

Saimaa University of Applied Sciences  
Faculty of Technology, Imatra  
Degree Programme in Paper Technology

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**FACTORS AFFECTING MEASUREMENT OF RAW  
EDGE PENETRATION / EDGE-WICKING  
TENDENCY**

Thesis 2011

## **Abstract**

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The primary goal of this thesis was to investigate and identify the significant factors affecting the measurement of raw edge penetration / edge wicking into raw board. In addition to this, an effort was made to analyse the variance of results with respect to different board samples, temperature, barrier materials, different examiners and test-life of coffee samples.

This study was mainly executed at the laboratory of the Research Centre, Imatra (RCI). The work utilised water-bath as the main equipment and three board samples. The main tests were executed within the framework of Taguchi model for quality engineering which optimises the combinations, between the test parameters and their measurement levels, which guarantee reliable results.

It was however inferred that sample area, covering, direction of cutting, liquid temperature, liquid age and test duration were the most significant contributors to edge wicking. Cutter efficiency, PE-coating of base board, difficulty of result reproducibility and long test-life (in hours) of coffee samples were additional findings. Based on the findings, it is therefore recommended that the optimal concentration and peak activity (with respect to age) of light-roasted coffee as well as different covering materials on 2PE base board sample be further analysed.

Keywords: Raw Edge Penetration, Edge Wicking, Quality Engineering, Taguchi Matrix

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## Terminology

REP	Raw Edge Penetration
EWT	Edge Wicking Tendency
PE	Polyethylene extrusion
1PE	One side polyethylene extrusion coated
2PE	Both sides polyethylene extrusion coated
AKD	Alkyl ketene dimer
ASA	Alkenyl succinic anhydride
SBS	Solid bleached sulphate board
Operator 1	Author

# LITERATURE PART

## 1 Introduction

This thesis work mainly set out to investigate and identify, among sample area; curing of sample; covering; direction of cutting; liquid sample; liquid temperature; liquid age; direction of sample and test duration, the most significant elements contributing to edge-wicking in raw board sample in a laboratory atmosphere (23<sup>0</sup>C, 50% RH). In furtherance of seeking better understanding of the wicking defect, comparative analysis of the results with respect to different board sample, temperature, barrier material, examiner and test-life of the coffee sample became imperative.

The need for this task is informed by the deterioration of coffee cups among others, especially during end use. This deterioration specifically refers to the penetration of coffee into the base-board through the raw edge which, unlike the board surface, is unprotected by any barrier material. Being a popular commodity in the consumer market, producers of cup stocks are challenged to continuously improve the quality of their products to the satisfaction of their customers.

This experiment based problem was treated using a statistical experiment plan developed for quality engineering and popularly referred to as the Taguchi Method. The method presents an orthogonal array (matrix) which significantly reduces the required number of tests that guarantees reliable result.

This work is presented in two parts: literature and experimental parts. The literature part provides an overview of the cup stock production process. It also discusses the theory of liquid penetration as well as the concept of edge wicking. The experimental part on the other hand introduces the methodology behind the work and evaluates the results which establish the premises for making conclusions and recommendations for further studies.

## 2 Overview of Paperboard (Cup Stock) Production Process

The basic production technology for paper and paperboard is the same except that paperboard is multi-ply and produces such properties like stiffness, bulk, etc in addition to the printing surface that paper offers (1).

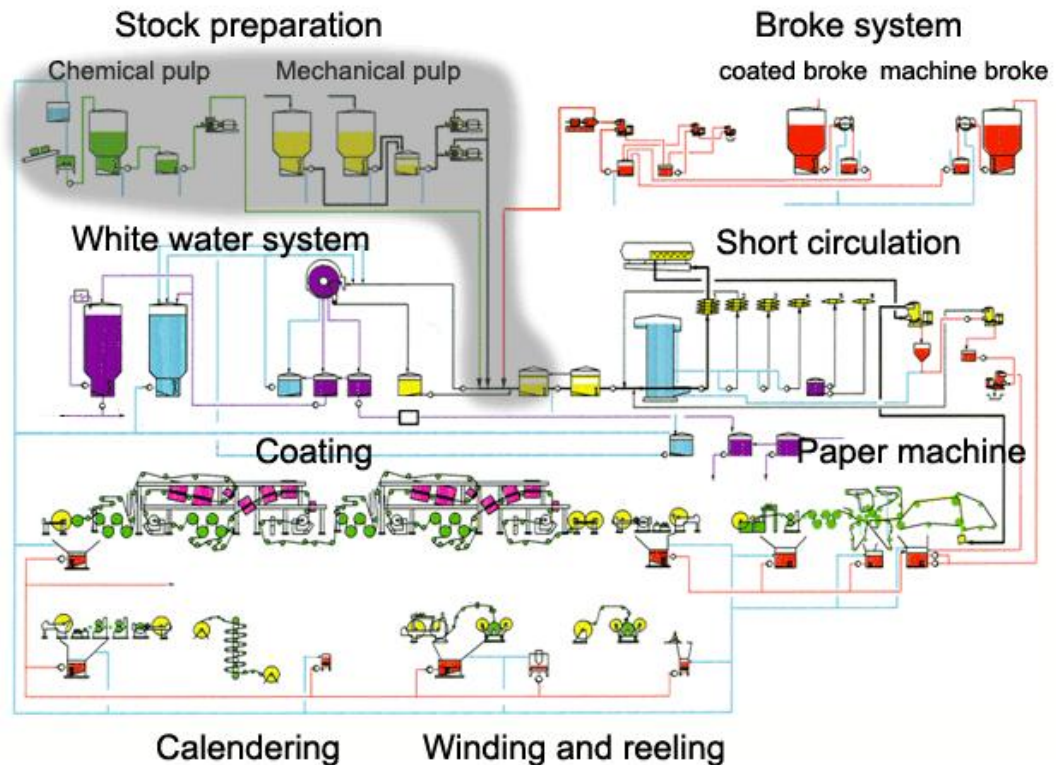


Figure 1. Schematic illustration of a paper(board) production line (2).

Paperboard production can be viewed in context with emphasis on solid bleached sulphate (SBS) board. SBS is a paperboard type made entirely from bleached chemical pulp and coated on either one or both sides by mineral or synthetic pigments (1).

