**WRITING SAMPLE**

**OF**

**A FINAL YEAR RESEARCH PROJECT**

**PRODUCTION OF PARTICLE BOARD FROM WASTE CARTONS USING GUM ARABIC AS RESIN.**

PRESENTED TO

**COLLEGE OF ENGINEERING**

**SCHOOL OF CHEMICAL AND PETROLEUM ENGINEERING**

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# INTRODUCTION

## BACKGROUND OF STUDY

Almost every factory and food product are usually placed in cartons for preservation purposes and easy transportation and distribution to the final consumers. Many of the packaging materials (glass, plastic, aluminium and paperboard) are consumed by the food, pharmaceutical and beverage industries and nearly 40% of the total packaging and the most widely used packaging material for beverage carton production is paperboards (PCD, 2005). Even appliances are put in paper packages known as corrugated boxes. When these products are consumed, the cartons are disposed of as waste even though they consist of the most recyclable fractions of waste. Cartons cannot be reused as refills like plastic bottles but can be recycled because they comprise of paper board, polyethylene and aluminium foil all of which have higher recycling values. Paper packaging is of two types which are boxes and bags. Cartons are classified under boxes. They are divided into corrugated and cardboard boxes. These boxes have a disadvantage when they come in contact with water, to prevent this issue, the cardboard boxes have been modified by the addition of aluminium and polyethylene. These types of cartons are of two types which are aseptic cartons (also known as shelf-stable cartons) and gable-top (refrigerated cartons). The aseptic cartons contain 74% paper, 22% polyethylene and 4% aluminium while gable-top contain 80% paper and 20% polyethylene. Waste management and recycling is a very important project with a lot of benefits which should be a priority for corporate sustainability programs. The benefits accrued to recycling are reduction in the amount of waste sent to landfills and incinerators, conservation of natural resources and prevention of pollution by reduction on the need to extract new raw materials. Recycling also saves energy and water and reduces greenhouse emissions that usually contribute to global climate change as opposed to manufacturing processes that rely basically on virgin materials. Most importantly, it has also been known to create jobs (Mackerron, 2015).

Lately, research work is being carried out on how to use Tetra paks in the production of roofing sheets. An initiative for financing facility upgrades and improving markets to make collection and recycling of aseptic cartons has led to an increase in the national availability of carton curbside collection, though, there is still a challenge in the actual recycling of these materials. So far, Colgate-Palmolive and Procter & Gamble have committed to making nearly all product packaging recyclable by 2020 (Mackerron, 2015). The corrugated and cardboard boxes, on the other hand, are re-pulped and used in the newspaper industries as short fibres.

## PROBLEM STATEMENT

Waste recycling in Nigeria is still in its infancy stage as opposed to the disposal of all these waste products on landfills and incinerators. Though most waste papers can be and are re-pulped most times to be used in newsprint paper mills, however, the beverage cartons waste separation and collection is not very effective and in most areas around the world, paperboard cartons are not recycled due to the low quality and contaminated fibre it yields (Twede *et al*, 2014). There is a major need to provide a solution to facilitate waste management so as to empower the youth by incorporating them into the recycling business. So far, most recycled waste products are polymer materials like plastics. However, household waste tetra paks are an uncharted territory (Elias Pemba and Anrew Chileshe, 2014).

## AIMS AND OBJECTIVES

1. To extract cellulose from waste cartons
2. To study the possibility of producing ceiling boards from waste cartons
3. To produce ceiling boards with thermal insulating and good acoustics properties
4. To produce a board with reduced cost so as to reduce importation and boost Nigeria’s economic status
5. To produce boards with potential use in the building industry.
6. To reduce the amount of waste in the environment and prevent air pollution resulting from burning these wastes.

## SCOPE

* To recycle waste cartons for the production of ceiling boards
* To carry out proximate mechanical analysis on the boards
* To analyze the physical properties of the product retrieved.

