COMPACT PAPER RECYCLING SYSTEM
(SOAKING, BLENDING AND DRYING MECHANISM)

DONICA KAN PEI XIN

A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering (Hons.) Mechatronics Engineering

Faculty of Engineering and Science
Universiti Tunku Abdul Rahman

April 2013

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

Signature : ____________________________

Name : Donica Kan Pei Xin

ID No. : 09UEB05017

Date : ____________________________

APPROVAL FOR SUBMISSION

I certify that this project report entitled **"COMPACT PAPER RECYCLING SYSTEM"** was prepared by **DONICA KAN PEI XIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Engineering(Hons.) Mechatronics Engeineering at Universiti Tunku Abdul Rahman.

Approved by,

Signature : ____________________________

Supervisor : Dr. Lee Poh Foong

Date : ____________________________

ACKNOWLEDGEMENTS

I would like to thank everyone who had contributed to the successful completion of this project. I would like to express my gratitude to my final year project supervisor, Dr. Lee Poh Foong for her invaluable advice, guidance and her enormous patience throughout the development of the project.

In addition, I would also like to express my gratitude to my final project partner, Lee Chun Hean who is willing to cooperate with me and give me encouragement throughout the project. Nevertheless, I am thankful to my family and friends who give me support and help in completing this project.

COMPACT PAPER RECYCLING SYSTEM

ABSTRACT

Paper recycling is a process of producing recycled paper from secondary fiber. Paper recycling is important in conservation of natural resources and environment. Besides conventional paper recycling system, end users can produce recycled papers by manual home-based paper recycling system. However, manual home-based paper recycling process is tedious and involves many steps. Therefore, compact paper recycling system is introduced to make the home-based paper recycling system automated. Compact paper recycling machine is built to shorten the recycling process and make paper recycling easier for user. This machine involves four processes: soaking, blending, pulp moulding and drying process. This report is focusing on the soaking, blending and drying mechanism of the machine. Literature review is done to understand and investigate the optimum parameters for each mechanism. The studies concluded that the properties of recycled paper are dependent on blending time and drying method. Preliminary test was carried out to select the optimum parameters for the machine which are 30 s papers soaking time, 1 min blending time and fan as drying method. The compact paper recycling machine consists of a blender, basin, pulp moulding frame, water reservoir and four magnetic drive water pumps with pipes that connect each section. This machine can produce an A5 size recycled paper from two A4 size waste papers. User is required to put papers into the blender and switch on the machine only. Papers are first soaked for 30 s and blended for 1 min to become pulp form. Then, the pulp is transferred to the pulp moulding frame for final product shaping. Excess water flows into the basin and is circulated from basin to pulp moulding frame to make the pulp sheet distributed evenly. Finally, the excess water flows back to water reservoir and the fan is turned on for 300 min to dry the pulp sheet. The recycled paper produced by the machine is compared with the recycled paper made manually by analysing its surface with scanning electronic microscope. Both methods produce a homogenous and less porous surface recycled paper.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS / ABBREVIATIONS

T	tensile strength of paper sheet
Z	zero-span tensile strength of paper sheet
b	bond shear strength per unit bonded area (specific strength of interfibre bonding)
k	morphological aspect of fibre
S_0	light scattering coefficient of the sheet in the absence of bonding between fibres
S	light scattering coefficient of the sheet in the presence of bonding between fibres.

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Introduction

Paper recycling is a process of obtaining pulp fibres from already made paper. Nowadays, paper recycling is increasing in the sense that it contributes to preservation and conservation of natural resources. Paper recycling helps to save wood raw stock, reduces energy consumption, reduce global warming potential, decreases the operation and capital costs of paper units and last but not least reduces overall environment impact (Cabalova et al., 2011).

In conventional paper recycling process, the recovered paper collected and sorted is sent to the paper mill. In paper mill, the paper will undergone pulping process to chop paper into small pieces and becomes mushy mixture called pulp. Then, pulp is forced through screens to remove small contaminants and is cleaned by spinning around in large cone-shaped cylinders. Sometimes the pulp must undergo deinking process to remove printing ink. After the pulp is cleaned, the pulp is ready to be made into paper. In the paper making process, the watery pulp mixture is sprayed onto huge flat wide screen, drains water and is dried under heated metal roller. The finished paper is then wound in giant roll and removes from the paper machine. The recycled paper is ready to be printed or made into products. However, the conventional paper recycling process takes time for the recycled product to reach back the end user.

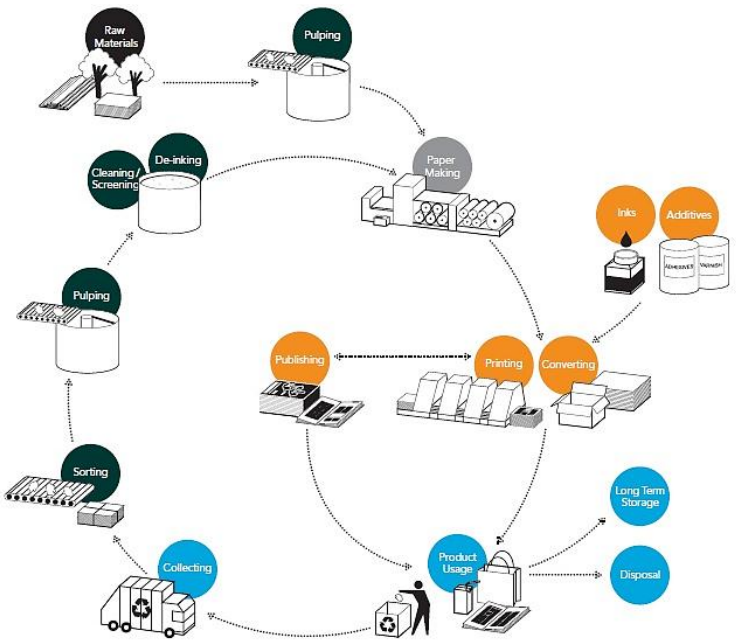

Figure 1.1: Flowchart of paper recycling

(European Declaration on Paper Recycling 2006-2010, Monitoring Report 2010)

Besides conventional paper recycling system, actually end user itself can produce recycled paper by introducing home-based paper recycling system. A home-based paper recycling system is the simplified version of conventional way. First, paper is cut into pieces and soaks in the water. Then the papers are blended to become watery pulp mixture followed by pulp moulding to shape the size of recycled paper. The final steps will be compressed the water out and dried to produce a piece of recycled paper. This home-based paper recycling process is simple but is time and human energy consuming.

In this project, the home-based paper recycling process is integrated into an automated machine namely compact paper recycling machine. This automated machine helps to make recycling easier and reduces paper recycling time by comparing to the home-based paper recycling process. Furthermore, it can promote environment preservation. This machine is separated into four sections: Soaking, Blending, Pulp Moulding and Drying. This report is focusing on the soaking, blending and drying mechanism of compact paper recycling machine.

1.2 Background

Paper forms a major part of the waste stream. In Malaysia, every month over 57,000 tonnes of paper, which occupies 456,000 cubic meters of landfill space, is thrown into landfills. The amount of paper is equal to chopping down 680,000 trees of marketable tress. Malaysia's recycling rate is about 5% which is relatively low compared to developed countries which have overall recycling rates of 50% or higher. Paper recovery rates in Malaysia currently hovers around 60%. This indicates that only 192,000 tonnes of newsprint from 320,000 tonnes of newspaper are recovered from the waste stream. The 128,000 tonnes of newspaper yet to be recovered for recycling is like throwing away 2.55 million trees into landfills (Malaysia Newsprint Industry, 2007).

By comparing to European countries, the recycling rate in Europe is very high and reached 68.9% in 2010. The total amount of paper send for recycling came to 58 million tonnes. The European Recovered Paper Council (ERPC) has done an excellent work in increasing paper recycling in Europe. The paper recycling rates has increased by 10% points since 2004. Nevertheless, 2010 European paper recycling rate of 68.9% is higher than the target set by the ERPC.

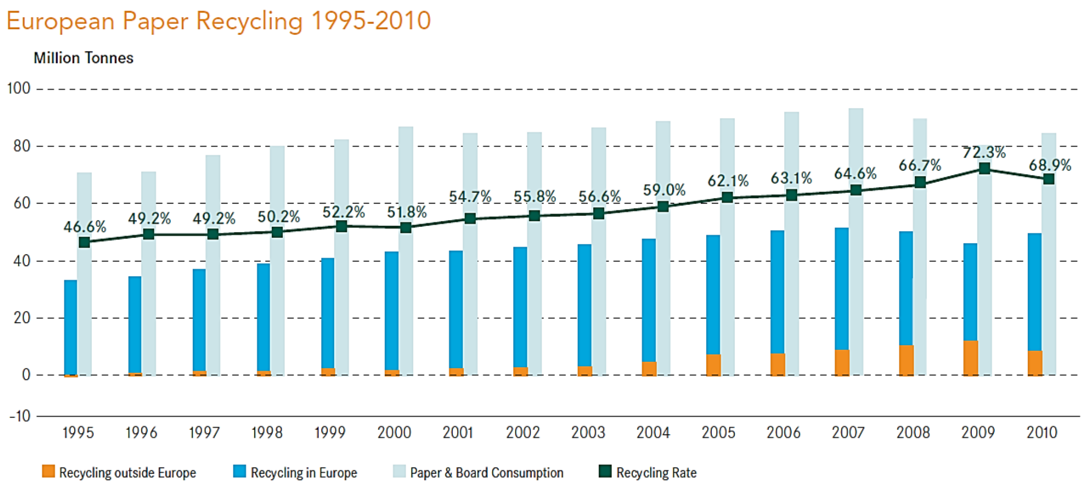

Figure 1.2: European Paper Recycling Rate 1996-2010

(European Declaration on Paper Recycling 2006-2010, Monitoring Report 2010)

1.3 Aim and Objectives

The aim of this project is to build a compact paper recycling machine.