Barrier coating under this circumstance refers to the use of polymers as extremely thin layers on the base board thereby giving it excellent product protection properties as well as substantial economical and biological benefits. (1).

Hot liquid dispensing cups, for example coffee cups, are made from paperboard which has been produced with chemistry that gives a relatively high liquid repellence. The board in this circumstance is usually PE-coated on one side so as to improve the board surface resistance to liquid take-up.

A somewhat general process of producing these cups is illustrated in figure 2 below.

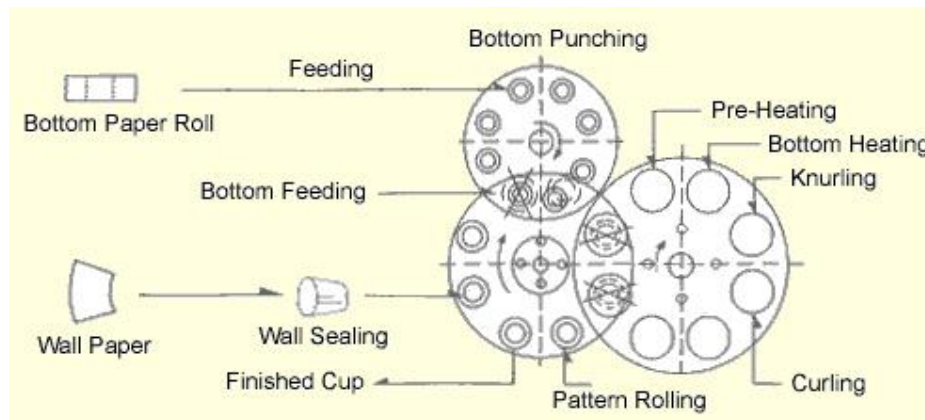


Figure 2. Schematic representation of paper cups making process (3; 4).

The cup wall paper having been die-cut is transmitted to the mould where it is shaped into conical structure. The wall is sealed in this mould before it advances for bottom inclusion.

The bottom paper roll is conveyed to the bottom-punching section where the cup bottom is cut out and advanced for combination with the shaped wall in the bottom feeding section.

There is pre-heating of the components parts and specific bottom heating operations preceding the cup bottom knurling to the cup cone body. The cup top is then curled into circular shape and the finished cup is subjected to various post production handling measures. (3; 4).



### **3 Theory of Liquid Penetration**

The concept of liquid penetration may be streamlined and appreciated from the perspective of the liquid, the porous material and the environment as the major contributing factors.

The imbibitions of water and other liquids in a fibre web is a dynamic and transient phenomenon characterized by non-uniform distribution of fluid, which varies with time, in the spatial dimensions of the fibre web. (5, p. 76)

Four notable mechanisms of water transport in paper considered are (6; 7; 8; 9)

- Capillary transport of liquid in the pores
- Water transport through the fibres
- Surface diffusion in the pores
- Diffusion transport of vapour in the pores

Every paper product is by virtue of its end use expected to serve out some degree of permeability (10, p. 285). Various paper grades therefore demonstrate exclusive features in this capacity as shown in table 1.

Table 1. Permeability of different paper grades (10, p. 28)

Paper grade	Basis weight (g/m <sup>2</sup> )	Permeability (cm <sup>3</sup> /min)
Tea bag tissue	18	22 000
Foam laid paper	30	19 100
Oil filter	139	18 500
Toilet tissue	17	12 700
Vacuum dust bag	42	11 150
Crepe filter	85	5 100
Electric filter	127	4 800
Blotting paper	130	4 600
Impregnating paper	205	1 060
Cigarette tissue	25	930
Bond paper	76	350
Newsprint	53	290
Copy paper	80	210
Writing paper	88	175
Wrapping tissue	12	130
Cardboard	247	20
Glassine, base paper	41	2.1
Glassine	36	1.2
Art printing paper	115	1.0
Tracing paper	111	0.3

Depending on the hydrophobicity of paper, the irregular and unevenly distributed pores, a water-based solution is either drawn into the paper network by capillary action or restricted from penetrating.

On the assumption that paper is made up of cylindrical capillaries of constant average radius,  $r$ ; its net resistance to penetration (capillary pressure),  $\Delta p$  is given by the Laplace equation as (11, p. 3)

$$\Delta p = \frac{2\gamma \cos \theta}{r} \quad (1)$$

where  $\gamma$  is the fluid surface tension.

The Hagen-Poiseuille law of laminar flow, applicable to ideal cylindrical structure, holds that the flow rate,  $q$ , is proportional to the pressure drop gradient,  $\Delta p$ , along the cylinder (11, p. 3)

$$q = \frac{dL}{dt} = \frac{r^2}{8\eta} \cdot \frac{\Delta p}{L} \quad (2)$$

where  $\eta$  is the fluid viscosity and  $L$  is the wetted length of the cylinder.

A combination of equations (1) and (2) yields the Lucas-Washburn equation applicable in horizontal geometry with no influence of gravity and given as (11, p. 4)

$$L = \sqrt{\frac{r\gamma \cos\theta}{2\eta}} \sqrt{t} \quad (3)$$

However, the deviations between the actual water penetration in paper and that predicted by the Lucas-Washburn equation have been suggested to be as a result of the following (8, p. 1):

- Air counter pressure
- Liquid transport through the vapour phase
- External pressure
- Expansion, swelling of the fibre network
- Dynamic nature of the capillary pressure

Another means of describing the flow in porous media from the perspective of a linear, slow and steady-state system is given by Darcy's law as (9, p. 4)

$$q = -K \frac{\Delta P}{L_0} = -\frac{k}{\eta} \cdot \frac{\Delta p}{L_0} \quad (4)$$

where  $L_0$  is the length of the sample,  $K$  is the flow conductivity of the medium and  $k$  is the permeability of the medium and inclusive of such structural and geometrical properties as porosity, tortuosity and specific surface area.