## JUSTIFICATION OF STUDY

Lately, a lot of experiments have been carried out to produce ceiling boards from waste materials and local raw materials. This recycling initiative supports the resource circulation by aiding in the reduction of extracting virgin raw materials and also helps in reducing greenhouse gas (GHG) emission. It increases the lifespan of the landfill sites and basically, it lowers the cost associated with waste management. 900kg of GHGs emission and 4m2 area of the landfill is reduced from just recycling 1tonne of beverage carton (Tetra Pak, 2012).

# LITERATURE REVIEW

Paper is produced from a natural source making it easily recyclable and this can be used over and over again. Almost 200 U.S. mills rely solely on recycled paper (AF&PA, 2002). The types of paper gotten from this process are majorly used for corrugated cardboard boxes and for newspapers sometimes.

The process of producing pulp from recycled paper involves blending the paper to be recycled with water in a large tank. Light contaminants float to the top of the slurry and are removed using ragger mechanism while heavy contaminants are removed from the bottom of the tank (Martin *et al*, 2000; Biermann, 2005). The ink from the recycled paper is removed by applying chemical surfactants. This method uses a small amount of energy compared to both mechanical and chemical pulping which varies with the type of contaminants present and the resulting pulp. Modern contaminant removal methods are being applied now which make the paper produced from recycled pulp to be almost as good as other types of paper except those of the highest quality gotten from long fibres (Martin *et al*, 2000). The resulting pulp must be bleached to prevent the pulp from being coloured.

## BLEACHING

Bleaching can be defined as the process where a chemical is added to the pulp in order to increase its brightness (U.S. EPA, 2002). The colour range from brown to crème in pulp occurs due to the presence of residual lignin. Bleaching, therefore, varies with the pulping process applied.

Initially, Chlorine bleach was used for chemical pulp but it had a drawback in that it damaged pulp fibres which led to the use of elemental Chlorine-free (ECF) processes which is commonly applied nowadays (over 95%) (AF&PA, 2005). By the year 2001, totally Chlorine free (TCF) processes were applied (about 1%) (U.S. EPA, 2002). The type of chlorine-free process that is to be adopted for chemical pulp is dependent on the environment, cost and desired pulp properties (U.S. DOE 2005a). the common ECF and TCF chemicals are Chlorine dioxide ClO2, Ozone O3, Sodium Hydroxide (NaOH), Oxygen (O2)and Hypochlorite (HClO, NaOCl, Ca(OCl)2)- which were majorly used in sulfite process till it was discovered that it was not safe for the environment due to its formation of chloroform (U.S. EPA, 2002; U.S. DOE 2005a). After bleaching, the pulp is washed so as to get the white pulp.

Kappa number is a measure of the bleach requirement of an unbleached (brown) pulp. Kappa Number is directly proportional to the lignin content of the wood. Sometimes it is called “Permanganate Number”.it is used to determine the hardness, bleachability and degree of delignification of pulp. The lower the kappa number, the easier a pulp can be bleached.

## GREEN NANOTECHNOLOGY

Over the past few years, one of the most popular subjects in the science and technology industries is Nanotechnology. It is one of the ever-growing advancement in technology. Engineers have been studying ways to make it beneficial to the environment and have termed it “green nanotechnology” as it focuses on nanoscale challenges that must be overcome to ensure eco-friendly processes and products and reduce health and environmental hazards and energy usage.

Green nanotechnology comprises of;

* Manufacturing with minimal energy usage
* Recycling after use
* Use of eco-friendly materials

Nanotechnology can be defined as the science and art of manipulating matter at the nanoscale so as to produce newer products with the potential to change society. Nanomaterials have been known to be lightweight and strong. Some areas where nanotechnology has been applied are in electronics and communication, HealthCare and life science, chemicals and material, energy nanotechnologies, food and agriculture, Transport, processing and manufacturing, environment and security amongst many others (H. Dosch, M.H and Van de Voorde, 2009).

1nm = 1 billionth of a meter.

Green nanotechnology is expected to aid the following;

* Wastewater decontamination and treatment
* Renewable energy generation
* Environmental remediation and waste management.

