This is to certify that the
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PERFORMANCE PROPERTIES OF A BIODEGRADABLE
FOAM (GRREN CELL®) FOR PACKAGING APPLICATIONS

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of the requirements for the

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Bruce Harte
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PERFORMANCE PROPERTIES OF A BIODEGRADABLE FOAM (GREEN CELL®) FOR PACKAGING APPLICATIONS.

By

Samina Arif

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ABSTRACT

PERFORMANCE PROPERTIES OF A BIODEGRADABLE FOAM (GREEN CELL®) FOR PACKAGING APPLICATIONS

By

Samina Arif

Green Cell® foam is a biodegradable foam packaging material produced from a proprietary cornstarch blend. It is commercially available in a variety of laminations and constructions. Cushioning ability and thermal resistance (R- value) are fundamental properties needed to compete against synthetics. Since Green Cell® foam is starch based and biodegradable, moisture is likely to affect its physical properties.

Cushioning characteristics and the R- values of 1 and 2-inch foams were determined as a function of temperature and moisture content. ASTM method 1596 was used to determine the cushioning properties and an ice melt method was used to determine thermal resistance. Moisture sorption isotherms were developed at three temperatures (20°C, 25°C and 30°C) to determine its moisture sensitivity. One-inch foam had a lower G value at lower static stress than synthetic foams, but at higher static stress had higher G values, while two-inch foam had G values similar to that of synthetic foam materials. Dimensional changes were observed at higher relative humidity conditions especially at 30°C. The R-values at higher humidity were also less than that of synthetic materials.

Biodegradable Packaging materials will find niche markets, as long as their properties are comparable to synthetic materials. Green Cell® foam's hygroscopicity and its density need to be more controllable, then this would open the door for new market opportunities for this biodegradable foam manufactured from renewable resources. In the near, the farm may make a significant in the area of biobased Packaging Materials.

Dedicated to my dear husband and son

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Last but definitely not least; I would like to thank my family (husband and son) during my very busy years of the school. My young son "Ibrahim Arif" could always cheer me up even on the worst of the days and my husband who always kept me pushing forward.

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Nomenclature

D= density

M = mass of the specimen

L1 = length of the specimen

L2 = width of the specimen

T = original thickness of the specimen in

H = free fall drop height

Vi = measured impact velocity

G = acceleration due to gravity 386

Dynamic set can be calculated

T = original thickness of the specimen

F = thickness of specimen after test

W_i = Initial weigh of the product

W_d = Final weigh of the product

W_e: Equilibrium or final weight of the product

W_i : Initial weight of the product

Mi: Initial moisture content of the product

M_e : Equilibrium moisture content

lb: pounds

in: Inches

in/sec: inches per second

sec: second

in Hg : inches of mercury

psi : pounds per inches

g: grams

inches/sec^2: acceleration

lb/ft^3: pounds per feet cube.

pcf : pounds per feet cube

BTU/lb: British thermal unit per pound

Temp. : Temperature

%RH : Percentage relative Humidity

GCF : Green Cell® Foam

Δw : Net weight

ΔV : Change in velocity

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INTRODUCTION

Through plastic engineering, it was recognized that expanded structures foams could be easily achieved with polymers, especially in thermally reversible plastics. During the twentieth century, polymer synthesis was greatly enhanced to improve polymer structures. Several methods were developed to create a broad range of polymer structures during the middle and later part of this century. This was the era when industrial foams were developed. Also during this time, companies and municipalities faced major problems in disposing of plastic foams because they are lightweight and bulky and do not lend themselves to a viable economic and environmentally responsible recycling operation because they are expensive to handle and transport. Synthetic foams are not biodegradable, which makes disposal in soil or composting operations untenable.

Further, issues such as sustainability, industrial ecology, biodegradability, and recyclability are becoming major considerations in a company's product packaging design, especially with single use disposable packaging.

There is thus, a market need for bio-based, biodegradable foam plastic packaging that can be safely and effectively disposed of in soil or in composting operations, and that has all of the current foam plastics performance requirements. Green Cell® foam is a commercially available, biodegradable foam produced from a proprietary cornstarch. It has recently become available in a variety of laminations and constructions. To compete with other presently available synthetic plastic foams, Green Cell® must have similar performance characteristics. Cushioning and thermal resistance (R-value) are fun

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fundamental properties required for the foam to function act as a Packaging material for insulating and cushioning applications. Since Green Cell® is biodegradable, it will absorb some moisture, which will likely affect the above properties.

ASTM standard 1596 was used to determine cushioning characteristics at 25°C and 50%RH and these results were compared with the published data of other synthetic plastic foams available in the market. 1-inch and 2-inch thick Green Cell® foams were evaluated. Green Cell® foam having a 2-inch thickness had G values similar to other synthetic plastic foams. However, 1-inch thick Green Cell® foam had lower G values at lower static stress, but at higher static stress showed significantly higher G values as compared to the synthetic plastic foams. Green Cell® foam was also stored at seven different relative humidity conditions at 30°C for two months and then tested to determine its G values. Another experiment was conducted to determine the time effect on G values and it was observed that G values decreased with passage of time.