The Kozeny-Carman equation in turn defines permeability,  $k$ , as a function of the Kozeny constant,  $k_0$  which encompasses both shape and tortuosity factors as (11, p. 4):

$$k = \frac{\phi^3}{k_0 S_0^2 (1-\phi)^2} \propto \frac{\phi^3}{(1-\phi)^2} \quad (5)$$

where  $S_0$  is the surface area of the channels per unit volume of the solid material and  $\phi$  is the porosity defined as a ratio of pore volume to total sheet volume.

### 3.1 Wetting

The practical distinction between a surface wetted by water and another not wetted is that the former allows spontaneous spread in a continuous film while with the latter, small, separate droplets which form a contact angle at the air-water-solid interface is witnessed. The formation of this contact angle is defined in an approximate form by Young's as a function of the interfacial (surface) tension,  $\gamma$ , between the solid and liquid as (9, p. 152):

$$\cos\theta = \frac{\gamma_s - \gamma_{sl}}{\gamma_l} \quad (6)$$

where  $s$ ,  $l$  and  $sl$  are solid, liquid and solid-liquid interfaces subscripts.

Wetting of paper expands the paper structure, in turn affecting the forced edgewise liquid absorption, and paper made from different pulps expand to different degrees (12, p. 345).

On a macroscopic level, the static contact angle,  $\theta$ , measured at equilibrium conditions is a common characteristic of wetting. Figure 3 below shows the effect on increasing contact angle (decreasing surface energy) on wettability.

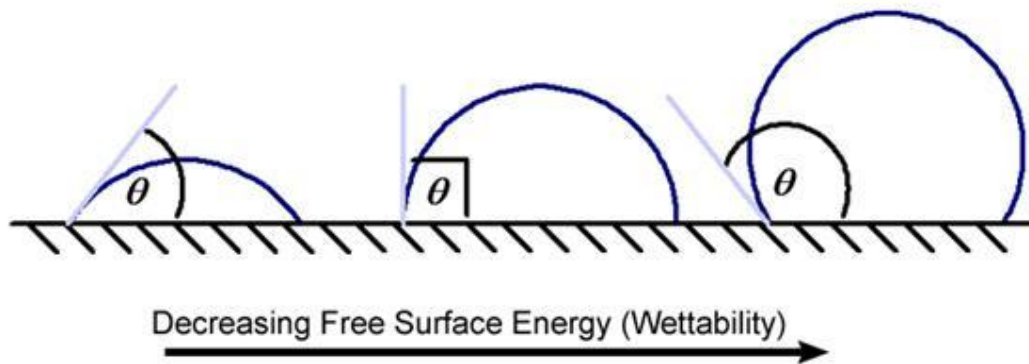


Figure 3. Effect of fibre surface energy on wetting (2). A decreasing free surface energy (increasing contact angle,  $\theta$ ) signals a reduction in wetting tendency.

Chemically, wetting is an adhesion phenomenon between a liquid and a solid surface and is capable of proceeding spontaneously on the strength of surface tension, even if the contact angle,  $\theta$ , is greater than  $90^\circ$  and external pressure is zero, provided there are converging capillaries in the paper. (10, pp.295-296).

### 3.2 Sizing

Sizing is the process wherein chemical additives are introduced to provide paper or paperboard with higher liquid-repellence. This is achieved as either internal sizing or surface sizing depending on whether the chemistry is influenced in the wet or dry end respectively.

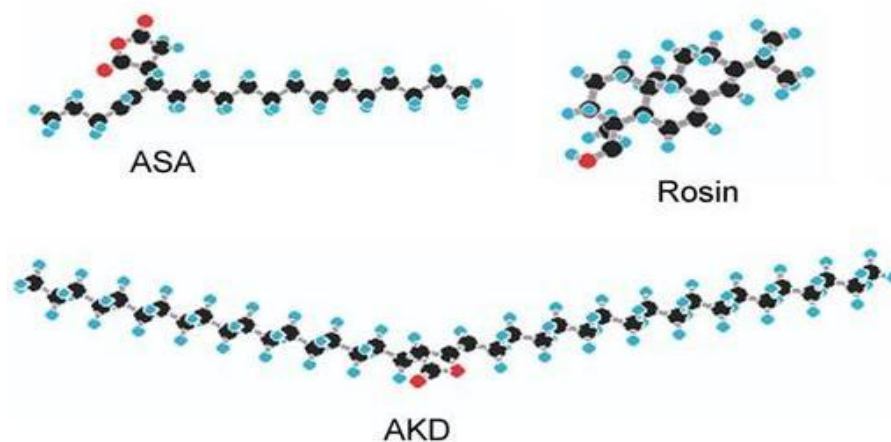


Figure 4. Structure of hydrophobic sizes (2).

The three most common internal sizing agents (figure 4) currently in use are rosin systems (in acidic conditions), alkyl ketene dimers (AKD) and alkenyl succinic anhydride (ASA) (both in the new trend of neutral sizing and indeed of growing relevance and acceptance). Table 2 below compares neutral sizing to rosin sizing techniques.

Table 2. Comparison of neutral sizing to rosin sizing (2)

Advantages	Disadvantages
- cleaner water system (no alum)	- potential for slipping problems
- better strength properties	- increase of bacterial growth
- higher filler content, CaCO <sub>3</sub>	- slower curing with AKD
- better archiving permanence	- more difficult to control sizing
- less corrosion	- durability against hot liquids
- good protection against lactic acid	- poor finish on machines

Sizing aims to reduce the pore size (radius) and also lower the free surface energy of the paper. This activity is necessitated by the following reasons (9, p. 151):

- Control of aqueous phase penetration in converting operations
- Control of liquid absorption or wetting in a printing process
- Control of the serviceability of many grades of paper and board

Internal sizing although hinders liquid penetration into the bulk of the paper structure, it does not prevent vapour penetration (4, pp. 19-21). For a sized paper however, this absorption of water vapour could not initiate much sheet expansion unless the flow resistance of the paper is subdued by liquid pressure (11, p.1).

