UTM). The scope of interest in terms of mechanical properties of the medium density fibreboards are internal bonding, modulus of rupture, and modulus of elasticity. The analysis of the results can be done in based on two different standards, European and American. One, the test is done in accordance to ASTM D 1037 (ASTM, 2005). The results are then compared to standard data in ANSI A208.2 Standard (ANSI, 2002). Two, the test is done in accordance to EN 310 and EN 319 (EN 310, 1993 & EN 319, 1993).

3.5.3.2 Determination of free formaldehyde emission

The method proposed to determine the free formaldehyde emission in wood composite is using the desiccator method to evaluate the formaldehyde emission. This method complies with the Japanese Industrial Standard JIS A1460 and Japanese Agricultural Standard, JAS MAFF 233.

The methodology to perform desiccator method is by cutting pieces of the medium density fibreboard into 50 × 150 mm dimension. Before placing them into the desiccator, a number of pieces is selected so that collectively the total surface area of the board is 1800 cm^2. Hence, a total of approximately 10 pieces of the board with the preferred dimension is selected. It is then kept into a desiccator. In the desiccator, 300 ml of water is poured into a vessel is placed. The condition is set at 20 ^oC during a 24-hours period. After the 24-hours period, the water in the vessel, in the desiccator is checked for formaldehyde photometrically. Since the water is in an enclosed space, the RH is relatively high (JAS 233, 2003 & JIS A 1460, 2001).

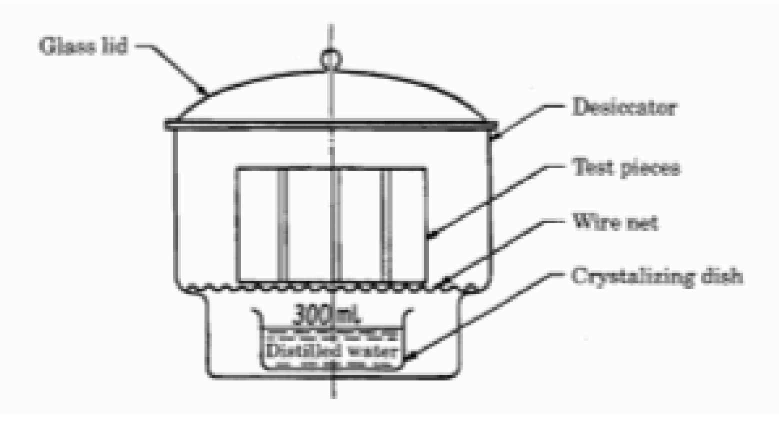

Figure 3.5.3.2-1: Schematic Diagram of Desiccator Method (Yukichi, 2001)

3.6 Summary

In short, the experimental procedures of this research can be fragmented to different parts and each is responsible to achieving a common goal. Those parts are development of coating for preparation of scavengers, fabrication of medium density fibreboard (MDF), evaluation of mechanical properties, and determination of free formaldehyde emission. In the first part, scavengers are coated with a type of wax or polymer to enable them to be melted once during curing occurs in the MDF production which will reduce the liberation of free formaldehyde. In the second part, fabrication of MDF is a standard procedure in everywhere, elsewhere, which is just some little minor changes in the procedures where scavengers are introduced in mid preparation.

Here onwards, parts three and four plays a crucial role in the future and path of MDFs in this research. In the third part, with the addition of scavengers it is required to see whether it has affected the credibility and quality of the board. The effectivity of scavengers are discussed and analysed in the last part.

4 RESULTS AND DISCUSSION

4.1 Preliminary Results

The results discussed later are results from different researches. These different researches provide a fundamental understanding to what the outcome of this research will yield. Moreover, these results are the backbone to how the results for this experiment will show.

4.1.1 Overview

.This chapter shows the statistical data obtained from experimental studies. The preliminary results are gained based on prediction due to inability to proceed with experiment as the required chemicals are not available for the time being. Detailed discussion is provided to justify the variation between different standards and to enhance literature values.

4.1.2 Mechanical properties of MDF

The mechanical properties are defined as shown below. These results are correlated from previous researches and are expected to have almost similar values to this research.

Table 3.5.3.2-1: Literature values for properties of particleboard produced with different scavengers (Costa, et al., 2013)

Scavengers	*Sodium metabisulfite*	*Ammonium bisulfite*
Internal bond (N/mm^2)	0.57	0.33
Density (kg/m^3)	696	684
Thickness swelling (%)	33.5	36.3
Moisture content (%)	7.3	7.9
Formaldehyde content (mg/100g oven dry board)	1.8	1.6
Formaldehyde emission (mg/L)	0.13	0.37

The results shown are literature values in wood-based panels. This is just an approximation due to the presence of scavengers and not the coating. The coating is assumed to add resistive properties towards water in wood-panels. This is because paraffin, when added to wood-composite, it exudes resistive properties towards water which in turn reduce the swelling thickness. Wax also have similar properties like paraffin, hence the assumption where it can reduce thickness swelling in water is rather valid.

Moreover, the literature results for usage of ammonium bisulfite are assumed to be similar to aqueous solution of 5 %wt. based on solid resin. The reason being, the referred journal conducted the experiment in ammonium bisulfite solution. The solution is at purity of 70 wt% with a basic pH of 5.0. These results are taken rather than other since it holds the most values in terms of effectivity. The effectivity of scavengers in affecting the mechanical property of internal bonding is shown in Figure 3.5.3.2-1.

Sodium metabisulfite is utilised in solid form due to its ability to cause respiratory irritation if release into air, which only if it is applied in aqueous liquid or gaseous form (Barberá, Metzger, & Wolf, 2000). Moreover, the test results are affected by the migration of sodium metabisulfite towards to core of the mat or wood composite or dissolved in vapour phase due during hot press could lower the effectiveness of reducing the liberation of free formaldehyde (Carvalho, Martins, & Costa, 2010). In addition, high temperature can cause the sodium metabisulfite to decompose into sodium sulphite which could lead to degradation of wood components. Like the butterfly effect, one negative drawback could lead to another, and in this case, the mechanical property of the wood panel is severely affected or in scientific terms, the physicomechanical properties are reduced (Dreyfors, Jones, & Sayed, 1989). Thus, the hot press-machine is operated way below the melting point of the scavengers and above the melting point of urea formaldehyde.

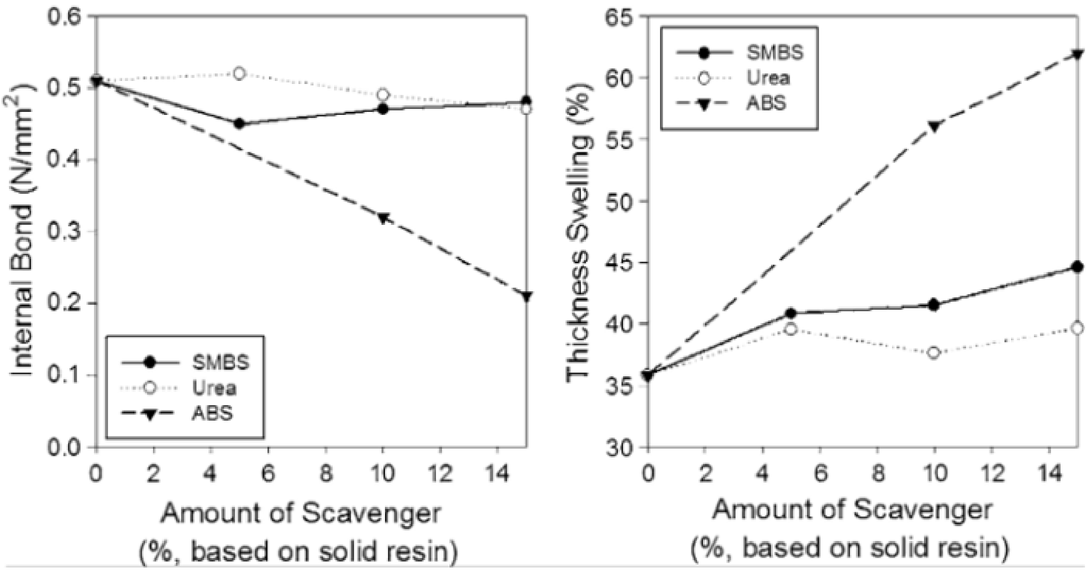

Figure 3.5.3.2-1: Comparison of internal bonding and thickness swelling with different amount of formaldehyde scavengers, sodium metabisulfite (left) and ammonium bisulfite (right) (Costa, et al., 2013).