The objectives of this project are:

a) To make an automated machine to make paper recycling easy, quick and efficient.
b) To investigate the optimum parameters used for soaking, blending and drying methods.

1.4 Report Layout

This report consists of five chapters. Chapter 1 discussed the introduction of this project followed by the background of paper recycling, aim and objectives of this project and finally the layout of the report. Chapter 2 is the literature review of soaking, blending and drying method of paper recycling process. The methodology used in this project is explained in Chapter 3. The conceptual design of the compact paper recycling machine, preliminary test, proposed flow chart and material selection are discussed here. Chapter 4 mainly presents the result and discussion of each mechanism built in the compact paper recycling machine prototype. Lastly, Chapter 5 concludes the report and some recommendations are listed to improve the machine’s limitation.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The properties of a recycled paper produced are influenced by the paper making process. The study of each stages of process is crucial to understand and investigate the optimum parameters for the compact paper recycling machine. Studies have been carried out on the properties change of pulp during soaking, beating, compression and drying in paper recycling process. In this chapter, the literature review will focus on the properties change of pulp in beating and drying process.

2.2 Soaking

Fiber and water interacted during the soaking of papers in the water. According to Scallen three basic phenomena occur during water-fiber interaction: absorption, swelling and wetting. Absorption is the process of fibers taking the water from the external liquid phase. Swelling of fibers is produced from the reaction of cellulose with water which results in structural change of fibers. The properties of fibers change upon wetting such as Water Retention Value, dimensional changes and strength changes (Scallen, 1978).

2.3 Beating

Blending is a process of beating the fibres. Beating improves the bonding ability of fibres as it causes fibres shortening, external and internal fibrillation affiliated with delamination, and fibres plasticizing. External fibrillation happens when the fibrils peeling from surface at the primary wall and secondary wall. Internal fibrillation is expressed as freeing and disintegration of a cell wall affiliated with strong swelling. The delamination is a coaxial cleavage in the middle layer of the secondary wall. It causes the increased water penetration to the cell wall and the fibre plasticizing. Fibres shortening take places at any angle wise across fibre in accordance with loading (Cabalova et al., 2011).

2.3.1 Tensile Strength

The strength of paper originates from both the strength of individual fibres in the network and the strength of forces holding them together. Tensile strength is widely used in characterizing of the strength of paper and board. The tensile strength of recycled paper decreases when the interfibre bonding strength decreases which is interrelated with the decreased of interfibre-bonded area. According to the modified Page Equation:

$$\left[\frac{1}{T} - \frac{9}{8Z}\right]^{-1} = \frac{b}{k} - \left[\frac{b}{kS_0}\right]S \qquad (2.1)$$

where

$\left[\frac{1}{T} - \frac{9}{8Z}\right]^{-1}$ = Page Bonding Strength

T = tensile strength of paper sheet

Z = zero-span tensile strength of paper sheet

b = bond shear strength per unit bonded area (specific strength of interfibre bonding)

k = morphological aspect of fibre

S_0 = light scattering coefficient of the sheet in the absence of bonding between fibres

S = light scattering coefficient of the sheet in the presence of bonding between fibres.

The S_0 value is constant with zero-span tensile strength while the value b/k is proportional to the specific strength of interfibre bonding. The constant value of b/kS_0 in the modified Page equation indicates the beating and recycling treatment does not affect the specific strength of interfibre bonding. The loss in the tensile strength of recycled paper only relied on the increase in the interfibre un-bonded area.

Higher beating degree of fibre is necessary to have better interfibre contact in recycled paper. The recycled paper produced from the beaten one is stronger than the unbeaten one as beaten fibres have larger interfibre bonded area and have slightly stronger cell wall. The cell wall of heavily beaten fibres could be tightly packed easier than that of mildly beaten ones due to its completely entire homogeneity of delaminated parts. The figure below shows that the recycling treatment increased the zero-span tensile strength of the paper made from heavily beaten fibres more remarkable than that of the paper made from mildly beaten ones. The continuous increase in the zero-span tensile strength of paper made from the unbeaten fibres was possibly due to the original structure of fibres walls (Khantayanuwong, 2002).

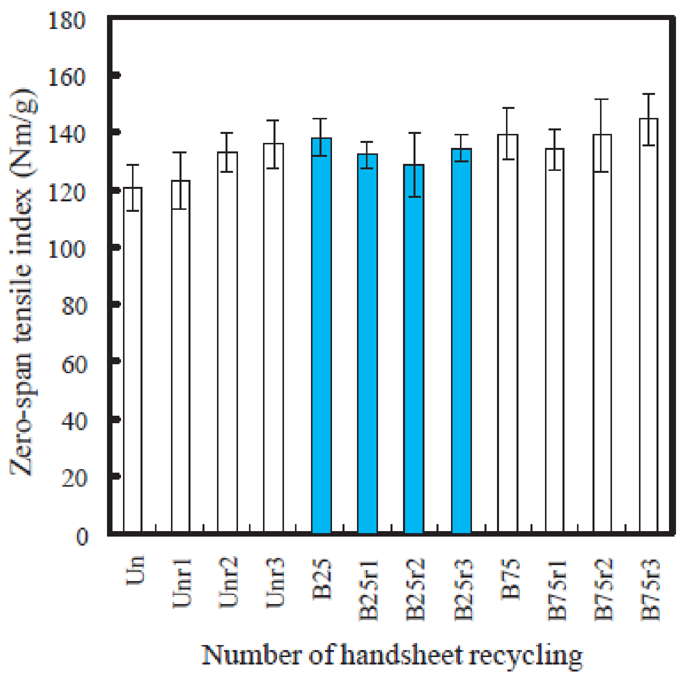

Figure 2.1: Changes in zero-span tensile index by recycling treatment.

A pair of bars denotes a rage of 95 % confidence level. N.B. Un, unbeaten; B25, beaten for 2,500 rev.; B75, beaten for 7,500 rev.; r1, recycled once; r2, recycled twice; r3, recycled for three times (Khantayanuwong, 2002)

2.4 Drying Method

Drying is the main cause of fibre damage in recycling process. Drying method has big influences on the properties of the paper produced from secondary fibre. Increasing temperature can reduce the drying time and increase drying rates. However, high drying rates will affect the properties and quality of the recycled paper. The quality of paper is evaluated by the physical properties of paper which is strongly dependant on types of drying process (Vieira and Rocha, 2007).

2.4.1 Physical Properties

The main physical properties characterise the quality of a paper are moisture content, grammage, apparent density, porosity, tension and burst resistance (Young, 1980). There properties are influenced by the drying condition of the paper. The table below is tabulated to show the summary of experimental results done by the authors to dry recycled papers under natural environment and by forced convective dryers.

Table 2.1: Physical Properties of Recycled Paper Dry using Different Method (Vieira and Rocha, 2007)

Physical properties	**Natural atmosphere convection**	**Forces (Convective Dryer)**	
		Mild (60 ˚C – 80 ˚C)	Severe (> 80 ˚C)
Drying kinetics	High time needed	Low	Low
Moisture content	Low value (high deviation due to nonuniformity of moisture in dried paper)	Low value	Low value
Grammage	High	Low	Lowest
Thickness	High	Low	Lowest
Porosity	Small	High	Highest
Absolute density	Same	Same	Same
Apparent density	High	Same with natural	Low density (case hardening

			phenomenon)
Tension resistance	Same	Same	Same
Burse resistance	Same	Same	Same
Longitudinal Stretch	Same	Same	Same
Paper sheet surface	Less porous surface Homogeneous	Porous surface Homogeneous	More porous surface Wrinkles on surface More brittle and rigid

The thickness, grammage and apparent density of recycled paper dried at natural environment condition have the highest values. The mild drying condition papers have higher value than the papers dried at severe drying conditions. Besides that, a more porous product is obtained at severe drying conditions. Although there are no significant changes in the tension and burst resistance, a tendency of increase of these properties is verified with the increase of the drying operating variables.

The paper sheets surface analysis is carried out using optical microscope and scanning electron microscope (SEM). Papers that dried naturally and at mild conditions are more homogeneous and have less porous surface while the paper dried at high temperature has a more deformed surface. Wrinkles on surface of the paper, at the fibres direction, were verified for the papers dried at the highest temperature. The recycled papers became more brittle and rigid, thus representing poor quality (Vieira and Rocha, 2007).