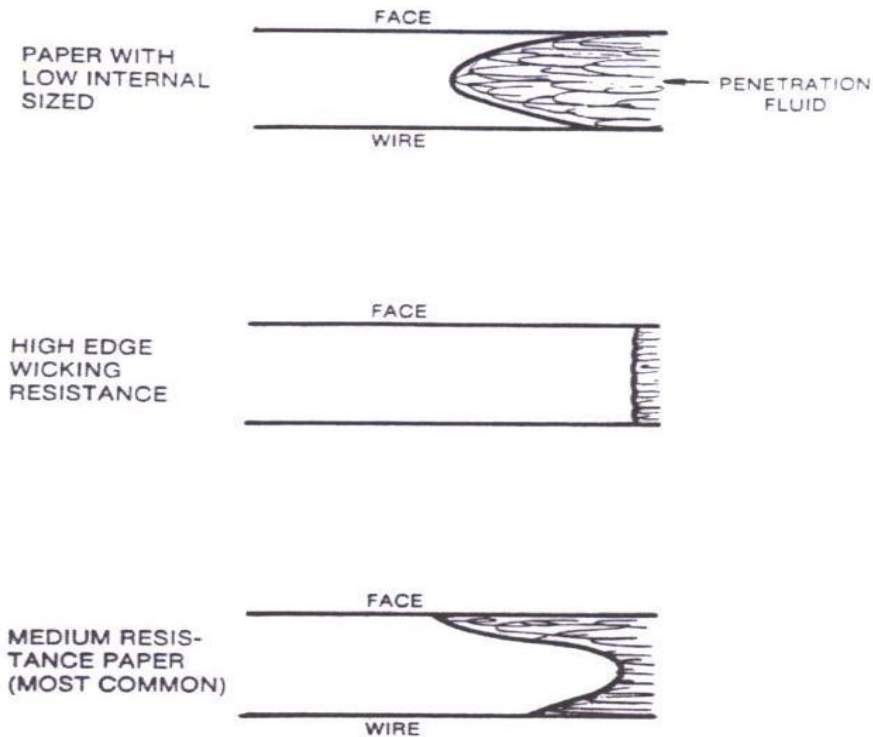


Figure 5. Illustration of the different sizing effect on penetrating fluid (8, p. 10)

The hydrophobicity of paper is a key parameter governing the absorption of water-based solutions into paper. Paper could therefore be said to be hydrophobic or well sized when the contact angle,  $\theta$ , between the paper and the liquid exceeds  $90^\circ$  while a contact angle of less than  $90^\circ$  characterizes a more hydrophilic, un-sized or soft-sized paper. (11, p. 3)

### 3.3 Classification of Test Methods

The various test methods can, on the basis of their nature, be roughly grouped as follows:

- Penetration of (aqueous) liquid in sample z-direction assessment methods
- Absorption of test liquid assessment methods
- Measurement of surface property as hydrophobicity parameter techniques

The selection of a suitable test method is in practice guided by the available information on the degree of sizing required. (9, p. 160).

### **3.3.1 Sample Penetrated by the Test Liquid**

This deals with methods involving penetration from top to bottom, namely:

- The Carrier test, KBB test and NBS method . all based upon measuring conductivity to detect the penetration of water
- The Hercules Size Test (HST) which involves optical recording of the penetration of a coloured test liquid

On the other hand, there are methods based upon the movement of liquid from the bottom of the sample toward the top and these include: (9, p. 160-162)

- Fluorescent Dye Size Test
- Dry Indicator Test
- Ink Flotation Test
- Ferric thiocyanate Test
- Lactic Acid (Penescope) Test

### **3.3.2 Measurement of Liquid Absorption**

In this category where test liquid absorption is assessed are: (9, p. 162-163)

- Cobb Test
- Total Immersion Test; and
- Edge-wick (Klemm Capillary Rise) Test

### **3.3.3 Surface Tests Related to Sizing**

Test methods which measure surface property as an index for hydrophobicity include: (9, p. 163-164)

- Contact angle
- Drop test
- Curl test



## **4 Edge Wicking / Raw Edge Penetration**

Edge wicking, or edge penetration, refers to the in-plane wetting of a paper structure. This is generally observed on the exposed edge of extrusion coated or other barrier layered products. (7, p. 7).

In context, edge wicking is of major interest because as a defect during the end-use of the product, it might result in cosmetic discrepancy or undesired opening at the sealing points (13, p. 1).

Edge wicking is of a very different nature from other water sorption tests with at least five characteristic weak points, namely (6, p. 20):

- The unsized fibre lumens
- The unsized cut edges of the fibres
- Unsized fibre-fibre bonds
- Cutting defects, resulting in delaminating and exposure of unsized regions
- Weak bonding between layers

### **4.1 Factors Affecting Edge Wicking**

The numerous factors affecting edge wicking can be largely attributed to the porous medium itself, the aqueous medium or the environment. Some of these factors, however, sometimes have a combined effect from the afore-mentioned.

#### **4.1.1 The Porous Medium**

From the perspective of the porous medium, the significant parameters include:

- The process chemistry of the paper(board) web including the degree of sizing
- Temperature
- Moisture content
- The adhesion potential with the barrier material

### 4.1.2 The Aqueous Medium

The test liquid brings forth a number of factors whose influence on edge wicking cannot be over-emphasized. Unlike pure water which would be an ideal liquid, in practice, most test liquids demonstrate unique properties as a result of their chemical composition. Notable amongst the influencing parameters of the test liquids are:

- Temperature, due to its effect on such properties like surface tension and viscosity
- Liquid Age
- Test Duration

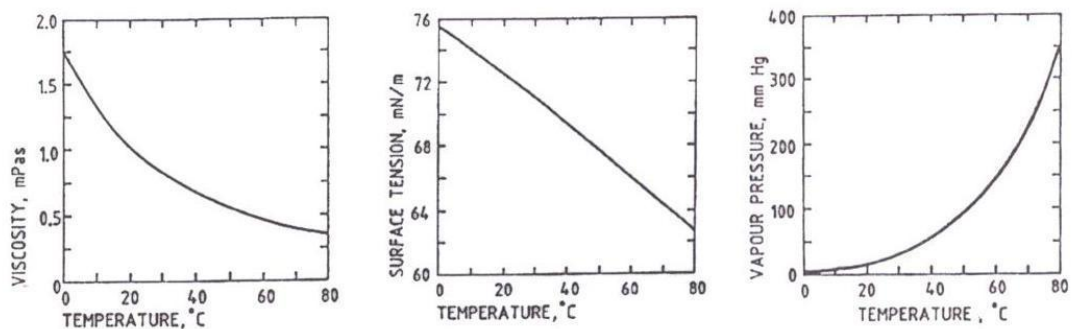


Figure 6. Effect of temperature of viscosity, surface tension and vapour pressure (8, p. 18).