Due to insufficient literature review of modulus of elasticity and modulus of rupture, another literature source is taken into consideration. In a study by Boran, et al, they discussed application of tannin as a free formaldehyde scavenger. Assuming the effectivity of scavengers of is nearly the same, or varied very little that could not affect the mechanical property of wood panel much; the results are correlated into this research for the advancement of the experiment.

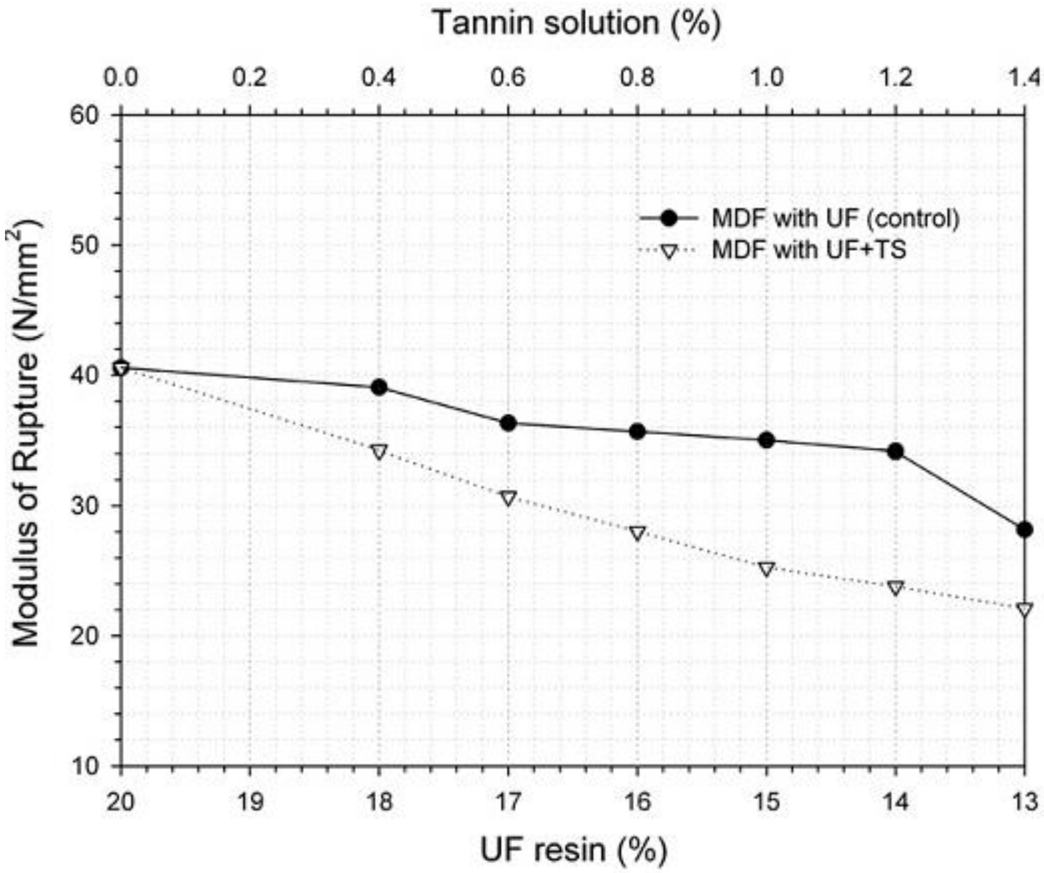

Figure 3.5.3.2-2: The modulus of rupture (MOF) values of MDF panels (Boran, et al., 2012)

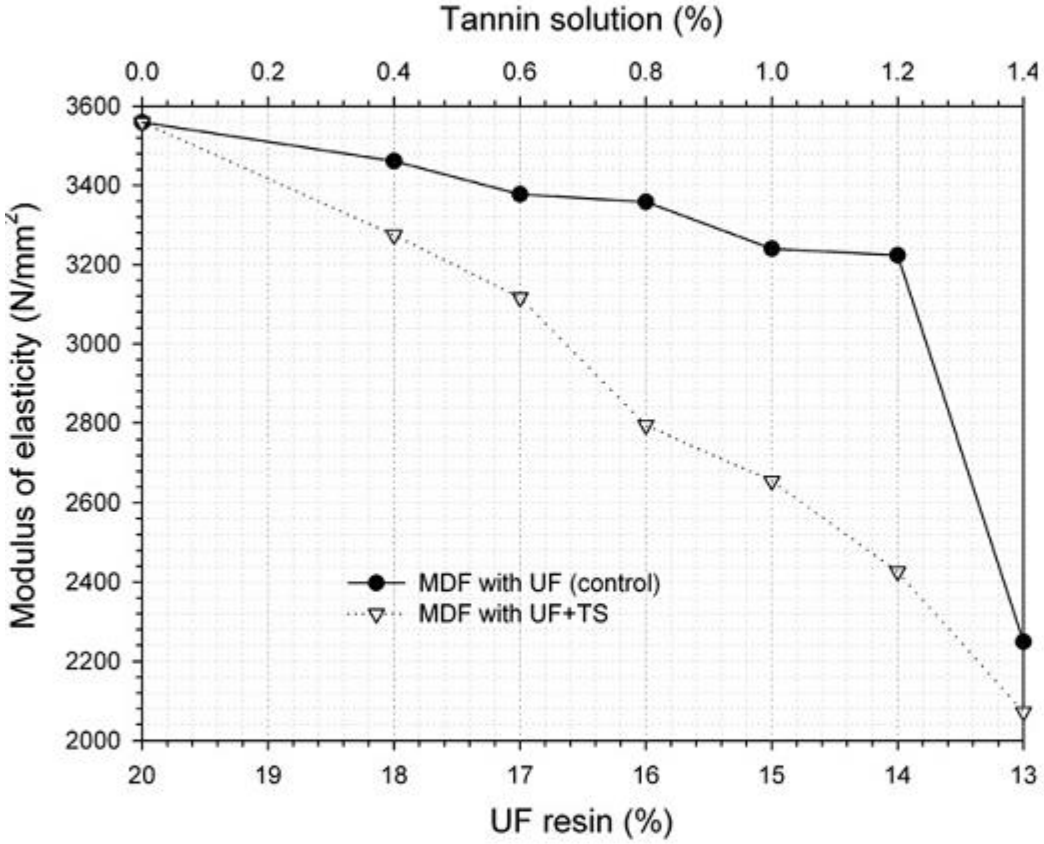

Figure 3.5.3.2-3: The modulus of elasticity (MOE) values of MDF panels (Boran, et al., 2012).

The results shown in Figure 3.5.3.2-2 and Figure 3.5.3.2-3 are just approximation to the results will be later evaluated. These results are just a guideline to enable the process of this research to proceed smoothly. The reason why tannin is assumed to have similar properties as sodium metabisulfite and ammonium bisulfite is because it does not contain any primary or secondary amine group (Coppock, 1996).

4.1.3 Evaluation of free formaldehyde emission

The results to be predicted throughout and during this research based on different test methods are shown in Figure 3.5.3.2-1 and Figure 3.5.3.2-2. The difference between the two methods is studied by Costa, et al, and found concrete reason similar to other researcher which affects the effectivity of scavengers. Likewise, the depletion of scavengers in the external layers reduced the effectiveness of formaldehyde capture in desiccator method which contradicts to measurement of formaldehyde content not being affected by scavenger distribution in perforator method (Costa, et al., 2013).