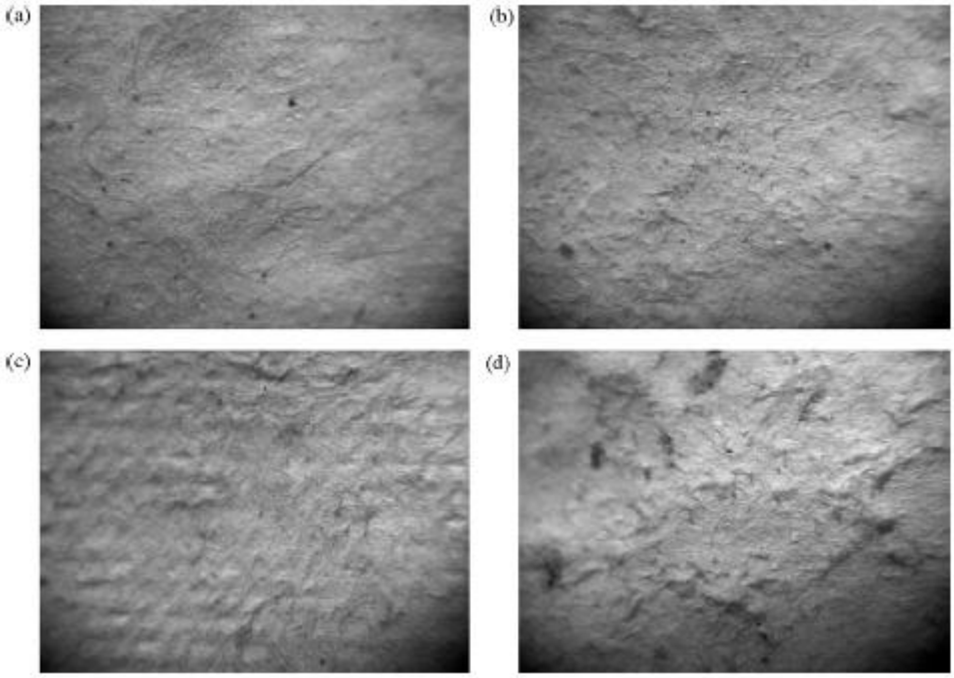

Figure 2.2: Photos of dried paper sheets analyzed by optic microscope: (a) natural drying (40×) ; (b) 70 ˚C (40×) ; (c) 80 ˚C (40×) ; (d) 90 ˚C (40×) (Vieira and Rocha, 2007)

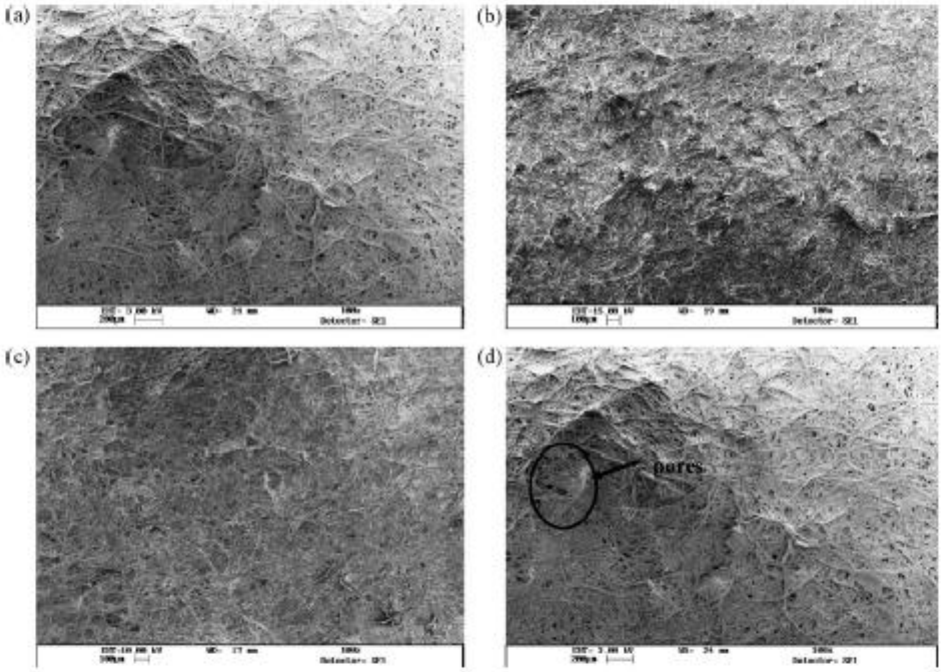

Figure 2.3: Photos of dried paper sheets analyzed by SEM: (a) natural drying (100×) ; (b) 70 ˚C (100×) ; (c) 80 ˚C (100×) ; (d) 90 ˚C (100×) (Vieira and Rocha, 2007)

2.4.2 Mechanical Properties

The mechanical properties of recycled papers are strongly influenced by the amount of shrinkage, which depends on the type of drying process employed. Shrinkage occurs both in direction of the paper thickness, width and length (Stenstrom, 2004). During drying, the delaminated parts of fibre wall that is the cellulose microfribrils become attached (Ackerman et al., 2000). The shear stresses are formatted in the interfibrilar bonding area. The stresses formatted in the fibres and between them affect the mechanical properties in the drying area (Cabalova et al., 2011).

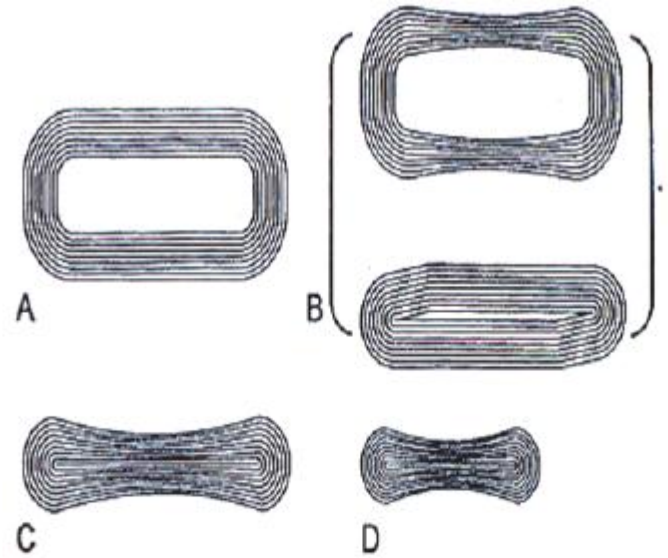

Figure 2.4: Shrinkage of a fiber cross section (Arkerman et al., 2000)

Stage A represented the wet fibre before drying. In stage B, the drainage has started to cause morphological changes in the fibre wall matrix at about 30% solids content. The fibre wall lamellae start to approach each other because of capillary forces. The lumen can collapse at this stage. With additional drying, spaces between lamella continue shrinking to phase C where most free voids in the lamellar structure of the cell wall have already closed. Toward the end of drying in stage D, the water removal occurs in the fine structure of the fibre wall. The fibre shrinks strongly and uniformly during this final phase of drying which has solid contents above 75-80%. The shrinkage of stage D is irreversible (Cabalova et al., 2011).

2.4.3 Curl Tendency

The curl of the paper is a measure of the tendency of the paper to deform from an ideally form when subjected to changes in moisture or temperature. Curl is normally due to either uneven fibre distribution or uneven drying from the two surfaces of the web (Stenstrom, 2004). The curl tendency of paper is affected by high temperature and one side drying. Paper is tended to curl towards the side that is dried last as the side against the dryer dried first cannot shrink once dried. However, paper that produced from recycled pulp has less curl tendency than paper that produced from virgin pulp. This is due to the reduction in the inter-fibre bonding when paper is recycled.

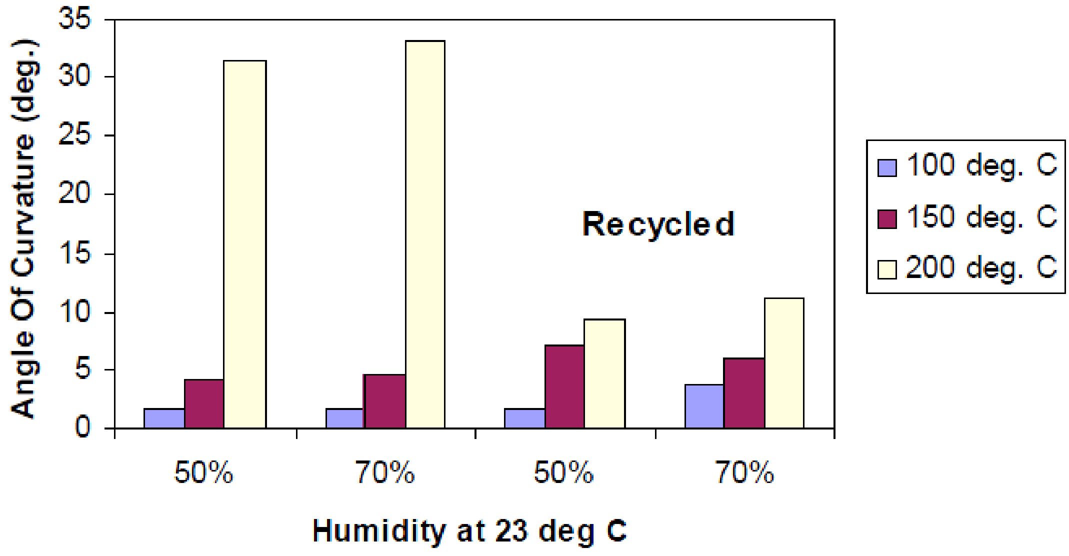

Figure 2.5: Effect of shell temperature paper curl (Alsaid et al., 2009)

However, in commercial machine trials, the recycled board had a natural curl tendency due to single high temperature drying. Curl cannot be controlled in such installation and may present when there is change in machine situation due to some factors such as furnish changes or machine speed a negative interaction between the high temperatures dryer and curl. Therefore, at least two high temperature dryers should be installed on a commercial machine for curl control (Alsaid et al., 2009).