### 4.1.3 The Environment

Other contributors to edge wicking measurement other than those directly linked to the porous and liquid media, including some auxiliary parameters, can be classified as external factors. This list includes among others

- Pressure
- Humidity
- Barrier material
- Cutting efficiency

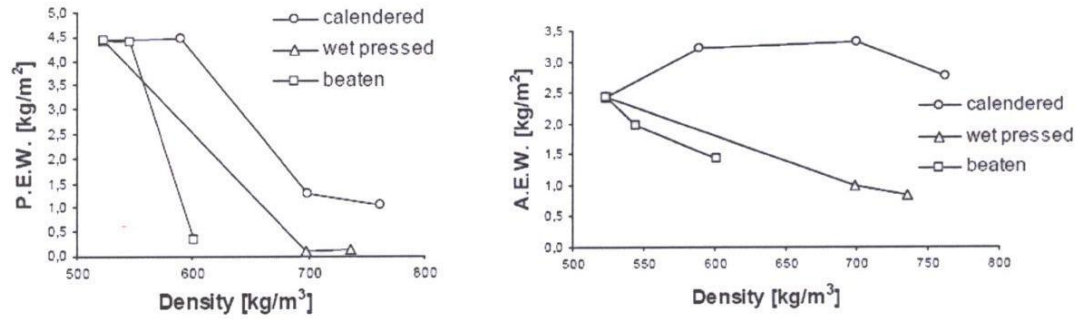


Figure 7. A comparison of pressurized and atmospheric edge wicking from the perspective of calendering, wet pressing and beating in the same material (13, p. 18).

#### 4.2 Measurement

Edge wicking measurement techniques can be broadly viewed as either undertaken in atmospheric or pressurized conditions.

In context, the edge wick result expressed as edge wick index, EW ( $\text{kg/m}^2$ ), is calculated according to the formula (12, p.4)

$$EW = \frac{W_2 - W_1}{t \cdot l} \quad (7)$$

where  $W_1$  and  $W_2$  are the weights (g) of the test piece before and after exposure,  $t$  is the thickness (mm) of the sample and  $l$  is the perimeter (m) of the exposed sample edge.

## **EXPERIMENTAL PART**

### **5 Objective of the Experimental Part**

The primary goal of this experimental task was to investigate and identify the significant factors affecting the measurement of raw edge penetration / edge wicking into raw board. The magnitude of each factor which constituted the test parameters was to be identified under the test conditions as a means of separating the important elements from the otherwise insignificant ones.

On a periphery, the work also sought to sketchily compare the edge wicking indices of

- different boards samples under the same general test conditions,
- one board sample as a function of temperature,
- one board sample as a function of barrier medium,
- the same board sample as examined by different individuals under the same general test conditions, and
- serial tests from one board sample in attempt to determine the feasible strength / test-life of coffee sample.

## 6 Materials and Method

The experimental methodology adopted in this work is presented in this section. It provides information on the materials used, as well as the test procedures.

### 6.1 Materials

The major items on the list of materials included

- the testing equipment (water bath),
- coffee samples (light-roasted and cream coffee),
- normal and new tapes, hot and cold lamination films, and
- three board samples namely board samples 1, 2 and 3.



Figure 8. Experiment set-up in the RCI laboratory

### 6.2 Method

The experimental work was executed within the framework of Taguchi model for quality engineering. This framework proposes suitable matrices for solving experiment-based problems within the limits of the contributory factors being investigated and their corresponding measuring levels (Table 3a) thereby significantly reducing the number of tests required to yield reliable results.

Table 3a. Definition of the measuring levels for each investigated factor

Variable	Level	Interpretation
Sample Area	1	25 mm X 75 mm
	2	80 mm X 38 mm
	3	40 mm X 40 mm
Curing of Sample	1	23 degrees celsius, 50% RH
	2	38 degrees celsius, 85% RH
	3	6°C, 62% RH -> 38°C, 85% RH -> 23°C, 50% RH (24hrs each)
Covering	1	Tape
	2	Hot lamination
	3	Cold lamination
Direction of Cutting	1	90 degrees (md)
	2	90 degrees (cd)
	3	45 degrees
Liquid Sample	1	Light-roasted coffee 1 (49g/l)
	2	Cream coffee
	3	Light-roasted coffee 2 (60g/l)
Liquid Temp.	1	84 degrees celsius
	2	80 degrees celsius
	3	93 degrees celsius
Liquid Age	1	Immediately
	2	4 hours
	3	8 hours
Direction of Sample	1	Horizontal (normal)
	2	Vertical (total immersion)
	3	Vertical (partial immersion)
Test Duration	1	10 mins
	2	20 mins
	3	30 mins

Table 3b. An outline of the L-27 matrix corresponding to the test conditions

ID	Sample Area	Curing of Sample	Covering	Direction of Cutting	SA X DoC	Liquid Sample	Liquid Temp.	Liquid Age	Direction of Sample	DoC X LS	Test Duration	SA X TD	LS X LT
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

The tests were carried out under atmospheric condition. The utilisation of table 3b above would be better understood by randomly defining one item from the 27 tests IDs on table 3a. Taking as an example ID-27, the test sequence went as follows:

- Firstly, a larger board sample was cut at 90<sup>0</sup> angle to the machine direction (Direction of Cutting . Level 1).
- The board sample was then kept for 24 hours in each of the different conditions of cold storage (6<sup>0</sup>C, 62% RH), tropical climate (38<sup>0</sup>C, 85% RH) and laboratory atmosphere (23<sup>0</sup>C, 50% RH) (Curing of Sample . Level 3) after which its thickness was measured.
- The board was then covered by hot lamination (Covering. Level 2).
- This board sample was at this point cut to strip size 40 mm X 40 mm (Sample Area . 3) and weighed as dry mass. In doing the cutting, the cutter was properly cleaned so as to minimise cutting defects in the test strip.
- The test strip was then immersed horizontally (Direction of Sample . Level 1) in about four-hour old (Liquid Age . Level 2) cream coffee sample (Liquid Sample . Level 2) that had been stabilised at 84<sup>0</sup>C (Liquid Temperature . Level 1) and the test was allowed to proceed for 10mins (Test Duration . Level 1).
- As promptly as the test duration lapsed, the strips were collected from the liquid sample and gently mopped-off of the excess coffee sample before weighing with each mass recorded as the corresponding wet mass of the strip.