The density of 2-inch thick Green Cell® foam was determined to be 3.37lbs/ft^3, while 1-inch thick foam had a density of 3.03lbs/ft^3.

Change of thickness under load at standards conditions and at ambient conditions was also observed. No significant change in thickness was observed. Material behavior at ambient conditions was also observed. One inch and two inch thick material was kept under observation at ambient conditions for about three months where relative humidity and temperature varied between 50%-85% and 70°F-80°F. Significant increase in thickness was observed, demonstrating that the material is hygroscopic.

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Dimensional changes were observed at different humidity conditions and at 30 °C (86°F) after three weeks. The most expansion in dimensional characteristics occurred at 75% and 84% relative humidity and the material gained moisture at these conditions. The material also gained moisture, but shrunk at higher humidity conditions (88% and 95%). No significant dimensional change was observed at 11%, 43% and 54% RH.

Moisture sorption isotherms at three temperatures (20°C, 25°Cand 30°C) were developed to determine its moisture sensitivity. Initial moisture content of Green Cell® Foam was found to be =0.1263 gH_2O/g solid. GAB model was used to develop the sorption isotherms. GAB model results were compared with experimental values.

The ice melt method was used to measure the package insulating ability and the thermal resistance (R- value). R-values of EPS and Green Cell® coolers were determined at standard conditions (50%RH, 72°F) and at 86°C, 80%RH. EPS has a 10% higher R-value than Green Cell® foam at standard conditions. But R-value of EPS cooler was found to be 20% higher at 86°F and 80%RH reflecting that Green Cell® foam degrades with increase in temperature and relative humidity. Green Cell® picks up moisture, which increased its thermal conductivity and lowered its R- Value.

Biodegradable packaging materials will find niche markets, as long as their properties are comparable. To be used more broadly, Green Cell® foam, must be modified to both control its hygroscopic properties and weight problems (Green Cell® foam has high density). In the near future, the farm may make a significant contribution for non-traditional based uses of starch.

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CHAPTER 1

LITERATURE REVIEW

1.1 Introduction

The discovery of Bioplastic is presented in the feature article "How green are green Plastics" by Tillman U. Gerngross, and Steven C.Slater. The author starts the paragraph in the following way,

"Driving down a dusty gravel road in central Iowa, a farmer gazes toward the horizon at rows of tall, leafy corn plants shuddering in the breeze as far as the eye can see. The farmer smiles to himself, because he knows something about his crop that few people realize. Not only are kernels of corn growing in the ears, but also granules of plastic are sprouting in stalks and leaves"[46].

Growing plastics, which seems achievable in the foreseeable future, looks more appealing than manufacturing plastic in petrochemical factories. According to the article 'how green are green plastics', "the plastic manufactured in the petrochemical factories consume about 270 million tons of oil and gas every year worldwide. Fossil fuel is the basic source, which provides both the power and the raw materials that transform crude oil into common plastic. It is difficult to imagine everyday life without plastic. But the sustainability of that production has increasingly been called into question. Known global reserves of oil are expected to run low in approximately 80 years, natural gas in 70 years and coal in 700 years but the economic impact of their depletion could hit much sooner. As the resources diminish, prices will go up—a reality that has not escaped the attention of policymakers"[46].

Biochemical engineers are pleased by the discovery of bioplastics/biodegradable plastics. Plant based plastic can be "Green" in two ways, plastic can be made from a renewable resource and it can break down upon disposal [16].

Using natural biopolymers is not totally a new idea. In one form or another, green plastics have been around for a long time. A brief review of green plastics (biodegradable plastics) is followed by a review of plastic foams.

1.2 History

1.21. Early History

Some natural resin was used even during the early Roman and Middle Eastern times. Like amber and shellac, gutta (one of the series of small drop like ornaments on a Doric entablature.), percha's name has been mentioned throughout history.

Native Americans used to make ladles and spoons from animal horns long before there was any European contact. In Europe, molded horn jewelry and snuffboxes were very popular in the eighteenth century [16].

1.22. 1800's

Meaningful commercialization of bioplastics actually began during the middle of the nineteenth century. An American inventor, John Wesley Hyatt Jr. was looking for a substitute for ivory in the manufacture of billiard balls. He was able to patent a cellulose derivative for coating non-ivory billiard balls in 1869. His effort was, however, affected by the coating's flammability. Balls were occasionally ignited when lit cigars accidentally came into contact with them. Hyatt did not loose his focus and continued working on this pro

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project and soon developed celluloid, the first widely used plastic. Today it is most widely known for its use in photograph and movie films [16].

1.23 1900's

In the 1900s the history of plastics changed dramatically, as petroleum started to emerge as a source of fuel and of chemicals. Early bioplastics were replaced by plastics made from synthetic polymers. The production of plastics occurred on a very large scale after World War II, and continues to the present time [16].