2.4.4 Microstructure

Cellulose crystallinity and pore structure of the fibre cell walls are two important parameters that may affect the fibre properties. Inter-fibre bond strength is affected by cystallinity, while the porous structure of the fibre affects its polymerization ability, swelling and paper strength. Water retention value (WRV) is a parameter that represents the amount of water held by the pulp as measured after centrifugation at 3000 g during 15 minutes. The result is assumed as the removal of water in the inter-fibre pores. If the drying conditions change during recycling, the WRV of the fibre, the cellulose crystallinity and porous structure of the fibre wall undergo some irreversible variation. This will result in lower fibre strength and thus in fibre decay.

In terms of effect of drying temperature on cellulose crystallinity and porous surface, the WRV decreases while crystallinity increases when drying temperature increases. The pore size decreases with increasing the temperature. The effect of the drying temperature on the fibre pore is mainly located in the mesopores. Through drying, the partially amorphous area is transformed into a crystallinity area, which leads to higher crystallinity, thereby restricting expansion on wetting, decreasing WRV and increasing the extent of fibre decay. Therefore, lower drying temperature should be applied for reducing the drying impact on fibre swelling.

Moreover, different drying time values with a constant fibre drying temperature (100 ˚C) do affect the WRV, cellulose crystallinity and porous structure of fibre. The longer the drying time, the smaller the WRV, while fibre crystallinity increased gradually with the drying time. The degree of non-reversible closure is enhanced with increasing the drying time. The reason is higher temperature can promote a change from elastic to plastic deformation in the cell wall pore structure, which influences the adsorption of free water in the fibre and has a reduced swelling capacity in water, resulting a lower fibre quality (Wan et al., 2009).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter describes the conceptual design of the compact paper recycling machine. In order to select the optimum parameters for this machine, preliminary test was carried out for soaking, blending and drying mechanism. A flow chart of the process was proposed from the result of the preliminary test. Materials were selected for each of the mechanism. Next, the paper recycling process of the compact paper recycling machine was illustrated. Lastly, the blending and drying mechanism were explained in the end of this chapter.

3.2 Conceptual Design

The proposed methodology of this machine is soaking mechanism, blending mechanism, pulp moulding and drying mechanism. The figure below shows the conceptual design of compact paper recycling machine. The soaking and blending process is processed in first compartment, blender. Meanwhile, the pulp moulding and drying mechanism is processed in the second compartment. Paper is soaked and blended in the blender. Then, the pulp is transferred to the pulp moulding session via a valve. The pulp moulding session is processed in a basin that fills with water. A pulp moulding frame is used to shape the pulp sheet. Besides that, a stirrer is put in the water for water movement to distribute the pulp evenly in the frame. Before the drying mechanism, the water in the basin is drained to a reservoir. Finally, drying mechanism will be turned on to dry the recycled paper thoroughly.

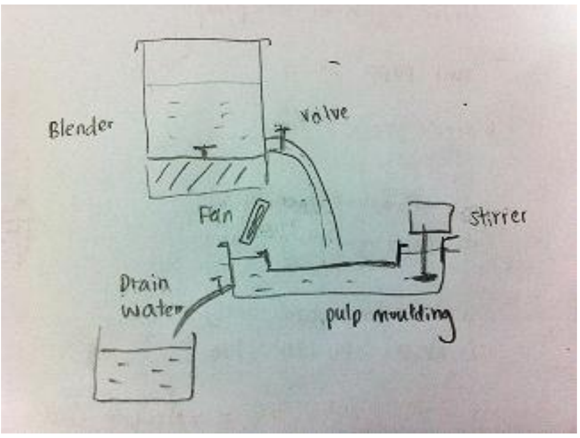

Figure 3.1: Conceptual design of compact paper recycling machine

3.3 Preliminary Test

The trial of recycled paper making process is done to improve the understanding and identify the solutions for each problem occurs. Preliminary test is carried out to select the optimum parameters for each section and to further verify the literature review that has been discussed above.

3.3.1 Soaking

Soaking experiment was done to analyze the properties of pulp for different soaking time. Paper samples were soaked for different period of time and the samples were viewed under the microscope to view the compactness of soaked papers. Also, the samples were blended for 30 s to view the pulp fibre.

3.3.2 Blending

The properties of the pulps on different beating time were analyzed in blending experiment. As mentioned in the literature review, higher beating degree can have better interfibre bonded area. This experiment was carried out to investigate the minimum blending time of pulp to have better interfibre contact. Papers were tore cut into small pieces and soaked for 1 min to wet the papers. These wet papers were then blended according to a variable of different duration of time. Next, the pulp samples were viewed under microscope to observe the changes due to different time frame during the processing.

3.3.3 Drying Method

Drying is the main influence on the quality of recycled paper produced. Experiment was done to find the suitable drying method to be used in the compact recycling machine. Three types of drying methods were tested in this experiment: heating using oven, dry by fan and dry naturally. Heating using oven is one of the forced drying methods where poor quality of recycled paper will be produced as mentioned in the literature review. Experiment was done to verify the results of the study. The temperature in the oven was observed by using thermocouple in order to maintain the environment with a constant temperature as shown in Figure 3.2. Pulp sheets were heated at 60 ˚C and 80 ˚C respectively.

Figure 3.2: Temperature in oven is observed using thermocouple

Dry pulp sheets with fan blow directly onto it is an alternative way to dry the recycled paper faster and can maintain better quality of paper. There are two ways of setting up the fan: vertical and horizontal position. Figure 3.3 shows the experimental set up consisted of both positions. Vertical position placed the fan at the centre of the pulp sheets. The wind was blow directly on top surface of pulp sheet. Meanwhile, horizontal position placed the fan at either side of pulp sheet. The wind will blow on both surface of pulp sheet. The last method tested for drying method was natural environment drying. This method depends on the atmosphere conditions. The pulp sheet was placed in a closed room with controlled environment temperature and humidity.

(a) (b)

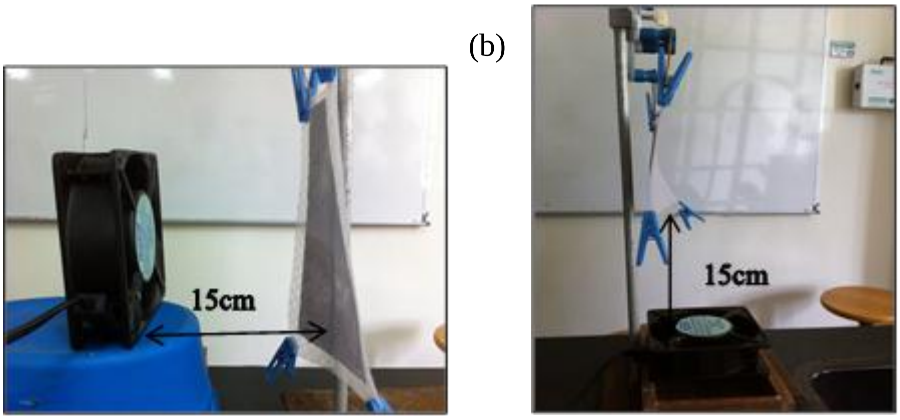

Figure 3.3: Experimental set up for fan position: (a) vertical; (b) horizontal

3.4 Proposed Flow Chart

From the result obtained from preliminary tests, the parameters selected for compact paper recycling machine are: 30 s soaking time, 1 min blending time and fan as drying method.

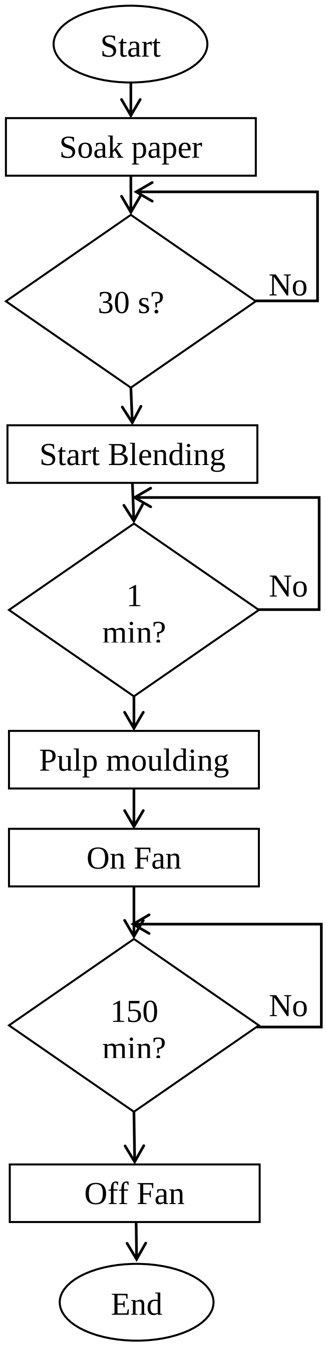

Figure 3.4: Proposed flow chart of paper recycling process

3.5 Material Selection

The blender selected for blending mechanism is Electrofast Super Blender with Circuit Breaker as shown in Figure 3.5. Blender is used to beat the paper into pulp form. Meanwhile, Kaku cooling fan in Figure 3.6 is selected for drying mechanism. The fan is used to dry recycled paper by blowing wind towards the centre of pulp sheet. Lastly, Life 908 magnetic drive pump in Figure 3.7 is used as valve to transfer pulp and water.