Manufacturing processes can be changed using nanotechnology in two main ways;

* Reducing waste by using nanotechnology for controlled and effective manufacture
* Use of nanomaterials as catalysts to ensure better efficiency in the manufacturing processes to reduce or totally eliminate the use of toxic materials so as to prevent the generation of unwanted by-products

Where waste management is concerned, so far tetra paks have been used in the production of roofing sheet in various countries like Thailand and Germany. These cartons have a very special quality of being waterproof due to the foil and polyethylene layers contained in them and the cardboard layer acts as the strengthening material to provide structural support. These qualities are evidence to the fact that they make suitable roofing sheet. They are also not expensive and are easy to come by because they are used prevalently as beverage containers and this shows that it will make an inexpensive building material. (Tetra pak, 2012).

Since most of the beverage cartons consist of valuable, recoverable and recyclable materials, the process used in the recycling of the cartons involve the following processes;

* Paper recycling
* Plastic and aluminium recycling
* and green board production.

### Paper recycling

This s the main material in the beverage carton production and the recycling process of the paper material is done by the re-pulping process. This paper recycling process has six steps which are;

1. Paper separation of the paper from the food and beverage carton
2. Fibre distribution
3. Paper segregation
4. Cleaning
5. Removal of the ink
6. Pulp bleaching

Usually, the packaging is recycled into cardboard boxes all over again and paper for office supplies. The paper fibre gotten from the recycling has 81.8% clarity and medium-length fibres thereby making it very useful in the production of paper products requiring medium-length fibres (Suwannapan, 2014). This recycling process can be carried out for more than five times with a downside of reducing fibre quality. Tissue papers, paper towels and writing papers can also be produced from the recycled beverage cartons (Tetra pak, 2013).

### Plastic and aluminium recycling

Both plastic and aluminium use in the production of beverage cartons are recyclable (DEQP, 2012). The aluminium and polyethylene are separated from the paper, dried and cut in small pieces and converted into the roofing material. The re-pulping process is what is used for recovering the aluminium and polyethylene. In some situations, the plant next to the paper mills change the polyethylene to gas and use it for energy and collect the aluminium in powder form. Lately, polyethylene is being recycled in plastic granules and used for other plastic applications and the aluminium-polyethylene combination is also recycled sometimes as composite materials or is used as stock for energy or as raw materials in other industries (ACE, 2013).

## CHEMICAL COMPOSITION AND FIBRE CHARACTERISTICS

Any biomass containing a combination of lignin and cellulose in the structural cell can be pulped with the right method applied. The reason for determining the physical and chemical composition of any material is to give an understanding of whether the fibres are appropriate for pulp and papermaking (Azeez *et al*, 2015). Biomass suitable for pulp and papermaking generally has to contain high cellulose content, low lignin, extractive and ash content. Since Kraft pulping is the method generally used. For pulp strength, the biomass should have long fibres because they reduce tearing and increase tensile strength. Other properties such as the cell-wall thickness, fibre diameter, runkel ratio e.t.c also affect the pulp strength (Pillai *et al*, 2003). The chemical constituents present in pulp are;

### Cellulose

Cellulose is the major component of the cell wall of all wood, grasses and straws. It is a polysaccharide that consists of 600 to 1500 repeated sugar units. Usually, it is a mass of hair-like inter-locking woody and non-woody fibres. Due to the presence of hydrogen bonds, cellulose fibres differ from synthetic polymers because they can be beaten, solubilized in water and easily deposited on a wire-mesh to coalesce easily and form a paper sheet. Cellulose is insoluble in cold and hot water and has good tensile strength. It is resistant to oxidation so it does not dissolve in bleaching agent thereby enabling easy removal of lignin and other contaminants. The higher the cellulose content, the higher the yield. The chemical formula of cellulose is (C6H10O5)n which can be structurally represented below;