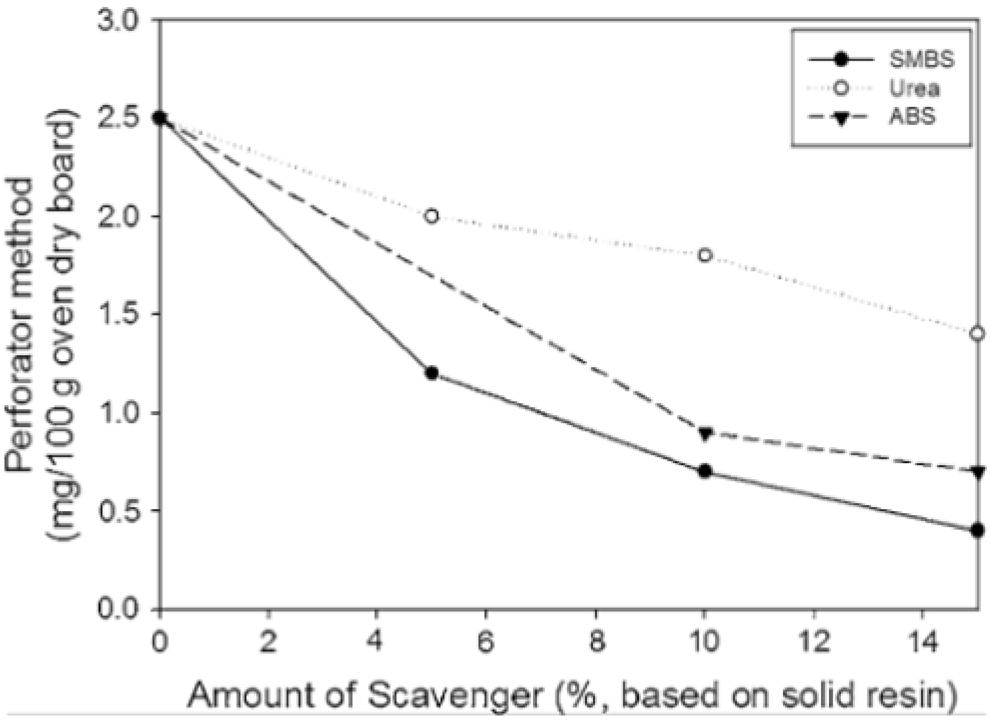

Figure 3.5.3.2-1: Formaldehyde content by EN 120, perforator method of MDF with respect to different formaldehyde scavengers (Costa, et al., 2013).

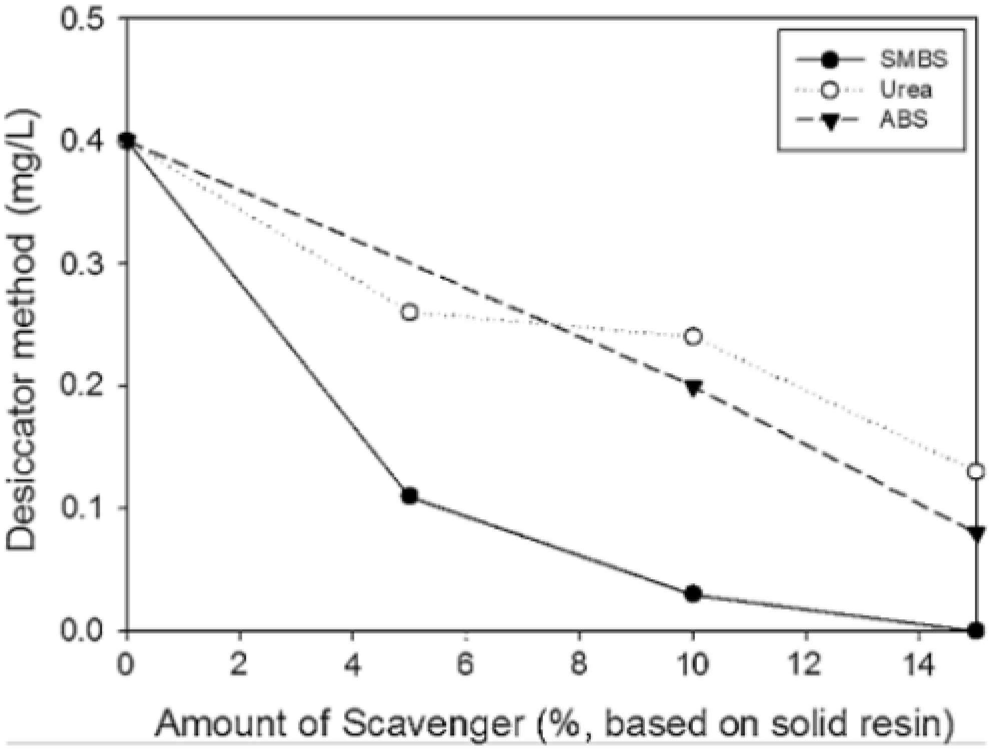

Figure 3.5.3.2-2: Formaldehyde content by JIS A 1460, desiccator method of MDF with respect to different formaldehyde scavengers (Costa, et al., 2013).

4.1.4 Summary

To summarise, these results stated here are just for referral purpose. Once when the chemicals are ready, the experiment will be conducted to determine the parameters of interest.

4.2 Actual Results

4.2.1 Mechanical Properties

4.2.1.1 Modulus of Rupture (MOR)

Modulus of rupture (MOR) is identified as the force necessary to break a specimen of specific width and thickness (Abood, et al., 2012). From the findings of this experiment, when no scavenger is used, the MOR seems to be higher than that of when scavengers are used. Compared to the two scavengers used in the production of the fibreboard, ammonium bisulfite has a significant effect on the board compared to sodium metabisulfite. The reason due to why the MOR is affected severely when scavengers are used is due to resin pre-cure in the blending process. Moreover, when liquid wax is used, once solidified, this enable improper bonding between urea formaldehyde and the wax itself. In directly, this will lead to brittleness since wax in generally is very brittle. The average MOR of each sample with respective conditions are shown below.

Samples	Average MOR (N/mm^2)
Urea Formaldehyde (UF)	26.0785272
UF + Sodium metabisulfite (SMBS)	24.55794675
UF + Ammonium bisulfite (ABS)	23.75746709

Table 4.2.1.1-1: Average Modulus of Rupture (MOR) for respective samples

The difference between ammonium bisulfite and sodium bisulfite is almost similar due to their similar properties since both a derived from the same functional group. But as compare to other researches done, their average MOR is better due to the availability of the liquid wax coating. This prevents pre-curing during the manufacturing of the medium density fibreboard. The calculation and results of modulus of rupture (MOR) can be seen in Appendix A.