Figure 3.5: Electrofast Super Blender with Circuit Breaker

Figure 3.6: Kaku cooling fan

Figure 3.7: Life 908 magnetic drive pump

3.6 Paper Recycling Process of Compact Paper Recycling Machine

Figure 3.8 shows the prototype of compact paper recycling machine built. Water is the main element in the paper recycling process. Water is stored in the water reservoir to keep for usage. Firstly, user has to put papers that have been torn cut into small pieces into the blender and close the cap of the blender tightly. The paper recycling process is started when the switch is turned on. Water is flowed from the water reservoir into the blender to a certain level and stop for 30 s to soak the papers. Then, the blender is turned on for 1 min to beat the papers into pulp form. After the blending process, the pulp is transferred via a pump to the pulp moulding frame for shaping. At the same time, the water is continuously flow from the water reservoir to the blender and finally to the pulp moulding frame to ensure all the pulp in the blender is transferred to the pulp moulding frame.

The pulp moulding frame is positioned on a basin where excesses water is flow into the basin. A pump circulates the water from the basin to the pulp moulding frame to make the layer of pulp even. Subsequently, the water in the basin is drained back to the water reservoir to be kept for next usage. Finally, the fan is turned on for 300 min to dry the dripping pulp sheet in the pulp moulding frame. Recycled paper can be removed manually from the pulp moulding frame after it is dry.

Figure 3.8: Compact paper recyling machine prototype

Figure 3.9: Water enters the blender to soak paper for 30 s

Figure 3.10: Blender is turned on for 1 min

Figure 3.11: Pulp in the blender is transferred to pulp moulding frame while water is continuously flow from reservoir via blender to pulp moulding frame

Figure 3.12: Water circulation by pump to make layer of pulp sheet even

Figure 3.13: Fan is turned on after the water in the basin is drained

3.7 Blending Mechanism

Soaking and blending process occurred in the blending mechanism. The blending mechanism is the combination of a blender and a magnetic drive pump as shown in Figure 3.14. The pump is installed at the lower part of the blender jar to behave as a valve. A hole is drilled at 5 cm apart from the bottom of blender jar to fit the diameter of pump's inlet. Silicone gel is used to seal the fitting to prevent water leakage. When the pump is switched on, water in the blender enters the pump's inlet and is forced to flow out from the outlet of pump which is connected with a pipe. Therefore, the pulp in the blender can be transferred to pulp moulding session after blending process. However, the limitation of this design is the pulp will remains at the bottom as the pump inlet is located 5 cm higher than the bottom blender jar.

Figure 3.14: Magnetic drive pump is fitted to the blender jar

Magnetic drive pump is selected because the pump mechanism is isolated from the motor with a solid wall. The water in the pump has no physical contact with the motor. The rotary power is transmitted from motor side to the pump side through magnets on both sides of the wall. The driver magnetic at the housing wall is spinned by the motor and rotates the driven magnets at drive shaft. The rotating shaft which attached with blades pushes the water upwards to the outlet of the pump.

Figure 3.15: Magnetic drive pump mechanism

Water in the reservoir is transferred to the blender via a water pump after the machine is switched on. The water pump stops after 5 second where the water level in the blender has reached approximately 10 cm. The process stops for 30 s to soak the papers. After that, the blender is turned on for 1 min to beat the papers into pulp form. The magnetic drive pump that fitted to the blender jar is then turned on to transfer the pulp from blender to pulp moulding frame. At the same time, pump in the water reservoir is turned on to continuously supply water to the blender. The magnetic drive pump at the blender and water pump in the water reservoir is turned on together for 30 s to flow water from water reservoir via blender and to the pulp moulding frame. This step is to ensure all the pulp in the blender is being transferred out as there is a gap between the inlet of magnetic driven pump and the bottom of blender jar. Some of the pulp may remain at the bottom of blender jar. The blending mechanism takes about 125 s including the soaking time of papers, blending process and pulp transportation. The flow chart of blending mechanism process is shown in Figure 3.16.

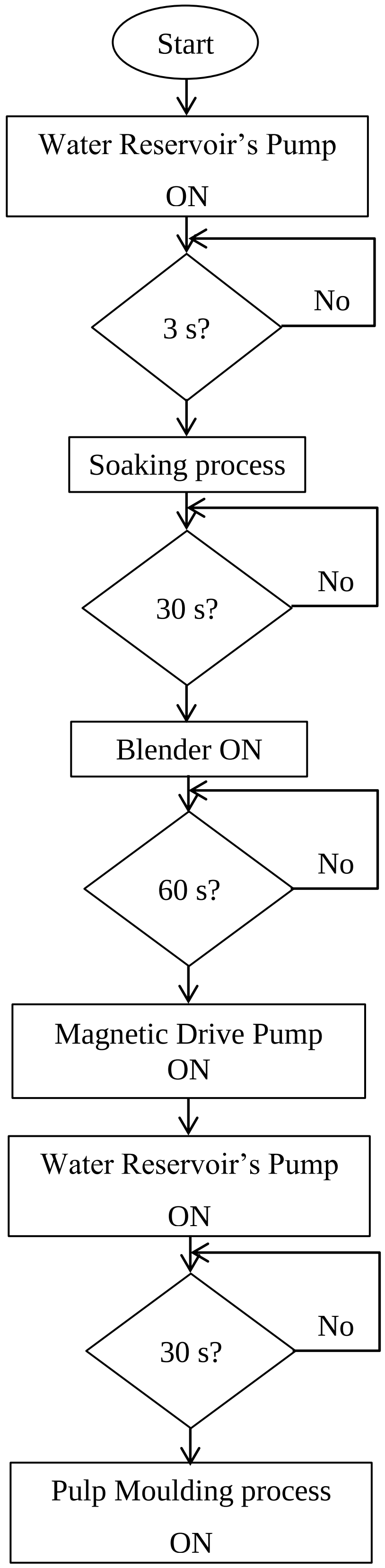

Figure 3.16: Process flow chart of blending mechanism

3.8 Drying Mechanism

Fan has been selected for drying mechanism as tested in the preliminary test. As the pulp sheet lays horizontal on the pulp moulding frame, the fan is installed horizontally on top of the centre of pulp moulding frame. The fan is mounted 18 cm higher from the pulp moulding frame on the steel rack as shown in figure 3.17. The wind is directly blown to the surface of the pulp sheet facing the fan. The water is forced to move outward from centre to the edge and dissipated to the surrounding. Therefore, the pulp sheet started to dry from the centre towards the edge.

Figure 3.17: Fan is installed on top of the pulp moulding frame

Furthermore, the fan has to be mounted diagonally on the rack to avoid blockage of airflow at rear end of fan. The amount of air enters the fan is reduced if the rear end of fan is blocked by the steel rack. Consequently, the amount of air blow out from the fan is reduced. Therefore, the fan is mounted diagonally to ensure no blockage of airflow.

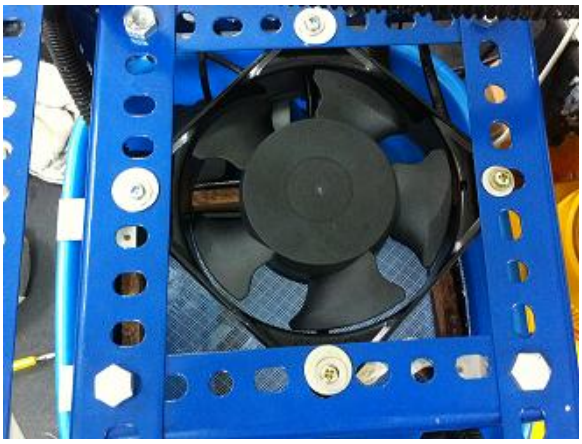

Figure 3.18: Fan is mounted diagonally on the steel rack

The fan is turned on after the water in the basin is drained. The fan will be switched on for 300 min (5 hours) and turns off automatically. The time needed for the pulp sheet to dry thoroughly is doubled the time needed in the preliminary test (150 min). This is due to the change of size of the pulp sheet from 113×185 mm to a bigger pulp sheet sized 148×211 mm. Also, the humidity level is higher as the pulp sheet is in contact with the wet pulp moulding frame that is made of wood. Recycled paper is produced at the end of the recycling process.

Figure 3.19: Pulp sheet is in contact with wet pulp moulding frame

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

The aim of this project had been achieved as a compact paper recycling machine prototype is built. The machine prototype consists of a water reservoir, a blender, a pulp moulding frame, a basin, four pumps and several pipes. All the parts are assembled in a steel rack with plastic covered wood base and the automated paper recycling process are controlled by microchip. This machine can transform two pieces of A4 (210×297 mm) size used papers into one A5 (148×211 mm) size recycled paper. This chapter shows the results obtained from preliminary test and analysis of recycled paper samples that produced from compact paper recycling machine.

4.2 Preliminary Test Results

4.2.1 Soaking

Figure 4.1 shows the images on sample of soaked pulp under microscope, which the soaking time varied at 1 min, 1, 2, 3, and 4 days . The fibre of dried paper was compact and the ink was absorbed into the paper. The images indicate that the fibre and ink detached well from paper after soaking in water for 1 minute. However, the fibre of the paper after blended did not show difference in properties as seen in Figure 4.2. This indicates that difference in soaking time does not bring much affect to the properties of pulp fibres.