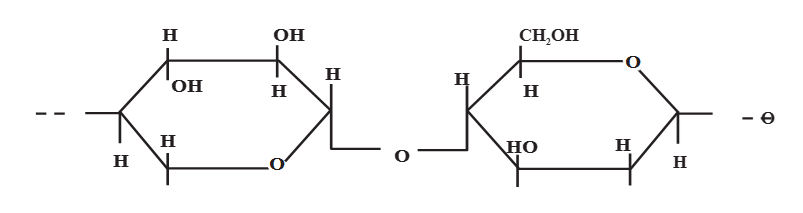


Figure 2.1: Cellulose structure

Source: J. Grant, Pulp and Paper Manufacturer,1985

### Hemicellulose

Hemicellulose is contained in biomass with cellulose after the contaminants and lignin are removed (imperfectly). It consists of 15 to 90 sugar units. They are non-fibrous and are adhesive. Some parts break out when put in water and some are retained in the pulp. They have an advantage of contributing to the tensile strength of paper and a disadvantage of causing a loss in the brightness of bleached pulps after a period of time.

### Holocellulose

Holocellulose is the term used to describe a pulp that is freed from lignin, other contaminants and less resistant holocelluloses. It is not common because pulping processes remove some hemicelluloses.

### Lignin

Lignin is a substance that binds fibres that makes wood tissue rigid. The removal of lignin is what gives a pulp of good quality. Lignin can be removed almost fully (chemical pulping), partially (semi-chemical pulping), or not at all (mechanical pulping). The amount of lignin has an effect on the strength and durability of the final paper product. Bleaching of the pulp can also contribute to the removal of lignin and other coloured substances from the pulp.

Table 2.1: Pulp and paper fibre sources and their chemical constituents

|  |  |  |
| --- | --- | --- |
| Chemical constituents | Softwoods | Hardwoods |
| α- cellulose | 38-46 | 38-49 |
| Hemicellulose | 23-31 | 20-40 |
| Lignin | 22-34 | 16-30 |
| Extractives | 1-5 | 2-8 |
| Minerals and other inorganics | 0.1-7 | 0.1-11 |

Fibre characteristics are the main determinants for pulp generation. One of the major property fibre should possess for it to be pulpable is;

**Length of fibre**: the strength of pulp is directly proportional to the fibre length. It is one of the most important fibre properties. Softwoods and wood grown in cold climates have long fibres generally. Chemical pulping generates long fibres compared to mechanical and semi-chemical. Since the other methods of pulping generate shorter fibres, long fibres can be added to the short fibres to optimize strength and cost. It also increases tearing resistance and bursting strength. Fibre length can be classified into

* Long fibres: it is usually ≥2mm
* Medium length fibres: its dimensions are between 1.5mm and 2mm.
* Short fibres: it has fibre that is ≤ 1.5mm

### Manufacturing steps of particleboard

Particleboard is a composite product mainly engineered from wood particles (chips, sawmill shavings, even sawdust) and gum or any other binder which is then pressed together. It has the advantage of being less expensive, denser and more uniform than customary wood and plywood and is substituted for them when appearance and quality are less critical than the cost. In any case, particleboard can be made more alluring by painting or the utilization of wood finishes that are stuck onto surfaces that will be obvious (Stark *et al*, 2009).

Particleboard is usually manufactured making use of thinnings and trimmings from pine plants. The wood stock is processed into coarse and fine drops, which are dried and sprayed with gum or binder, for example, urea-formaldehyde or phenol-formaldehyde (Stark *et al*, 2009). Flakes are then formed and pressed into mats with the coarse flakes in between the fine flakes thereby giving a smooth surface for painting or for applying lacquers. Some of these mats are put in a hot press where they are packed (Franco Bulian, and Jon Graystone, 2009).

Curing of the binder or resin occurs due to the high temperature of the press thereby generating a strong sheet which is then treated with chemicals to avert assault by termites and boring insects. These sheets are brushed till there is a uniform thickness and trimmed to the desired sizes. Particleboards can be used as panels in showcases, partitions, fridge and tabletops, door-window panels (Gay, 2014).