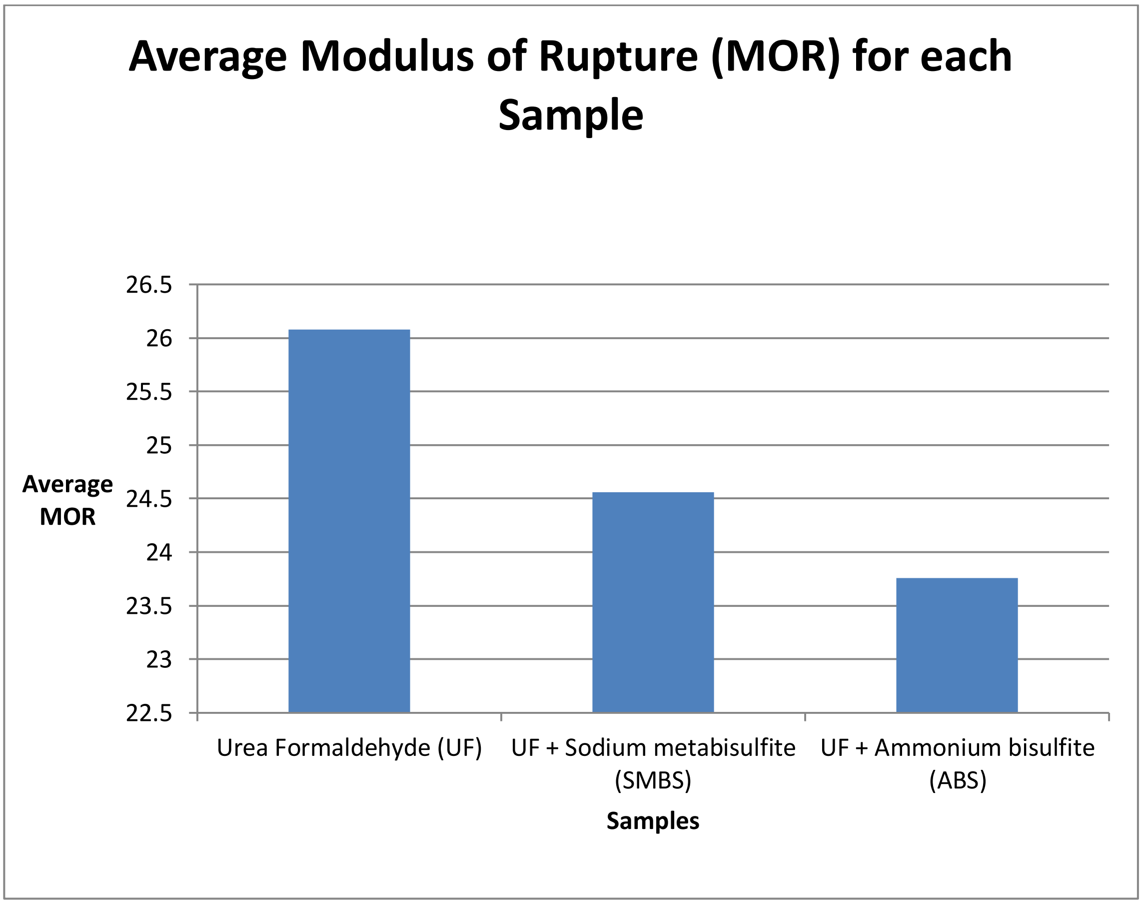

Figure 4.2.1.1-1: Graph of average Modulus of Rupture (MOR) for respective samples

4.2.1.2 Internal Bonding (IB)

The internal bonding is a rough indicator to predict or characterise the performance of the adhesive in wood composite (Abood, et al., 2012).Utilizing this test method, the tensile strenght properties of the sample boards or adhesive bonds in the board could be determined. The internal bonding of samples made from urea formaldehyde (UF) alone, samples made from UF and with sodium metabisulfate (SMBS) scavengers, and samples made from UF and with ammonium bisulfite (ABS) scavengers are shown in the table below.

Samples	Average IB (N/mm^2)
Urea Formaldehyde (UF)	0.874398491
UF + Sodium metabisulfite (SMBS)	0.617160109
UF + Ammonium bisulfite (ABS)	0.392616494

Table 4.2.1.2-1: Table of average Internal Bond (IB) of respective samples

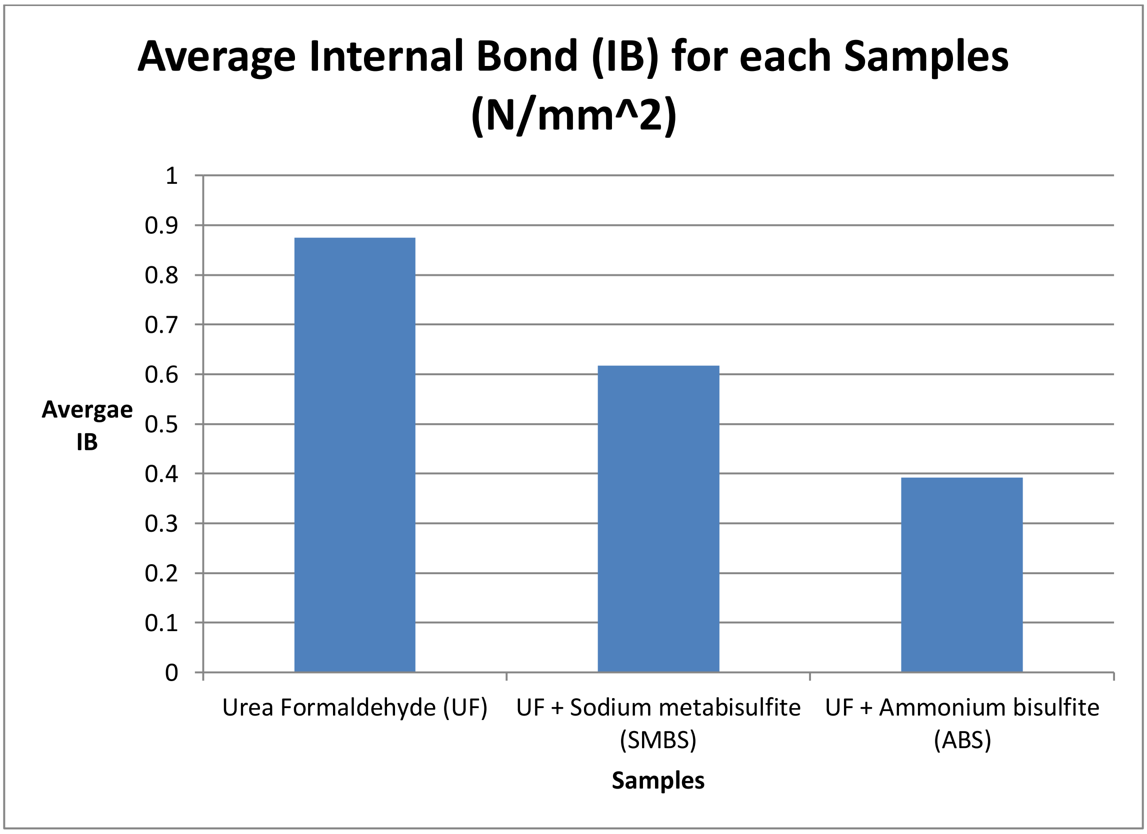

Figure 4.2.1.2-1: Graph of Average Internal Bond (IB) with respect of respective samples

The internal bond decreases between samples is due to the pre-cure of the resin or the premature consumption of formaldehyde due to dispersibility of the scavengers during the board preparation process. Compare to the preliminary results gained by other researches, the internal bonding when formaldehyde scavengers used in the board showed a significant increase when a coating is applied. This shows that the liquid wax applied on the scavengers has a positive effect on the board. The results and calculations of internal bonding can be seen in Appendix B.

4.2.1.3 Thickness Swelling (TS)

The measure of the dimensional stability of the fibreboard is called thickness swelling. In Layman's terms, the higher the thickness swelling results in the board which are more unstable. Board with lower thickness swelling is much better for general consumption. A study conducted by Kojima and Suzuki found that the thickness swelling of a board varies due to the wide array of factors such as wood species, element geometry, board density, resin level, blending efficiency, and pressing condition, to name a few. Through this research, it is found that the thickness swelling significantly increase from not using scavengers at all to using two different types of scavengers. Ammonium bisulfite as a scavenger shows higher thickness swelling than that of sodium metabisulfite. This is because; the resin has undergone pre-curing or premature consumption of formaldehyde due to scavenger dispersion during the preparation of the board. The thickness swelling of respective samples, samples with urea formaldehyde (UF) only, samples with UF and sodium metabisulfite (SMBS) as scavengers, and sample with UF and ammonium bisulfite (ABS) as scavengers, are shown below.

Samples	Average TS (%)
Urea Formaldehyde (UF) only	20.81
UF + Sodium Metabisulfite (SMBS)	29.47
UF + Ammonium Bisulfite (ABS)	32.26

Table 4.2.1.3-1: Average thickness swelling (TS) of respective samples.