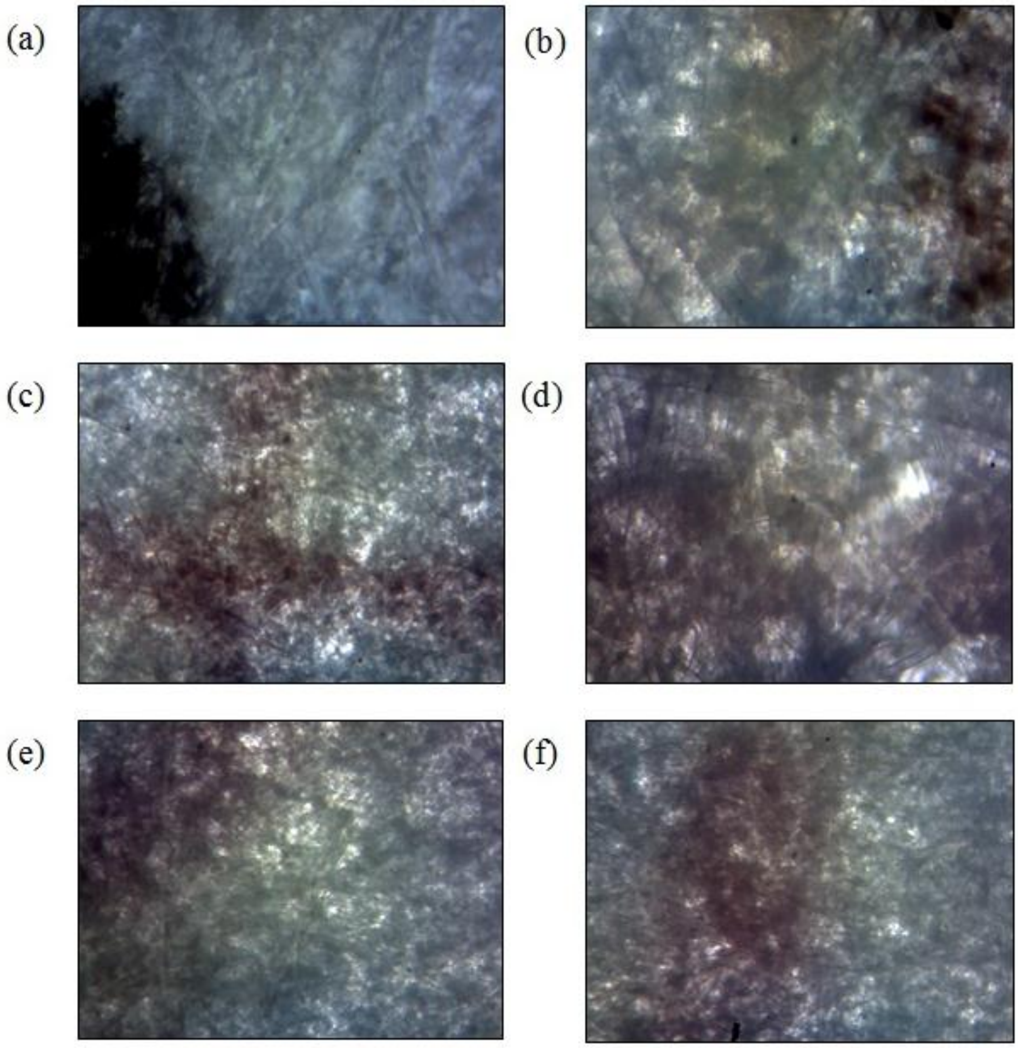

Figure 4.1: Photos of soaked paper sheets analyzed by microscope: (a) dried condition; (b) 1 min; (c) 1 day; (d) 2 days; (c) 3 days; (d) 4 days

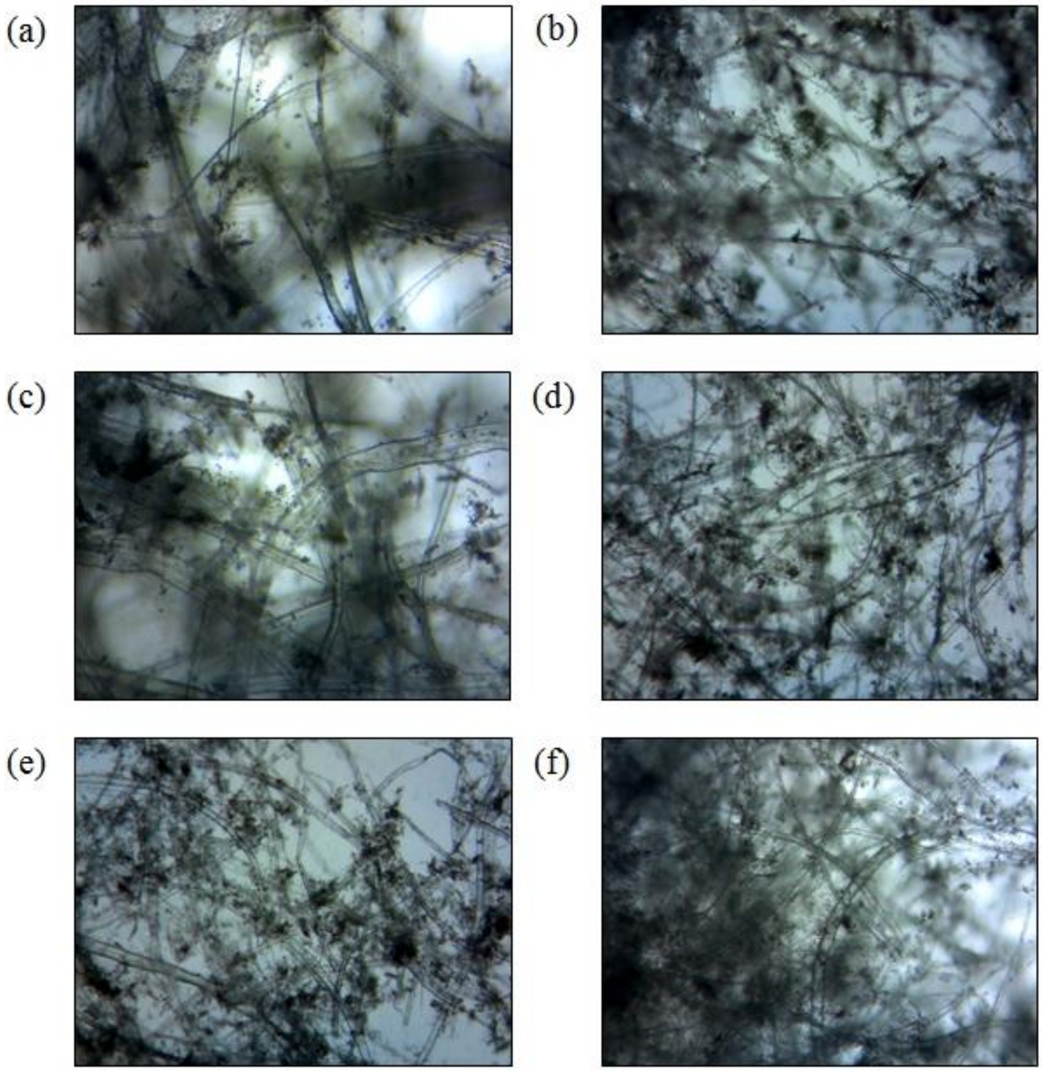

Figure 4.2: Photos of soaked pulp analyzed by microscope: (a) 1 min; (b) 1 day; (c) 2 days; (d) 3 days; (e) 4 days; (f) 5 days

4.2.2 Blending

Figure 4.3 shows the photos of blended pulp obtained by microscope, blended for 30 s, 1 min, 2 min, 3 min, 4 min and 5 min. As seen from the figure, the fibre of the pulp blended for less than two minutes did not show any properties difference. However, the fibres of the pulp showed obvious cross linkage to each other when they are blended for three minutes and above. This phenomenon verifies that delamination occurs and the interfibre bonded area of fibre increases with blending time.