Two parallel measurements were made for each set of four strip collections and the corresponding EWT index was calculated according to equation (7).

The details of this procedure applied to the fundamental aspect of this thesis work and specifically with board sample 1 only. The secondary tasks however as enumerated in section 5.1 were executed, with respect to table 3, at Level 1 for all factors with the exception of Sample Area in which only Level 2 was used and also Liquid Sample and Liquid Temperature where Levels 1 and 2 were utilised.

## 7 Results and Discussion

The results of the experiments were considered separately for the primary task as scheduled by the L-27 matrix and variation analysis.

### 7.1 Analysis of Investigated Factors

The parameters that were directly examined in this work are discussed independently of each other in this section. This was intended to allow exhaustive and careful analysis of their various roles.

Table 4. Extract of the test results representing ID-19 (Appendix 1)

Sample	Thickness	Wet Mass	Dry Mass	REP	REP	mean REP
	mm	g	g	g/m	kg/m <sup>2</sup>	kg/m <sup>2</sup>
19-1-1	0.360	0.720	0.662	0.604	1.678	
19-2-1	0.359	0.704	0.659	0.469	1.306	
19-3-1	0.357	0.708	0.659	0.510	1.430	
19-4-1	0.358	0.700	0.659	0.427	1.193	
R1						1.402
19-1-2	0.360	0.712	0.670	0.437	1.215	
19-2-2	0.366	0.716	0.673	0.448	1.224	
19-3-2	0.362	0.711	0.673	0.396	1.093	
19-4-2	0.363	0.719	0.673	0.479	1.320	
R2						1.213

The EWT indices in all cases were calculated according to the example of 19-1-1 as follows:

$$EW = \frac{(0.720 - 0.662) \cdot 10^{-3} \text{ kg}}{0.36 \cdot 10^{-3} \text{ m} \cdot 96 \cdot 10^{-3} \text{ m}} = 1.678 \text{ kg/m}^2 \quad (8)$$

#### 7.1.1 Sample Area

The tests showed that the 80mm X 38mm test strips produced the highest EWT index but it remains the most practical in spite of the result. The chemistry that produces the sample board material is a major factor since the raw edge of the board cannot be improved under the test conditions.



### **7.1.2 Curing of Sample**

Although Level 2 (38<sup>0</sup>C, 85%) gave the highest wicking index, all three measurement levels of this factor appeared in a close range which suggested that it did not significantly affect the measurement of edge-wicking as set out by this work.

### **7.1.3 Covering**

Making a good choice of barrier material for the base board was observed to be a very important tool in curbing edge-wicking into the board. These tests revealed that cold lamination was an outright failure as the laminating film practically detaches from the board thereby allowing endless absorption of the coffee sample. In effect, the results suggested that good binding of the covering material to the base board was key in achieving lesser wicking.

### **7.1.4 Direction of Cutting**

The alignment of the length of the test strip on the machine direction appeared favoured by these tests as poor results were seen in the reverse case. This could be traced to the fact that the dominance of long fibres within the base board is in the machine direction and when cut perpendicularly in that direction, it exposed those long fibres more readily thereby causing wicking (figure 9).

### **7.1.5 Liquid Sample**

Despite the concentration edge of light-roasted coffee 2 over light-roasted coffee 1, it yielded the lowest EWT index while the latter gave the worst result, though in close range. This arouses the curiosity about the potency of the coffee components at a yet-to-be identified concentration between these margins.

### **7.1.6 Liquid Temperature**

It was realised that the EWT index was generally increasing with temperature. Greater wicking was established with increased temperature and this was in agreement with literature which holds that important liquid characteristics such as viscosity and surface tension reduce with increasing temperature thereby aiding higher wicking.

### **7.1.7 Liquid Age**

An assessment of the effect of coffee sample age on the EWT indices obtained showed that the lowest result was obtained with as fresh coffee as possible and an increasing trend continued towards four hours after which a decline was recorded towards eight hours. This brings on the question of the peak activity (with respect to age) of the coffee samples, too.

### **7.1.8 Direction of Sample**

The orientation of the test strips into the coffee samples clearly showed insignificance since the wicking encountered had to do with the perimeter of the exposed edges and this is independent of immersion method in total immersion cases.

### **7.1.9 Test Duration**

Test duration like liquid temperature produced an increasing EWT index over time. A direct correlation was established between the wicking result and the test time. It demonstrated a tangible effect on the result as would be anticipated by mere reasoning.

### **7.1.10 Auxiliary Factors**

This class refers to other perceived contributing factors apart from those that were directly examined. For instance, the cutting efficiency was found to be highly relevant to the end result as demonstrated in figure 9 below.



Figure 9. Effect of cutting efficiency on edge-wicking. Test strips from sharp and clean cutter (top) clearly showed less wicking compared to strips obtained from blunt cutter (bottom).

The case illustrated above (figure 9) arose as a result of initial measurement defect for ID-17 (table 2). This particular test was repeated four times solely because of cutting defect which was not realised immediately.

It was also observed that hydraulic head played a significant role in the measurement of EWT index for a set of four strips. A pattern of increasing edge-wicking was observed with the heights of the strips since they were immersed above each other in the liquid sample.

## **7.2 Analysis of Variations**

The various tests made in an attempt to analyse the EWT index variations under different parameters are evaluated in this section.

### **7.2.1 Comparison of EWT Indices of Different Board Samples**

The test compared the EWT indices for board sample 1, board sample 2 and board sample 3 (with 1 and 2-sided tape covering). All tests were made at 84<sup>0</sup>C and normal tape covering for both black (light-roasted) and cream coffee samples were used.