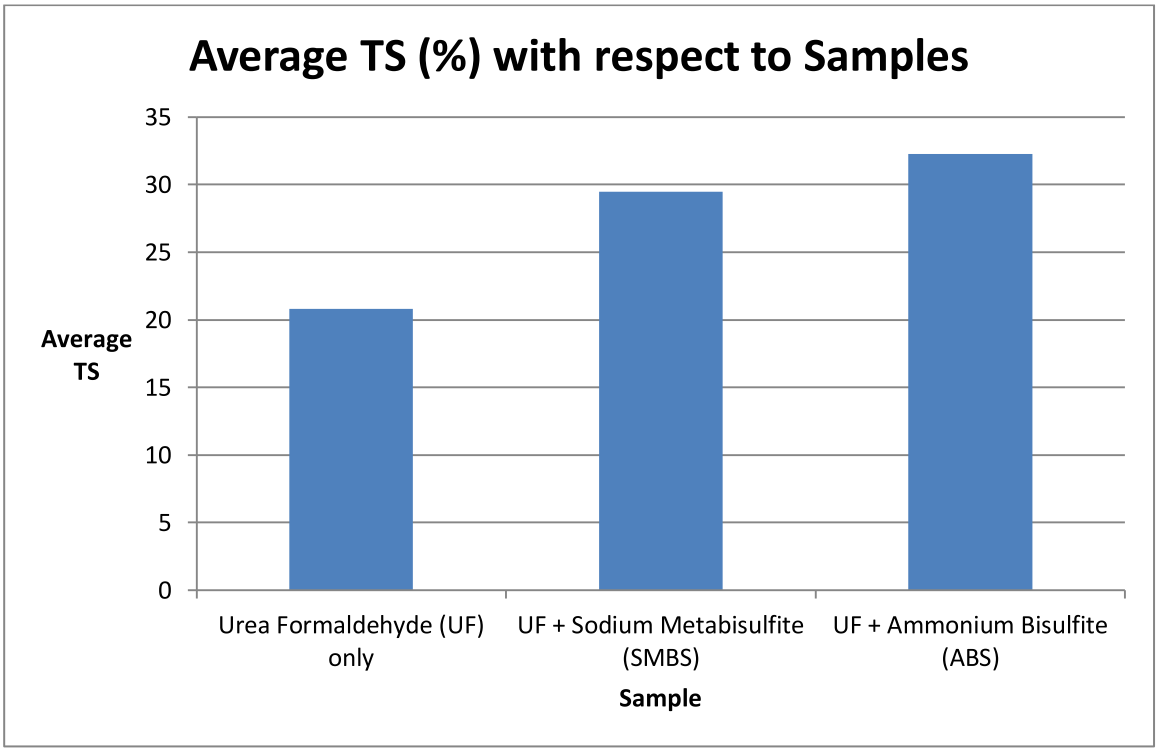

Figure 4.2.1.3-1: Graph of Thickness Swelling (TS) of each respective sample

The results and calculation for the thickness swelling of the samples can be seen in Appendix C.

4.2.2 Formaldehyde Emission

The formaldehyde emission is calculated using Japanese Internal Standard, JIS A 1460, determination of formaldehyde emission using desiccator method. In a nutshell, this method determines the concentration of formaldehyde absorbed in distilled water.

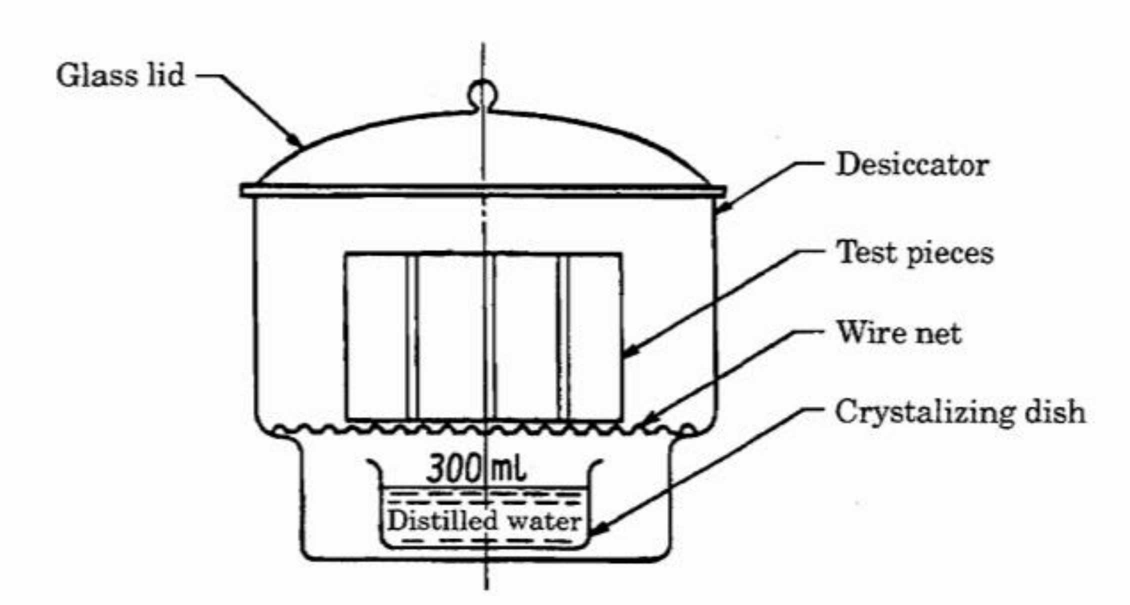

Figure 4.2.1.3-1: A schematic diagram of the desiccator method

A sufficient amount of sample is put inside a desiccator with an amount of liquid distilled water over the period of a day, where after the incubation period; the concentration of formaldehyde is detected in the distilled water using a UV/VIS spectrometer. The formaldehyde concentration in the distilled water for medium density fibreboards manufactured from using urea formaldehyde (UF) only, and with scavengers, sodium metabisulfite (SMBS) and ammonium bisulfite (ABS) respectively are shown below.

Water Samples	Absorbance				Concentration		
	Trial 1	Trial 2	Trial 3	Average	g/L	PPM	Per board
UF	0.0150	0.0140	0.0180	0.0157	0.2178	217.8099	0.0073
UF + SMBS	0.0100	0.0090	0.0120	0.0103	0.1215	121.5403	0.0042
UF + ABS	0.0130	0.0140	0.0120	0.0130	0.1697	169.6751	0.0057

Table 4.2.1.3-1: Concentration of Formaldehyde in distilled water from samples of urea formaldehyde (UF) and sample with scavengers, sodium metabisulfite (SMBS) and ammonium bisulfite (ABS)

From Table 4.2.1.3-1, the overall concentration of the boards for each samples, samples prepared only from urea formaldehyde (UF), samples prepared from UF while utilising sodium metabisulfite (SMBS) scavengers, and also samples prepared from UF while using ammonium bisulfite (ABS) scavengers show significant results. These results differ from one another which prove a significant advantage to the science field. More significantly, the average formaldehyde emitted per board is shown below, as referred to the table above.