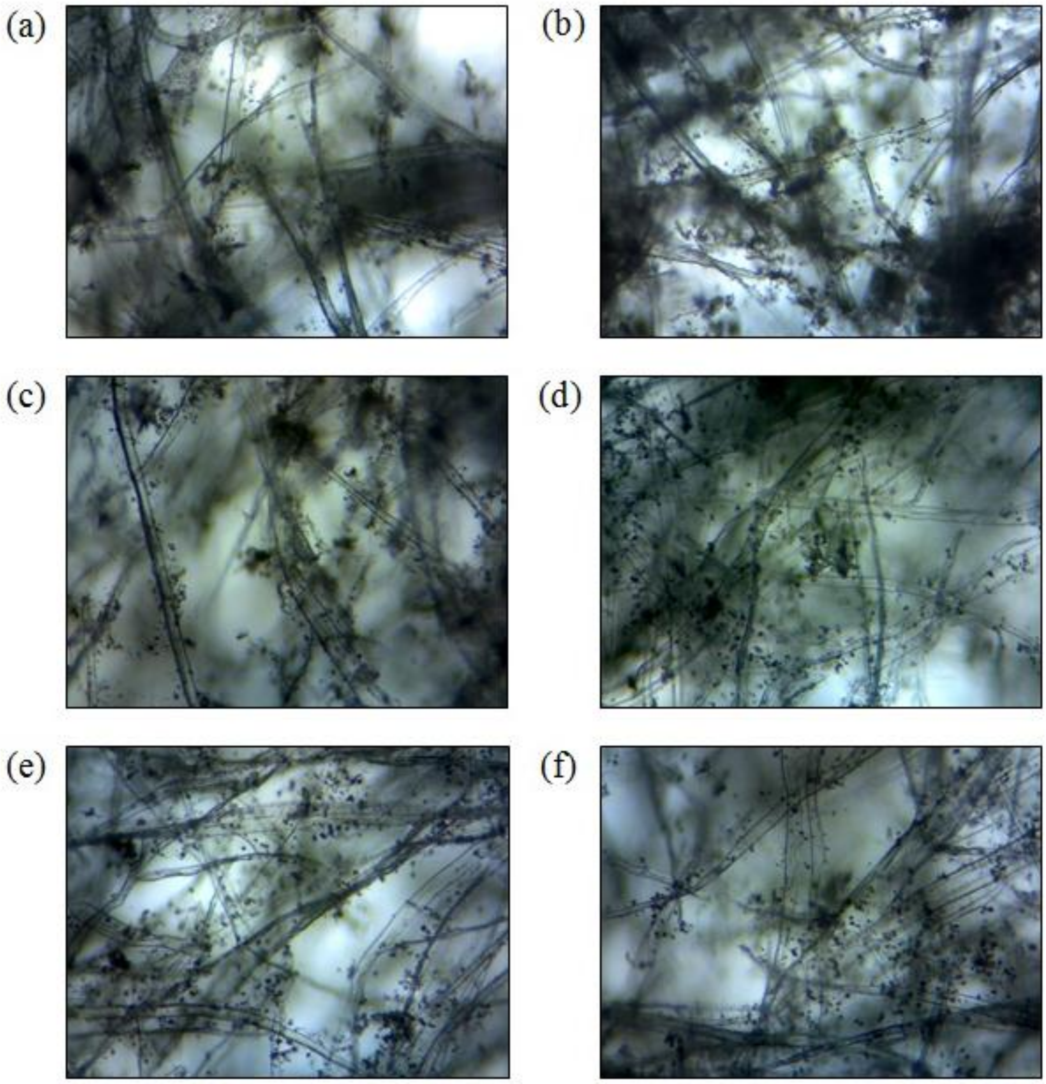

Figure 4.3: Photos of blended pulp analysed by microscope: (a) 30 s; (b) 1 min; (c) 2 min; (d) 3 min; (e) 4 min; (f) 5 min

4.2.3 Drying Method

Figure 4.4 shows the photos of recycled paper were dried at different conditions. Recycled paper were heated at 60 ˚C took a total of 30 min to dry thoroughly while 80 ˚C took a total of 25 min to dry thoroughly. From observation, the pulp sheets was started to dry from the edges towards the centre .The recycled paper dried at mild temperature, 60 ˚C showed burnt edges while the recycled paper dried at severe temperature, 80 ˚C was brownish, more brittle and rigid. A more deformed surface was obtained by paper dried at 80 ˚C can be clearly seen on the paper as shown in Figure 4.4.

In fan drying, both horizontal and vertical position drying methods took about 150 min to dry thoroughly. The recycled paper dried from the centre towards the edge for vertical position. For recycled paper that was dried horizontally, the paper dried from the side nearer to the fan towards another side. From observations, recycled papers were dried with fan showed less porous surface than heated recycled papers. Both drying methods with fan and oven took shorter duration compared to natural environment drying method which took more than 12 hours for the recycled papers to dry thoroughly. As seen from Figure 4.4, surface of recycled papers are more homogenous for drying with fan and natural way compared with oven drying.

Figure 4.5 shows microscopic view on surface of the recycled paper with scanning electronic microscope with different drying methods. The figures indicated that the paper heated at 60 ˚C and 80 ˚C formed more wrinkles on the surface, became rigid and brittle which due to the deformation of paper fibre during the high drying temperature in oven. Case hardening phenomenon caused the heated recycled paper formed more pores on paper surface compared to the recycled paper was dried with fan and in natural environment. The surface of recycled paper was dried with fan and in naturally seems to be more homogeneous.

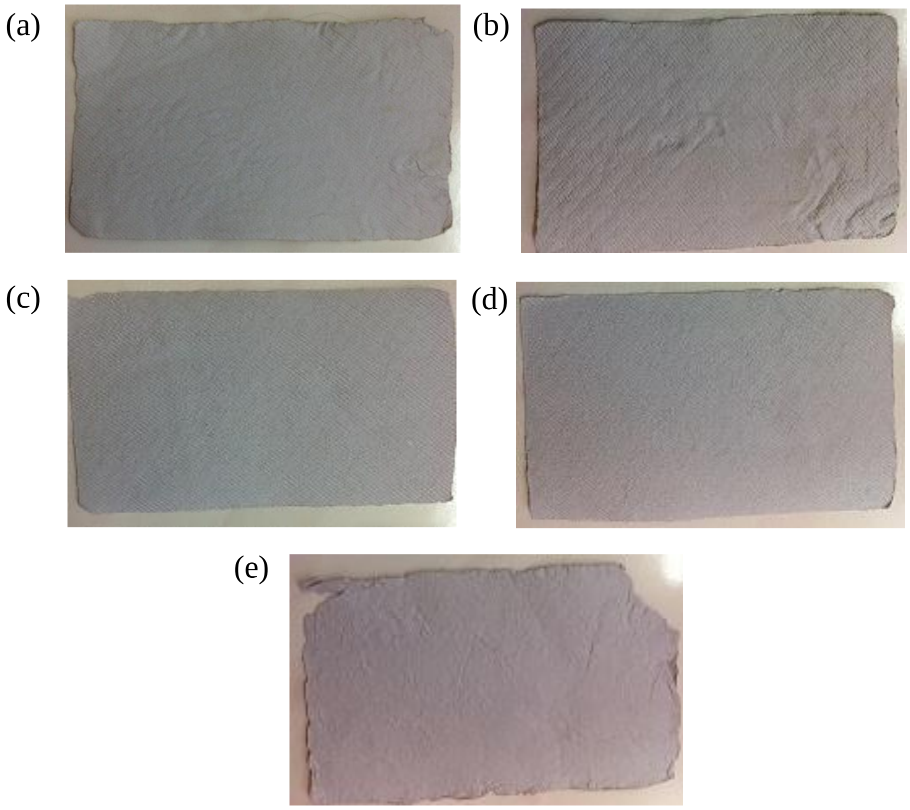

Figure 4.4: Photos of dried recycled paper: (a) heat at 60 ˚C; (b) heat at 80 ˚C; (c) fan at vertical position; (d) fan at horizontal position; (e) natural drying

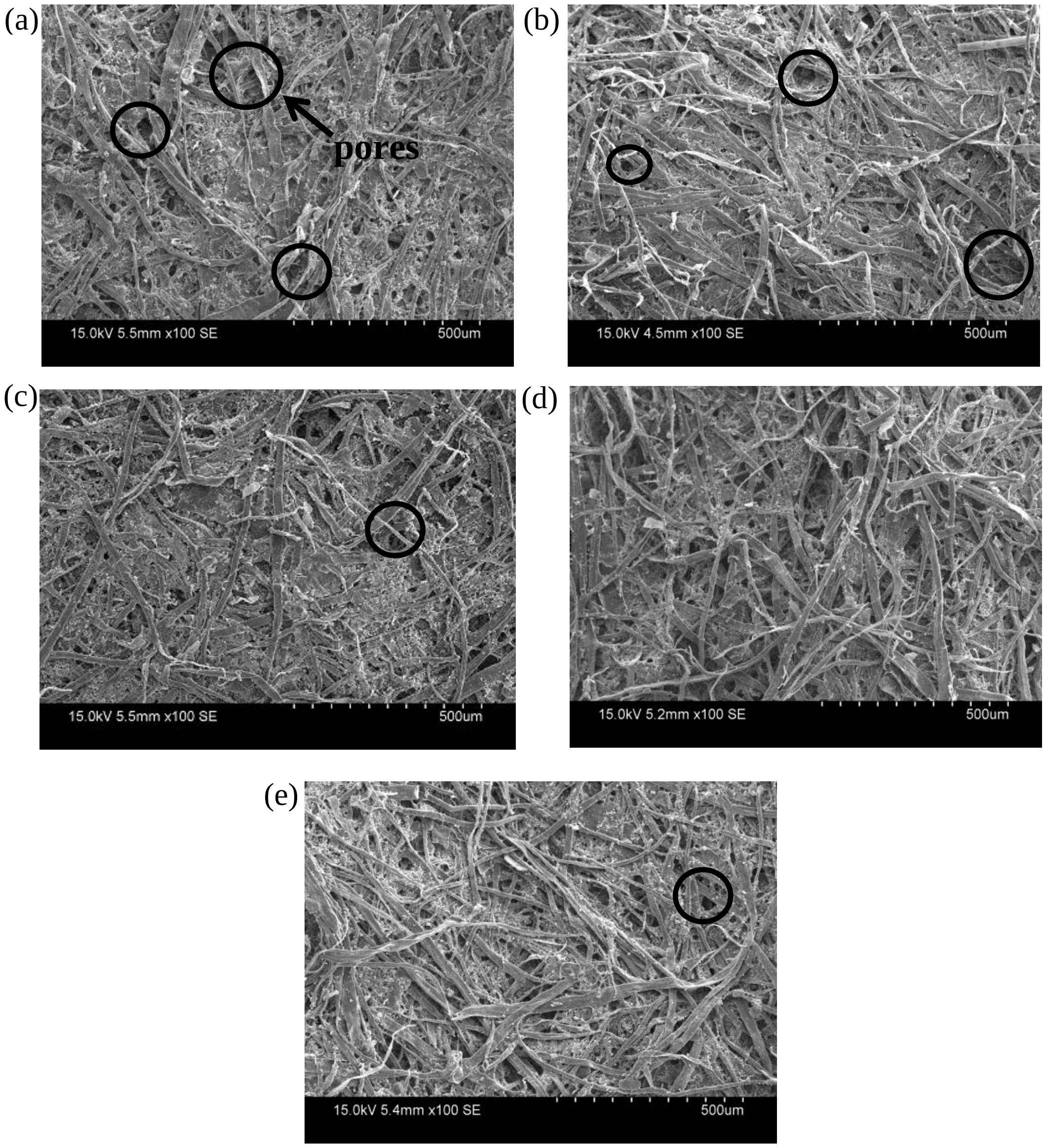

Figure 4.5: Photos of dried recycled paper analyzed by scanning electronic microscope: (a) heat at 60 ˚C; (b) heat at 80 ˚C; (c) fan at vertical position; (d) fan at horizontal position; (e) natural drying

4.3 Recycled Paper Samples

The recycled papers that produced from the compact paper recycling machine are analyzed using scanning electronic microscope. The position of fan on top of the pulp sheet is similar to dry in vertical position during preliminary test. Therefore, the microscopic view of the surface of the recycled papers produced by machine is compared with the recycled paper produced manually that dried vertically during preliminary test. Figure 4.6 shows some of the recycled paper produced from the machine and Figure 4.7 shows the microscopic view on surface of the recycled paper with scanning electronic microscope for paper produced manually and by compact paper recycling machine. Figure 4.7 indicates the surface of recycled papers produced from compact paper recycling machine are similar to the recycled papers produced manually during preliminary test. Both methods produce a homogenous and less porous surface recycled paper.