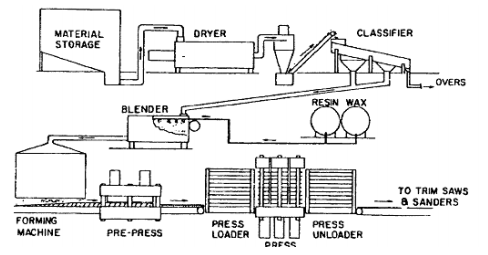


Figure 2.2: Particleboard Manufacturing Process

# METHODOLOGY

## Production of paper

* Waste carton pulp was bleached. Using Sodium Hypochlorite in the pulp/bleach ratio of 1:10, bleaching was carried out.
* The water bath was set to a temperature of 60°C
* The mixture of the pulp and bleach were put in small cellophane nylons and placed in the water bath.
* The pulp was then poured out into a sieve and the bleached pulp was washed off manually by allowing running water to be poured on it thus allowing the pulp to become lignin free.
* The bleached pulp was mixed with starch and water in a bowl to a consistency of 5% (Medium consistency).
* The mesh framework was then dipped into the bowl of pulp and shaken to ensure uniformity and the water was allowed to drain off.
* The formed paper was then put out in the sun to dry for 4 hours
* The dry paper was then calendered using an electric iron to get a smooth surface.
* Samples were made from long fibres, short fibre and a mixture of long and short fibres.
* Other samples were prepared using dye for colour.

### Physical analysis

After bringing the samples to uniform sizes, they were analyzed in the Chemical Engineering Laboratory, Covenant University for Density, moisture content, Thermal conductivity, water absorption and thickness swelling.

#### Density

* A test piece of the particleboard was cut and weighed by the use of a weighing balance
* Water was measured into a measuring cylinder
* The sample was immersed into the water-filled measuring cylinder to determine the volume

The formula to determine the density of any substance is;

(3.1)

Where; = air-dried weight

= air-dried volume

#### Water Absorption

* A test piece of the particleboard cut and weighed by the use of a weighing balance
* Distilled water was poured into a bucket and kept at room temperature of 20-30°c
* The sample was immersed in the distilled water
* The sample was then weighed after 2 hours
* Weight was again taken after 24 hours

The formula for calculating water absorption is;

(3.2)

Where; = final weight

= initial weight

#### Moisture content

* A test piece of the particleboard cut and the weight of the air-dried sample was taken
* The sample was then put in an oven at 105°c
* The sample was weighed after 1 hour
* The sample was weighed again till constant oven-dried weight was obtained

The formula for determining the moisture content is;

(3.3)

Where; = air-dried weight

= oven-dried weight

#### Thickness swelling

Absorption of water and moisture content affect the thickness of the particleboards as it causes it to swell.

* A test piece of the particleboard cut
* The thickness of the sample was taken using a Vernier calliper
* The sample was immersed in distilled water at room temperature
* The sample was weighed continuously till constant weight was obtained
* The thickness was then taken after constant weight had been achieved.

The formula for determining thickness swelling is;

(3.4)

Where; = Final thickness

= Initial thickness

# RESULTS

## DISCUSSION OF RESULTS

The results of the physical analysis of the particleboards at different Gum Arabic percentages are discussed below.

### Effect of % Gum Arabic on Density, Moisture content, Water absorption and Thickness swelling.

The density of the waste carton particleboards ranges from 0.600g/cm3- 0.733g/cm3 for gum Arabic quantities of 3% to 10%. It was observed that the different impregnation ratios had an effect on the density of the boards due to the fact that as the amount of gum Arabic was increased, the density of the board also increased. Harshavardhan et al, 2016 states that the density of particleboard has the ability to affect the modulus of rupture (MOR), modulus of elasticity (MOE), internal bonding, water absorbance and thickness swelling of the board. Hiziroglu, 2009 carried out experiments to compare the panel density to MOR and MOE and it was discovered that as the panel density increased, the modulus of rupture and elasticity increased and also the internal bonding increased. The British Department of Environment (1973) states that the maximum density for a material to be classified as a lightweight building material is 1.6g/cm3. According to ANSI A 208.1, for commercial particleboards, it must be of medium density which ranges from 37-50 lb/cubic ft (0.600 – 0.800g/cm3). Therefore, it was observed that the density gotten for the particleboards at different percentages of gum Arabic is in correlation with the standard.