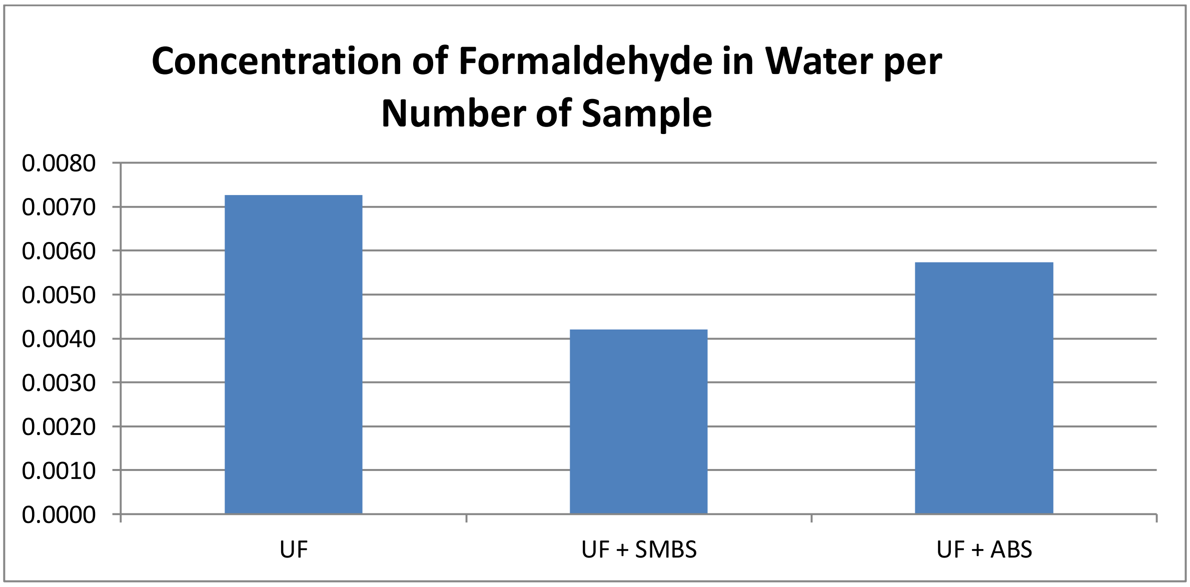

Figure 4.2.1.3-2: Graph of average concentration of formaldehyde emitted by each samples with respective conditions

The graph in Figure 4.2.1.3-2: Graph of average concentration of formaldehyde emitted by each samples with respective conditions showed that sodium metabisulfite works as an excellent formaldehyde scavenger than ammonium bisulfite. Moreover, compared to the preliminary results from previous researches, the scavenger coated with liquid wax proves to be more efficient than that of the just utilizing scavengers alone. This is due to the reason because the scavengers do not react during the manufacturing process unlike when a coat is applied which it reacts with formaldehyde after the curing process.

The results and calculation for the formaldehyde emission can be seen in Appendix D.

5 CONCLUSION & RECOMMENDATION

5.1 Conclusion

As a conclusion, results from this research study indicate that the objectives of this experiment have been achieved. Throughout this research, I have somehow developed a coating method which is not relatively new. Using liquid wax which has long serve in this wood composite industry, the scavengers are just coated with it. Moreover, the best scavenger for the capture of free formaldehyde emitted from wood composite is sodium metabisulfite. Sodium metabisulfite has shown positive results as a scavenger compared to ammonium bisulfite. Also, the mechanical properties of the samples were tested and calculated. The results are further supported by previous researches done which are almost similar but methods conducted are totally different. Last but not least, the emission rate of free formaldehyde of medium density fibreboards is calculated using desiccator method. In short, in order to reduce free formaldehyde emitted to the air, the mechanical properties are in jeopardy. Hence, using sodium metabisulfite as scavenger in medium density fibreboards can yield in relatively strong boards with less emission of free formaldehyde. Hence, in short it is like having the best of both worlds.

5.2 Recommendation

This research can be improved further in order to provide an overall picture of the board produced. There are various ways it can be done in order to gain more efficient and accurate results. These are some suggestion to enhance this research:

I. By varying the temperature and curing time, a suitable board can be made. Since pre-cure is very common, hence a new temperature should be tracked to avoid this problem

II. Having other types of coating is also encouraged. Since the amount of scavengers used is very little, liquid coating is preferred. Maybe solid wax should be given a try.

III. Morphological study should have been done and FESEM analysis should be done for the board to see how well the scavengers are dispersed throughout the board.

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7 APPENDICES

APPENDIX A

Calculation of Modulus of Rupture (MOR)

A) Modulus of Rupture (MOR) for board made of Urea Formaldehyde alone

The modulus of Rupture (MOR) is calculated using the equation below:

$$MOR = \frac{3PL}{2ba^2}$$

Where P = Peak force, N

L = Length, mm

b = width, mm

a = thickness, mm

The average value was calculated using the equation below:

$$MOR_{avg} = \frac{Total\ MOR}{Number\ of\ Samples}$$

The dry density was calculated using the equation below:

$$\rho = \frac{\omega}{w \times l \times t}$$

Where ω = weight, kg

w = width, m

l = length, m

t = thickness, m

The results and the calculation of Modulus of Rupture for medium density fibreboard made of urea formaldehyde alone are shown below.

Sample	Weight (g)	Width (mm)	Length (mm)	Thickness (mm)	Peak Load (N)	MOR (N/mm^2)	Density (kg/m^3)
1	28.57	50.00	150.00	6.00	228.33	28.54	634.80
2	30.55	51.00	148.00	6.10	230.74	26.99	663.53
3	28.84	52.00	140.00	5.80	190.30	22.85	683.02
4	31.22	49.00	145.00	6.00	210.34	25.93	732.45
Average						26.08	678.45

For sample 1:

MOR Calculation:

$$MOR = \frac{3PL}{2ba^2} = \frac{3 \times 228.33 \times 150}{2 \times 50 \times 6^2} = 28.54\ N/mm^2$$

Average MOR Calculation:

$$MOR_{avg} = \frac{Total\ MOR}{Number\ of\ Samples} = 26.08\ N/mm^2$$

Dry Density Calculation:

$$\rho = \frac{\omega}{w \times l \times t} = \frac{28.57}{50.0 \times 150.0 \times 6.0} \times 1000000 = 634.80\ kg/m^3$$

These steps are repeated for the other samples. These calculations are made easier using Microsoft Excel.

B) Modulus of Rupture (MOR) for board made of Urea Formaldehyde and using sodium metabisulfite (SMBS) scavengers

The results and the calculation of Modulus of Rupture for medium density fibreboard made of urea formaldehyde with SMBS scavengers are shown below.

Sample	Weight (g)	Width (mm)	Length (mm)	Thickness (mm)	Peak Load (N)	MOR (N/mm^2)	Density (kg/m^3)
1	28.37	51.00	149.00	6.10	228.33	26.89	612.02
2	28.35	49.00	149.00	6.00	190.45	24.13	647.11
3	31.20	52.00	150.00	6.00	192.33	23.12	666.67
4	29.88	50.00	149.00	5.90	187.63	24.09	679.86
Average						24.56	651.41

For sample 1:

MOR Calculation:

$$MOR = \frac{3PL}{2ba^2} = \frac{3 \times 228.33 \times 150}{2 \times 51.0 \times 6.1^2} = 26.89\ N/mm^2$$

Average MOR Calculation:

$$MOR_{avg} = \frac{Total\ MOR}{Number\ of\ Samples} = 24.56\ N/mm^2$$

Dry Density Calculation:

$$\rho = \frac{\omega}{w \times l \times t} = \frac{28.37}{51.0 \times 149.0 \times 6.1} \times 1000000 = 612.02\ kg/m^3$$

These steps are repeated for the other samples. These calculations are made easier using Microsoft Excel.

C) Modulus of Rupture (MOR) for board made of Urea Formaldehyde and using ammonium bisulfite (ABS) scavengers

The results and the calculation of Modulus of Rupture for medium density fibreboard made of urea formaldehyde with ABS scavengers are shown below.

Sample	Weight (g)	Width (mm)	Length (mm)	Thickness (mm)	Peak Load (N)	MOR (N/mm^2)	Density (kg/m^3)
1	31.20	52.00	150.00	6.00	192.33	23.12	666.67
2	27.78	49.00	149.00	6.00	184.30	23.35	634.16
3	28.37	51.00	149.00	6.10	228.33	26.89	612.02
4	26.16	50.00	149.00	5.90	132.69	17.04	595.20
Average						23.76	633.09

For sample 1:

MOR Calculation:

$$MOR = \frac{3PL}{2ba^2} = \frac{3 \times 192.33 \times 150}{2 \times 52.0 \times 6.0^2} = 23.12\ N/mm^2$$

Average MOR Calculation:

$$MOR_{avg} = \frac{Total\ MOR}{Number\ of\ Samples} = 23.76\ N/mm^2$$

Dry Density Calculation:

$$\rho = \frac{\omega}{w \times l \times t} = \frac{31.20}{52.0 \times 150.0 \times 6.0} \times 1000000 = 633.09\ kg/m^3$$

These steps are repeated for the other samples. These calculations are made easier using Microsoft Excel.