Figure 4.6: Recycled papers produced by compact paper recycling machine

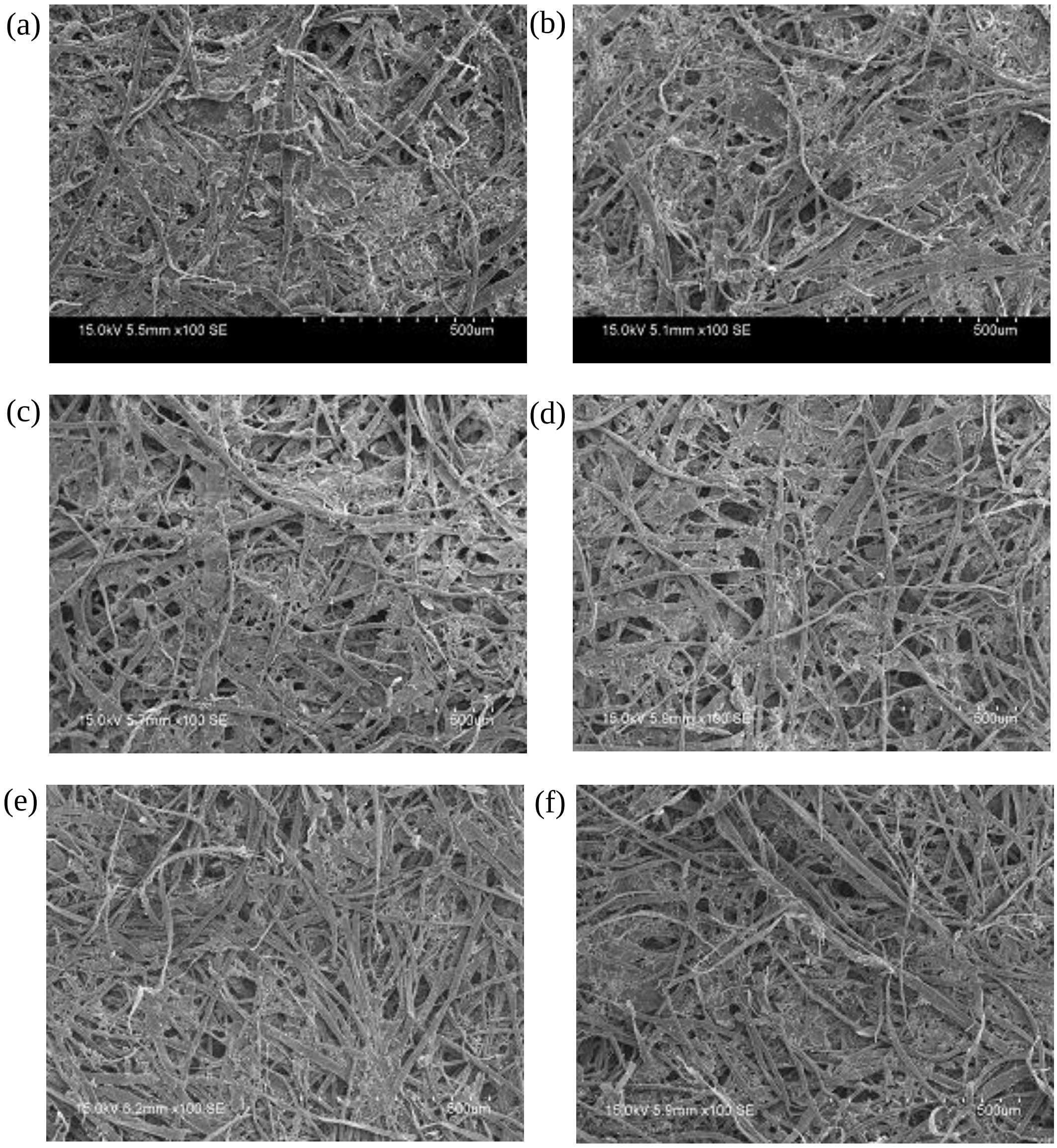

Figure 4.7: Photos of recycled paper analyzed by scanning electronic microscope: (a) recycled paper A (manually); (b) recycled paper B (manually); (c) recycled paper 1 (machine); (d) recycled paper 2 (machine); (e) recycled paper 3 (machine); (f) recycled paper 4 (machine)

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This report presents the outcome of the project from idea generation to prototype development of compact paper recycling machine. The aim of this project has been met as a prototype has been built. Besides that, the objectives listed out at the beginning of the project have been achieved too. The first objective is to make an automated machine to make paper recycling easy, quick and efficient. The paper recycling process of this machine is easy as the user is only required to put in papers and turned on the machine. The total duration time of the paper recycling process is approximately 305 min. The duration time is shorter compared to home-based paper recycling process which takes around one day to produce a recycled paper. The second objective is to investigate the optimum parameters used for soaking, blending and drying methods. The optimum parameters are 30 s soaking time, 1 min blending time and 300 min drying time with fan as drying method. Lastly, this compact paper recycling machine is helping in environment preservation as water used for paper recycling can be reused and waste paper is transformed into useful product.

5.2 Recommendations

There are some limitations in this compact paper recycling machine prototype. Further improvement should be made to increase the efficiency of the machine. In terms of blending mechanism, the water will remain in the blender jar after the paper recycling process as there is a gap between the inlet of the pump and the bottom of blender jar. The remaining water at the bottom of blender jar cannot be transferred out. It is suggested to locate the inlet of the magnetic drive pump at the bottom of the blender jar. Furthermore, the pulp sheet is recommended to be removed from the pulp moulding frame before drying process. Without the contact of pulp sheet with wet pulp moulding frame, the humidity level is lower hence shorten the drying duration.

REFERENCES

Ackerman, C., Göttsching, L. and Pakarinen, H., 2000. Papermaking potential of recycled fiber, In: Göttsching, L. & Pakarinen, H. (eds). *Recycled Fiber and Deiking*. Papermaking Science and Technology, Book 7. Fapet Oy: Helsinki, pp. 358- 438.

Alsaid, D., Alkhasawneh, H., and Cameron, J., 2009. Effect of High Temperature Drying of Recycled Paper on Heat Transfer Rates and Sheet Properties. *Tappi Journal*.

Cabalova, I., Kacik, F., Geffert, A., et al., 2011. The Effects of Paper Recycling and its Environmental Impact. *Environmental Management in Practice*, pp. 229-345.

European Declaration on Paper Recycling 2006 – 2010, Monitoring Report 2010. 2011. [Online]. Available at: http://www.paperforrecycling.eu/uploads/Modules/Publications/MonitoringReport2010_FIN_webcorrected.pdf [Accessed 19 August 2012].

Khantayanuwong, S., 2002. Effects of Beating and Recycling on Strength of Pulp Fibers and Paper. *Kasetsart J.* (Nat Sci) 36(2), pp. 193-199.

Scallan, A.M., 1978. The accommodation of water within pulp fibres. In Fiber-Water Interactions in Papermaking. Transactions of the 6th Fundamental Research Symp. Vol.1. London: William Clowes & Sons Limited, pp. 9-27.

Malaysian Newsprint Industries, 2007. *Secret of Recycling.*[Online]. Available at: http://www.newsprint.com.my/open.html [Accessed 30 August 2012].

Stenström, S., 2004. Product engineering by the paper drying. Drying 2004, In: M.A. Silva, S.C.S. Rocha (eds.), *Proceedings of the 14th International Drying Symposium (IDS 2004),* Vol (A), pp. 89–98.

Vieira, M. G. A., and Rocha, S. C. S., 2007. Drying Conditions influence on physical properties of recycled paper. *Chemical Engineering and Processing*, 46, pp. 955-963.

Wan, J. Q., Wang, Y., Ma, Y. W., et al., 2009. Influence of pressing and drying on the microstructure of recycled plant fibers. *Cellulose Chemistry and Technology*, 43(1-3), pp. 71-79.

Young, J.H., 1980. Fiber preparation and approach flow, In: P. James and Casey (eds.), *Pulp and Paper: Chemistry and Chemical Technology*. 3rd ed., 2, pp. 869–88.

APPENDICES

APPENDIX A: Gantt Chart