The moisture content obtained was in the range of 9 -11%. Harshavardhan et al, 2016 states that the equilibrium moisture content of Particleboards is 8-12% and should usually be at equilibrium with the humidity level at which it is supposed to be used as change in moisture content affect the dimensions of the board. The results gotten are in accordance with the standards. A plot of the variation of moisture content to the percentage of Gum Arabic in showed that as the quantity of gum Arabic increased, the moisture content also increased. The low values gotten from the density and moisture content proves how reliable the results got will be as they affect other properties to be tested.

Strength of a material can be reduced by excess absorption of water or moisture from the surrounding environment, which is why water absorption is one of the most important properties of particleboard. The water absorption experiment carried out for 2 hours on the particleboard samples gave a result which ranged from 380-480% and 460-560% after 24 hours. There was an average of 18% increase of water absorption of the particleboard samples from 2 hours to 24 hours. The results gotten from water absorption analysis of the particleboard was subjected to a T-test at 95% confidence level to determine any significant difference between the results obtained for 2 hours and those for 24 hours and it was observed that there was no statistically significant difference between the results obtained at the time variations but according to ANSI A 208.1, the requirement for particleboards that can be commercialized is absorption levels of up to 35%. Thickness swelling of particleboard occurs due to moisture and water absorption. The range of thickness swelling of the particleboard samples had a range of 1-8%. The result was in accordance with the standard which has standard MDF at not more than 8% for 2 hours and 8-15% for 24 hours.

This result shows that waste carton as the raw material for particleboards has very high water absorption capabilities and high thickness swelling. It was observed that as the quantity of gum arabic increased, the water absorption and thickness swelling decreased. The range of results obtained shows that for water absorption properties and thickness swelling the particleboard produced doesn’t meet up to the commercialization standard. This particleboard can, therefore, be classified as a standard reinforced with wood or more gum arabic can be added in order to reduce the hydrophilic nature of the cellulose pulp. The boards produced are standard MDF’s.

### Comparing the density of the material to water absorption and thickness swelling

After plotting a graph of density against water absorption for 2 hours and 24 hours in figure 4.5 and 4.7, it was observed that after both the 2-hour and 24-hour immersion of the particleboard samples into water, as the density increased, the water absorption increased which is similar to the results obtained by Rafael Rodolfo de Melo *et al*, 2014 and Harshavardhan *et al,* according to these authors, the very high water absorption percentages of the particleboard samples are related to the low content of lignin present in the material and increased portion of cellulose chemical constituent as they have high hydrophilic behaviour. Addition of resin addressed the water absorption and thickness swelling challenge as gum arabic is hydrophobic in nature. Which explains why an increase in the percentage of gum arabic led to a decrease in the density which then led to a decrease in water absorption and thickness swelling and vice versa.

### Comparing the density of the material to moisture content

The plot of density against moisture content produced an inversely proportional graph. As the density of the particleboard increased, the moisture content of the board decreased. Addition of water or moisture to any material makes particles move through one another during compression force. This, therefore, brings the particles closer and therefore reducing the void and causing the density to increase.

### Thermal conductivity of particleboards

The results obtained showed that the thermal conductivity was in the range of 0.17-0.30 W/mK. According to ewpaa, 2016, the range of thermal conductivity for MDF’s is from 0.1-0.3 W/mK. The results obtained fall between the specified range. This proves that the particleboards have a low thermal conductivity which is the same as that of natural timber.

# CONCLUSION

The search for cheap building materials in Nigeria is essential as the cost of these materials are ever-increasing. The most predominant material in the building industry is the asbestos which is being reviewed because of the discovery of its hazardous nature. The use of sustainable materials as raw material for particleboard production has a lot of advantages. The particleboard manufacturing process, use and composition made from these materials are quite similar to those of the conventional timber board making the difference in the quality infinitesimal. In this research project, ceiling boards were produced from waste carton pulp and Gum Arabic at different percentages of 3,4,5 and 10%. Writing paper was also made from the residual pulp in bleached form, in a mixed form (i.e. long and short fibres), in coloured form and also as long fibre. Tests were carried on the particleboards, the average value of density obtained was 0.679g/cm3. The moisture contents average value was 10.079%. An average of 431.255 and 508.196 % water absorption was obtained after a time of 2 hours and 24 hours respectively and the average thickness swelling after 2 hours was 5.34%. The thermal conductivity was obtained at an average of 0.230W/mK. From the data obtained, the ceiling boards produced shows great potential as a good building material.