APPENDIX B

CALCULATION OF INTERNAL BONDING (IB)

a) Calculation of Internal Bonding (IB) for board made of Urea Formaldehyde alone

The internal bonding is calculated using the equation below:

$$IB = \frac{P}{w \times l}$$

Where P = Peak force, N

w = Width, mm

l = Length, mm

The results and the calculation of Internal Bonding for medium density fibreboard made of urea formaldehyde alone are shown below.

Sample	Weight (g)	Width (mm)	Length (mm)	Thickness (mm)	Peak Load (N)	IB (N/mm^2)	Density (kg/m^3)
1	9.72	51.00	50.00	6.00	2209.65	0.87	635.46
2	10.11	51.00	51.00	6.10	2215.43	0.85	637.35
3	8.89	51.00	51.00	6.00	2200.73	0.85	569.47
4	8.13	49.00	49.00	6.20	2240.60	0.93	546.06
Average						0.87	597.09

For sample 1:

IB Calculation:

$$IB = \frac{P}{w \times l} = \frac{2209.65}{51.0 \times 50.0} = 0.87 \frac{N}{mm^2}$$

Dry Density Calculation:

$$\rho = \frac{\omega}{w \times l \times t} = \frac{9.72}{51.0 \times 50.0 \times 6.0} \times 1000000 = 635.46\ kg/m^3$$

These calculations are repeated for the other samples. These calculations are made easier using Microsoft Excel.

b) Calculation of Internal Bonding (IB) for board made of Urea Formaldehyde with Sodium metabisulfite (SMBS) as scavengers

The results and the calculation of Internal Bonding for medium density fibreboard made of urea formaldehyde with SMBS as scavengers are shown below.

Sample	Weight (g)	Width (mm)	Length (mm)	Thickness (mm)	Peak Load (N)	IB (N/mm^2)	Density (kg/m^3)
1	9.82	50.00	50.00	6.10	1498.36	0.60	643.72
2	10.22	50.00	49.00	6.00	1588.78	0.65	695.48
3	8.78	48.00	50.00	6.00	1431.22	0.60	609.65
4	9.32	49.00	49.00	6.20	1499.36	0.62	626.18
Average						0.62	643.76

For sample 1:

IB Calculation:

$$IB = \frac{P}{w \times l} = \frac{1498.36}{50.0 \times 50.0} = 0.60 \frac{N}{mm^2}$$

Dry Density Calculation:

$$\rho = \frac{\omega}{w \times l \times t} = \frac{9.82}{50.0 \times 50.0 \times 6.1} \times 1000000 = 643.72 \; kg/m^3$$

These calculations are repeated for the other samples. These calculations are made easier using Microsoft Excel.

c) Calculation of Internal Bonding (IB) for board made of Urea Formaldehyde with ammonium bisulfite (ABS) as scavengers

The results and the calculation of Internal Bonding for medium density fibreboard made of urea formaldehyde with ABS as scavengers are shown below.

Sample	Weight (g)	Width (mm)	Length (mm)	Thickness (mm)	Peak Load (N)	IB (N/mm^2)	Density (kg/m^3)
1	9.18	50.00	50.00	6.10	993.63	0.40	602.29
2	9.26	50.00	49.00	6.00	1001.79	0.41	629.93
3	8.72	48.00	50.00	6.00	823.34	0.34	605.56
4	9.78	49.00	49.00	6.20	1010.98	0.42	656.96
Average						0.39	623.69

For sample 1:

IB Calculation:

$$IB = \frac{P}{w \times l} = \frac{993.63}{50.0 \times 50.0} = 0.40 \frac{N}{mm^2}$$

Dry Density Calculation:

$$\rho = \frac{\omega}{w \times l \times t} = \frac{9.18}{50.0 \times 50.0 \times 6.1} \times 1000000 = 602.29\ kg/m^3$$

These calculations are repeated for the other samples. These calculations are made easier using Microsoft Excel.

APPENDIX C

CALCULATION OF THICKNESS SWELLING

The thickness swelling calculation is calculated using the equation below:

$$TS = \frac{T_f - T_i}{T_i} \times 100\%$$

The average thickness swelling is then calculated using the equation below:

$$TS_{avg} = \frac{Total\ TS\ \%}{Number\ of\ Samples}$$

1) Calculation of Thickness Swelling (TS) for board made of Urea Formaldehyde only

The results and the calculation of thickness swelling for medium density fibreboard made of urea formaldehyde only are shown below.

Sample	Weight (mm)	Width (mm)	Length (mm)	Initial Thickness (mm)					Final Thickness (mm)					Thickness Swelling (%)	Density (kg/m^3)
				1	2	3	4	Average	1	2	3	4	Average		
1	10.23	52.00	50.00	6.1	6.2	6.0	6.1	6.10	7.50	7.80	7.60	7.50	7.60	24.59	645.21
2	9.45	51.00	49.00	6.0	6.1	5.9	6.0	6.00	6.90	7.60	7.20	7.30	7.25	20.83	630.49
3	9.55	50.00	48.00	5.9	6.2	6.0	6.0	6.03	7.50	7.50	7.20	7.30	7.38	22.41	660.72
4	9.79	50.00	51.00	6.1	6.0	5.9	6.0	6.00	7.10	6.90	6.80	6.90	6.93	15.42	639.72
Average														20.81	644.03

2) Calculation of Thickness Swelling (TS) for board made of Urea Formaldehyde with sodium metabisulfite (SMBS) as scavengers

The results and the calculation of thickness swelling for medium density fibreboard made of urea formaldehyde with SMBS as scavengers are shown below.

Sample	Weight (mm)	Width (mm)	Length (mm)	Initial Thickness (mm)					Final Thickness (mm)					Thickness Swelling (%)	Density (kg/m^3)
				1	2	3	4	Average	1	2	3	4	Average		
1	9.23	50.00	49.00	6.00	6.00	6.00	6.10	6.03	8.60	8.10	8.30	8.70	8.43	28.49	624.99
2	9.37	51.00	49.00	6.00	6.10	5.90	6.00	6.00	8.20	8.60	8.10	8.50	8.35	28.14	624.63
3	9.55	50.00	48.00	6.10	6.20	6.00	6.00	6.08	8.60	8.70	8.10	8.50	8.48	28.32	655.28
4	10.37	50.00	50.00	5.90	6.10	6.30	6.00	6.08	8.20	8.10	7.90	8.30	8.13	25.23	682.48
Average														27.54	646.84

3) Calculation of Thickness Swelling (TS) for board made of Urea Formaldehyde with ammonium bisulfite (ABS) as scavengers

The results and the calculation of thickness swelling for medium density fibreboard made of urea formaldehyde with ABS as scavengers shown below.

Sample	Weight (mm)	Width (mm)	Length (mm)	Initial Thickness (mm)					Final Thickness (mm)					Thickness Swelling (%)	Density (kg/m^3)
				1	2	3	4	Average	1	2	3	4	Average		
1	9.37	50.00	50.00	6.10	5.90	5.90	6.10	6.00	9.00	8.70	8.70	8.70	8.78	31.62	624.51
2	9.22	51.00	49.00	6.00	6.00	6.00	6.00	6.00	8.90	8.80	9.00	9.10	8.95	32.96	614.63
3	9.00	49.00	48.00	6.10	6.20	6.30	6.00	6.15	8.90	8.70	8.90	9.20	8.93	31.09	622.03
4	9.37	52.00	50.00	5.90	5.90	6.30	6.00	6.03	8.90	9.30	9.20	9.30	9.18	34.33	597.98
Average														32.50	614.79

APPENDIX D

FORALDEHYDE EMISSION RATE CALCULATION

Based on Japanese International Standard A 1460, JIS A 1460, the concentration of formaldehyde in water is calculated using the formulae below:

$$G = F \times (A_d - A_b) \times \frac{1800}{S}$$

Where, G: concentration of formaldehyde from the test piece (mg/L)

A_d: absorbance of solution inside desiccator containing test piece

A_b: absorbance of background formaldehyde

F: slope of calibration curve

S: surface area of test piece (cm)

From the results of UV/Vis testing on the water samples, a calibration curve is first plotted. The graph is shown below.