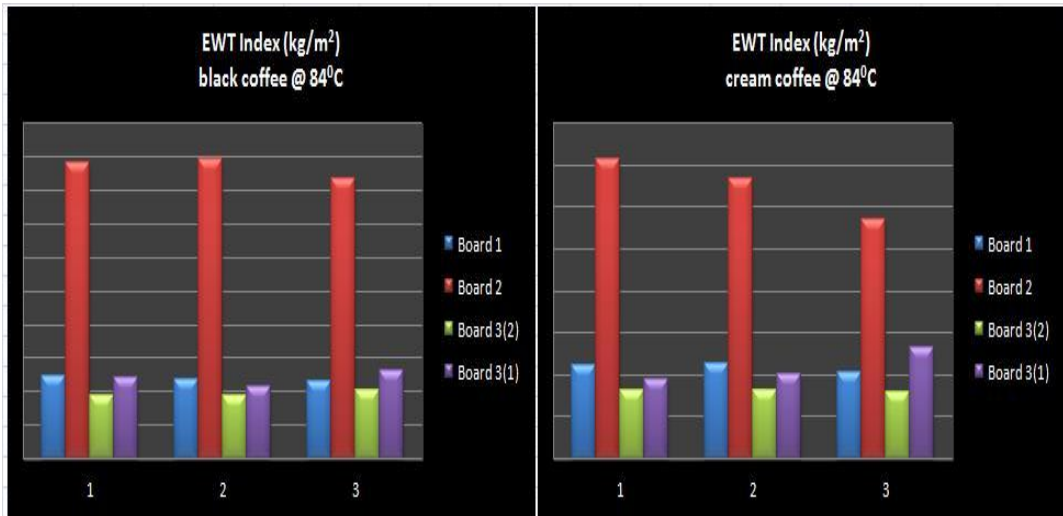


Figure 10. EWT index results for different board samples

The result portrayed board sample 2 with the highest wicking index while board sample 3(2) had the least wicking. The result also reflected that board sample 3(2) consistently had lower results compared to board sample 3(1).

### 7.2.2 EWT Index as an Effect of Temperature

An attempt was made to assess the effect of temperature on wicking by subjecting the same board material to the same test conditions with exception of temperature. The two test temperatures were 84°C and 93°C.

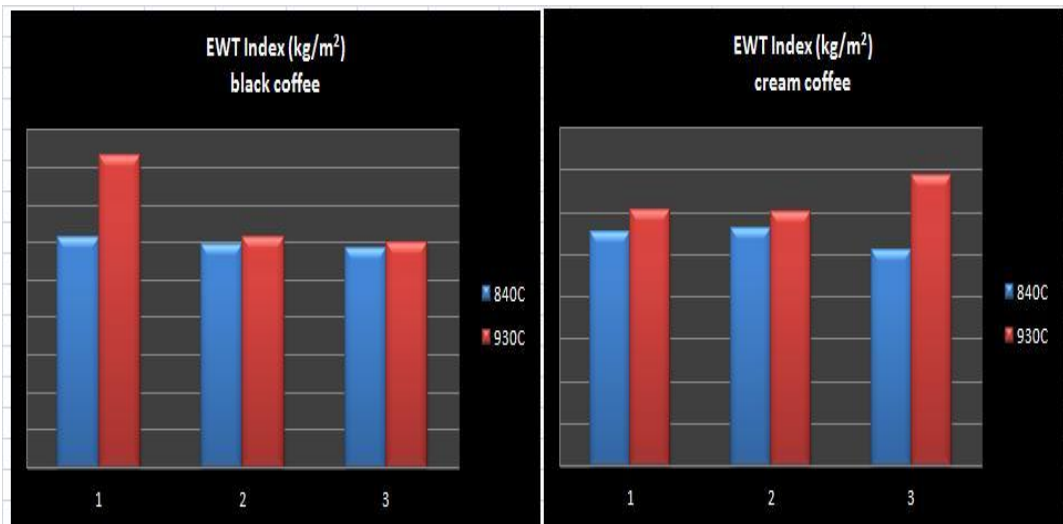


Figure 11. Result of EWT index as an effect of temperature showing a generally higher wicking at 93°C.

### 7.2.3 EWT Index as an Effect of Barrier Material

In comparing the barrier material efficiency, the normal tape in use in the laboratory and a new one were examined due to their practical relevance even though hot lamination showed a comparative advantage over the normal tape.

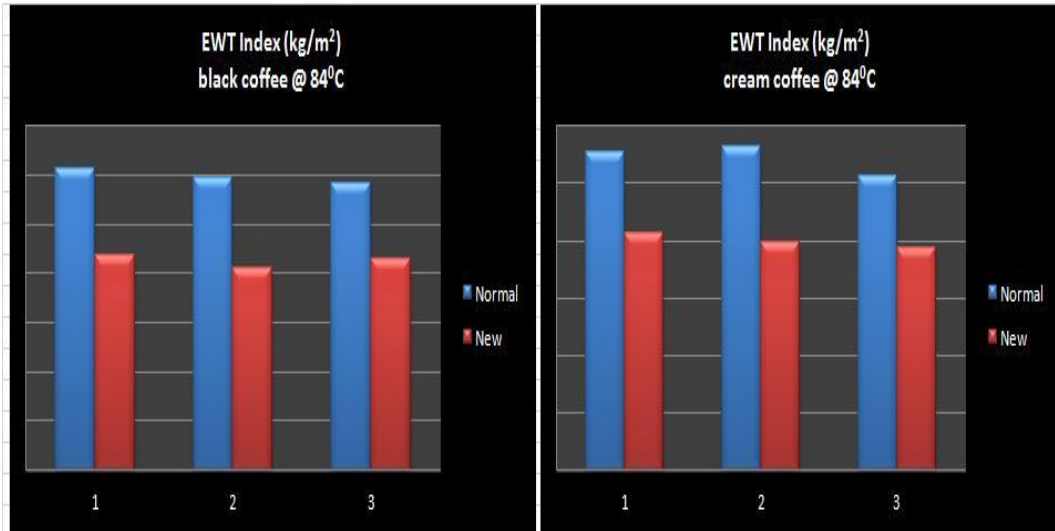


Figure 12. Result of EWT index as an effect of barrier material.