# APPENDIX

# APPENDIX A: EXPERIMENTAL RUNS

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Gum Arabic (%) | Density (g/cm3) | Moisture Content (%) | WA 2hrs (%) | WA 24hrs (%) | TS (%) |
| 3 | 0.733 | 9.231 | 478.947 | 547.368 | 7.91 |
| 4 | 0.714 | 9.756 | 437.500 | 518.750 | 7.14 |
| 5 | 0.667 | 10.577 | 428.571 | 500.000 | 5.10 |
| 10 | 0.600 | 10.753 | 380.000 | 466.667 | 1.21 |

# APPENDIX B: FORMULAE



Where; = air-dried weight

= air-dried volume



Where; = final weight

= initial weight



Where; = air-dried weight

= oven-dried weight



Where; = Final thickness

= Initial thickness

# APPENDIX C: CALCULATIONS

1. DENSITY AT DIFFERENT GUM ARABIC PERCENTAGES

For 3% Gum Arabic;

Weight= 1.1g

Volume V1=25.00cm3

Volume V2= 26.50cm3

Density= = 0.733g/cm3

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Gum Arabic (%) | Weight (g) | V1(cm3) | V2 (cm3) | Density (g/cm3) |
| 3 | 1.1 | 25.00 | 26.50 | 0.733 |
| 4 | 0.5 | 19.00 | 19.70 | 0.714 |
| 5 | 0.6 | 25.10 | 26.00 | 0.667 |
| 10 | 0.6 | 60.00 | 61.00 | 0.600 |

1. MOISTURE CONTENT AT DIFFERENT GUM ARABIC PERCENTAGES

For 3% Gum Arabic;

Air-dried weight= 21.30g

Oven-dried weight= 19.50g

Moisture content (%)= = 9.231%

|  |  |  |  |
| --- | --- | --- | --- |
| Gum Arabic (%) | Wa | Wo | Moisture Content (%) |
| 3 | 21.30 | 19.50 | 9.231 |
| 4 | 9.00 | 8.20 | 9.756 |
| 5 | 11.50 | 10.40 | 10.577 |
| 10 | 10.30 | 9.30 | 10.753 |

1. WATER ABSORPTION AT DIFFERENT GUM ARABIC PERCENTAGES

For 3% Gum Arabic; (2 hours)

Final weight= 11.0g

Initial weight= 1.9g

Water absorption= = 478.947%

(24 hours)

Final weight= 12.3g

Initial weight= 1.9g

Water absorption= = 547.368%

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | After 2hrs | | | After 24hrs | | |
| Gum Arabic (%) | Wf | Wi | Water Absorption 1 | Wf | Wi | Water Absorption 2 |
| 3 | 11.0 | 1.9 | 478.947 | 12.3 | 1.9 | 547.368 |
| 4 | 8.6 | 1.6 | 437.500 | 9.9 | 1.6 | 518.750 |
| 5 | 7.4 | 1.4 | 428.571 | 8.4 | 1.4 | 500.000 |
| 10 | 7.2 | 1.5 | 380.000 | 8.5 | 1.5 | 466.667 |

1. THICKNESS SWELLING AT DIFFERENT GUM ARABIC PERCENTAGES

For 3% Gum Arabic;

Final thickness= 0.600cm

Initial thickness= 0.556cm

Thickness swelling= = 7.914%

|  |  |  |  |
| --- | --- | --- | --- |
| Gum Arabic (%) | Tf | Ti | TS (%) |
| 3 | 0.600 | 0.556 | 7.914 |
| 4 | 0.600 | 0.560 | 7.143 |
| 5 | 0.330 | 0.314 | 5.096 |
| 10 | 0.500 | 0.494 | 1.215 |