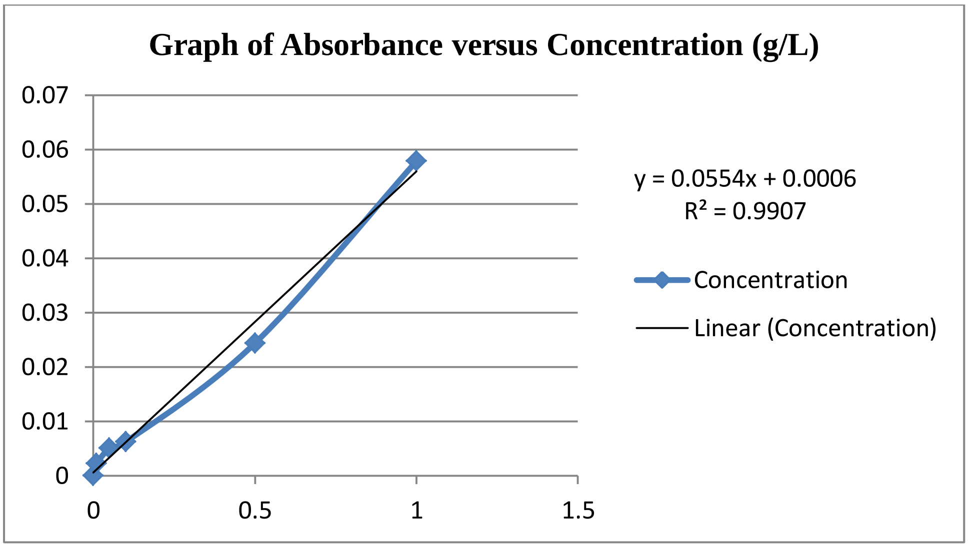
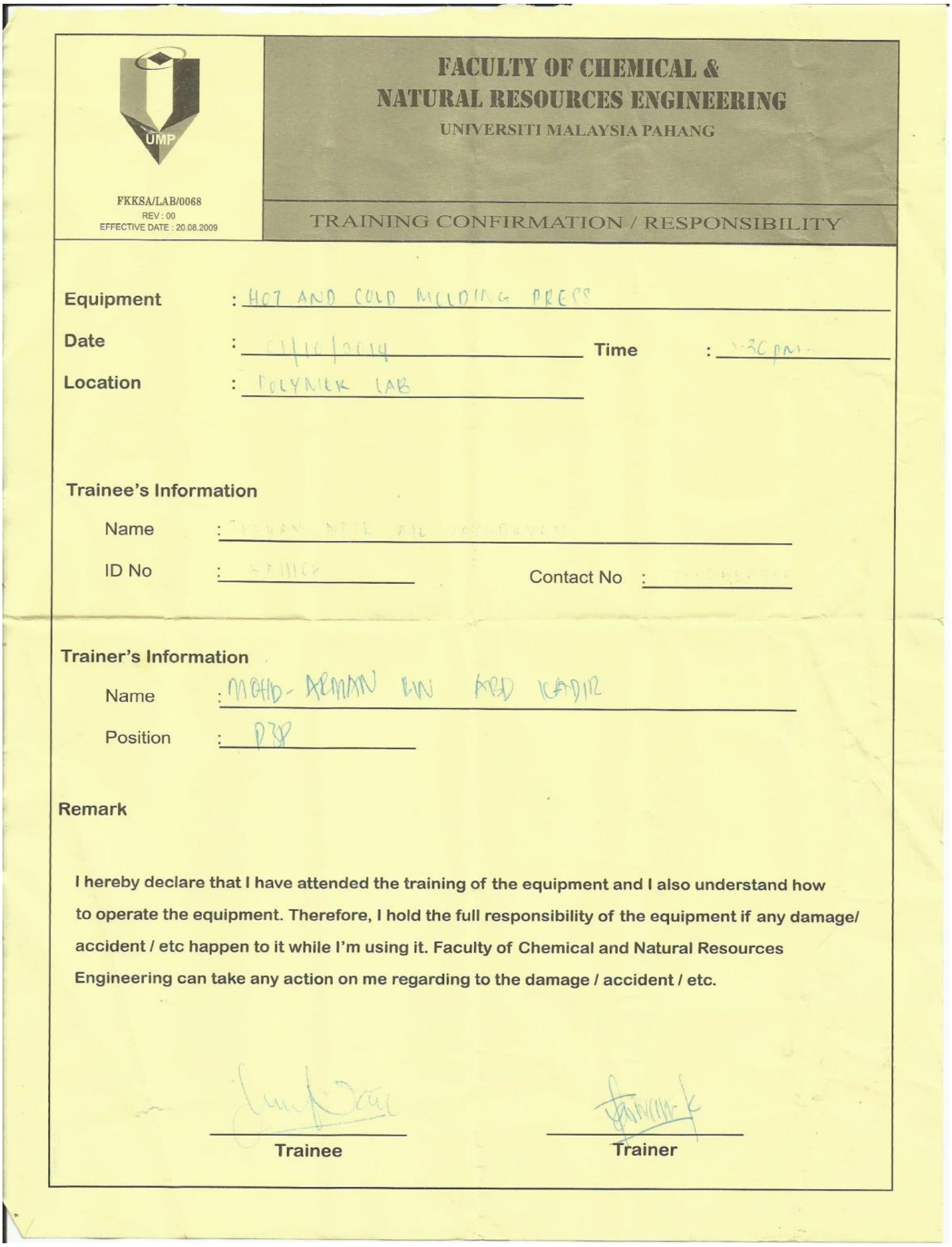


Figure 4.2.1.3-1: Calibration graph of absorbance versus concentration

Hence with that information the information above, the concentration of formaldehyde in the water can be calculated. The results are shown below.

Water Samples	Absorbance				Concentration		
	Trial 1	Trial 2	Trial 3	Average	g/L	PPM	G (g/L)
Formaldehyde	0.015	0.014	0.018	0.0156667	0.2178099	217.80987	0.0072593
Formaldehyde + SMBS	0.01	0.009	0.012	0.0103333	0.1215403	121.54031	0.0042028
Formaldehyde + ABS	0.013	0.014	0.012	0.013	0.1696751	169.67509	0.005731

Table 4.2.1.3-1: Table of Absorbance of samples with its respective concentration



FACULTY OF CHEMICAL &
NATURAL RESOURCES ENGINEERING
UNIVERSITI MALAYSIA PAHANG

FKKSA/LAB/0068
REV : 00
EFFECTIVE DATE : 20.08.2009

TRAINING CONFIRMATION / RESPONSIBILITY

Equipment : HOT AND COLD MOULDING PRESS
Date : 01/10/2014 Time : 2.30 pm
Location : POLYMER LAB

Trainee's Information
Name : [illegible]
ID No : [illegible] Contact No : [illegible]

Trainer's Information
Name : MOHD. ARMAN BIN ABD KADIR
Position : PJP

Remark

I hereby declare that I have attended the training of the equipment and I also understand how to operate the equipment. Therefore, I hold the full responsibility of the equipment if any damage/ accident / etc happen to it while I'm using it. Faculty of Chemical and Natural Resources Engineering can take any action on me regarding to the damage / accident / etc.

Trainee Trainer

Figure above 1 shows the training approval form done to conduct the hot and cold moulding machine