This test showed a clear distinction between the results obtained from the different tapes. The much lower wicking witnessed with the new tape could be attributed to the strength of adhesion of the tape to the base board.

### 7.2.4 Comparison of EWT Indices from Different Examiners

This analysis was conducted in two phases: in RCI among 3 persons and Board Mill between 2 people. While the test in RCI was conducted at 84°C, the one made in the Mill was done at 80°C. Although on individual basis, the results obtained were not widely deviated in the parallel measurements, it remained a case of inconsistent figures.

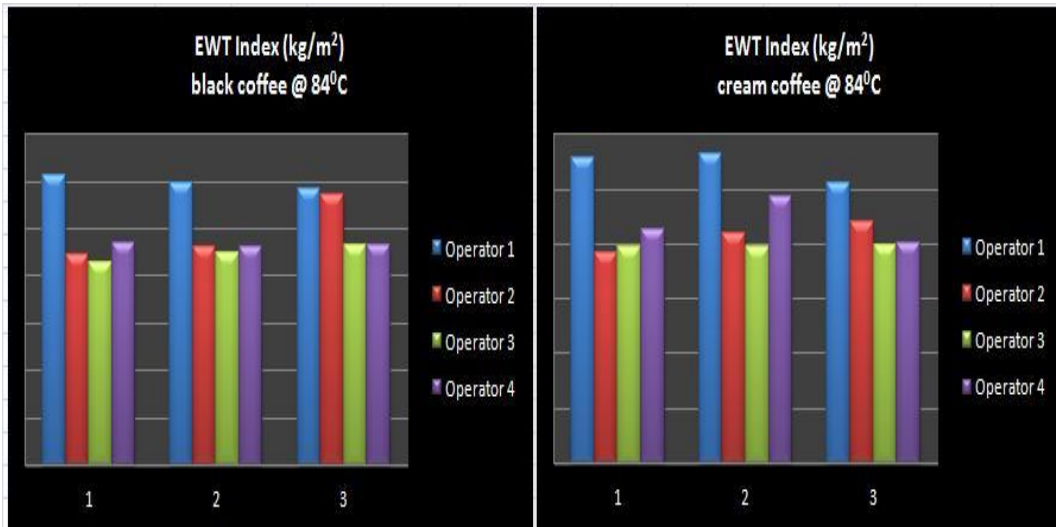


Figure 13a. Result of EWT Indices from Different Examiners (RCI)

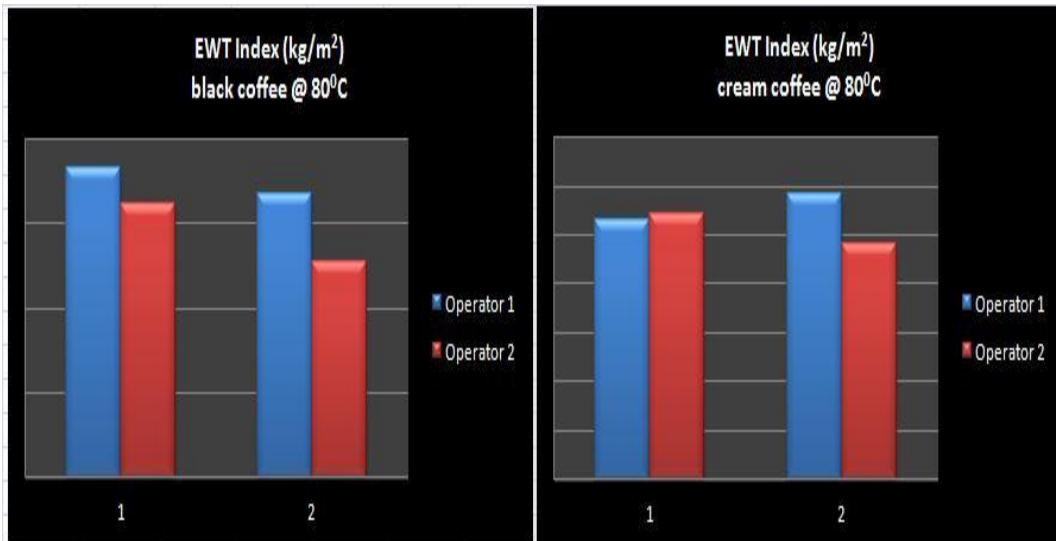


Figure 13b. Result of EWT Indices from Different Examiners (Mill)

An overview of these results showed difficulty of reproducibility of the same result by all participating examiners. It is indicated that the Mill-executed tests were characterised by higher EWT indices compared to those taken in RCI laboratory.

Considering the test execution technique, the higher values obtained in the Mill could be assumed to have arisen as a result of the closeness of the test strips in the coffee samples. This is viewed from the perspective of possible liquid entrapment that could aid forced absorption by the strips.

### **7.2.5 Assessment of Test-life of Coffee**

In an attempt to investigate the practical strength of coffee samples, a series of tests made revealed that the coffee sample remained indifferent as reflected by the EWT indices obtained over four hours of testing. The same coffee samples, having been left for about 24 hours in laboratory atmosphere (23<sup>0</sup>C, 50% RH) produced still wicking results of negligible difference. This therefore suggested that the coffee samples might retain potency for several days.

## 8 Conclusions

This thesis work revealed that the following parameters contributed significantly to the measurement of raw edge penetration / edge wicking in board sample 1:

- Sample area
- Covering
- Direction of cutting
- Liquid temperature
- Liquid age
- Test duration

Although it was discovered that board sample 3 gave the lowest result, a clear-cut comparative analysis could not be made for the three board samples because they were not exactly the same and with different matrices. It also proved a daunting task for an examiner to reproduce the same result under the same atmosphere.

The sharpness and cleanliness of the cutting blade was also found to be very crucial to the test result. While the blade sharpness helped in obtaining relatively smooth and even raw edges, frequent cleaning of the blade prevented the transfer of adhesive from previous operations onto successive test strips.

In furtherance of this work, it is therefore recommended that the following be undertaken:

- Determination of the optimal concentration of the light-roasted coffee.
- Determination of the peak activity (with respect to age) of the light-roasted coffee.
- Determination of EWT index of the new tape and other practicable covering materials on a 2PE base board sample.



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