1.24 1920's

In the 1920s Henry Ford experimented using soybeans in the manufacture of automobiles. He had a desire to find non-food applications for agricultural surpluses, which existed as they do now. Soy plastics were used in number of automobile parts, like steering wheels, interior trim, and dashboard panels. Ford was able to produce a complete prototype "plastic car." He exhibited the prototype with great fanfare in 1941 but was not able to commercialize a new plastic car by the end of that year, because of a variety of reasons. At this point, World War II played a role; armament work supplanted almost everything else, and steel shortages limited all non-defense production. Today, plastic automobile parts are common, but the use of plastics made from renewable raw materials got side-tracked [16].

1.25 1960's

Cellophane is a well-established bioplastic. This material is derived from cellulose. Its peak production was recorded during the 1960's but it is still being used in packaging for candy, cigarettes, and other articles though its total usage in Packaging has substantially decreased [16].

1.26 The 2000's and Beyond

Demand for plastics material is continually growing and it is not abating. The plastics industry is an important component of any country's economy in today's world. The U.S. plastics industry has over 20,000 facilities that produce or distribute materials or products. The industry also employs over 1.5 million workers, and ship over $300 billion in products each year [16].

The plastics industry does have some concerns, however pressures relating to waste and diminishing resources are major hurdles that are leading many to re-discover natural polymers and use them as materials for manufacturing and industry. Because of this, there is an increasing interest in a new generation of green /biodegradable plastics [16].

Research on starch-based products has taken place in many countries around the world. The Australian Government funded in 1995 a research project to develop starch-based plastics from corn and wheat, using water and glycerin as a plasticizer. The biodegradable plastic society was formed in 1989 with 48 member companies located mainly in Japan. By 1990, the membership increased to 69 companies, including a significant number of non-Japanese members. In 1992 a U.S Bio/environmental society was formed and had over 200 members by 1998. As an example, many companies sell sta

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starch based foam peanuts for loose fill packaging as a substitute for expanded polystyrene [21].

1.3 History of Plastic Foam

The texture of matter has been modified since ancient times. Survival of the human race depended on softening rice and other foods using yeast, water and heat to make these ingredients soft enough so that they would be acceptable to digestive organs. These techniques were designed to create expanded structures. These structure can be found everywhere in nature, ranging from tree pulp to marine organisms [46].

Through plastics engineering, it was recognized that expanded structures could be easily achieved in polymers, especially in thermally reversible plastics. During the twentieth century, polymer synthesis was upgraded to enhance the polymer structure. Several methods were developed to create a broad range of polymeric products, during the middle of this century. This is the era when industrial foams were developed. [46]

1.31 Early History (2680-2565 B.C)

It may have stated before 2680 B.C, no one knows for sure, but the architects of Stonehenge engaged the services and discoveries of foam masons. [7]

Figure 1. Historic pyramids (2680-2565 B.C)

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Pharoah Rameses II (2680-2565 B.C) presented the idea of a gigantic stone pyramid to his engineers. They were, at that time hardly enthusiastic. No one wanted to spend the rest of his career-watching slaves, stacking stones on top of each other. Yunghotstuff II , an intelligent bright engineer presented the idea of using foam for the pyramids. He explained that the lightweight blocks would skim easily over the sand, and would be easily elevated, as it grew taller. This also resulted in the tremendous reduction in building cost. After that, pyramids popped up all over Egypt and they remain there resisting the elements of sun and sand, a memorial to human ingenuity and the power of foam [7].

1.32 1000-1500 History

Recent ethnographic studies of today's Easter Islanders have revealed a fondness for decorating the front's parts of their homes with small icons. Experts have concluded that they were simply large-scale foam lawn ornaments. The ancient figures on Easter Island are a confirmation of the durability of well-build foam art [7].

Figure 2. Easter island (1000-1500)

1.33 1887 History

When French Sculptor Fredeic Auguste Bartholdi was commissioned to build a monumental statue, arcane zoning regulations could have blocked the famous statue installation.

Figure 3. Statue of Liberty (1887)

Before the American Revolution, New York City ordinance 56-0894 required that all structures and vessels in New York Harbor be able to float. Originally the Statue of Liberty had been originally commissioned to be built of bronze, sculptor Bartholdi realized that his project could be easily scuttled if he could not propose an alternative construction material. Bartholdi's own countryman Gustave Eiffel was studying the use of foam as substitute for steel in large engineering constructions. Eiffel was persuaded to share his patented procedure with the sculptor. The bottom line is that, "it was foam, francs and delightful Bordeaux that saved the jour" [7].

Polymer synthesis and processing have been improved since the middle of the twentieth century. Many foaming methods have been started and transferred from lab scale to industrial scale [22].

1.4 Biodegradability:

“The term biodegradability means that living organisms can use the plastic as a food source, transforming its chemical structure within a reasonable period of time” [5]. In practice we rely on microorganisms to transform carbon in the polymer to CO_2, CH_4 and other small molecules. Usually the time period required is several weeks to months. One way to obtain biodegradable plastic is to use natural polymers, that is, those formed by living organisms [14].

In figure 4, the basic “Central Principle” for biodegradation of polymers is shown in the form of a schematic diagram.

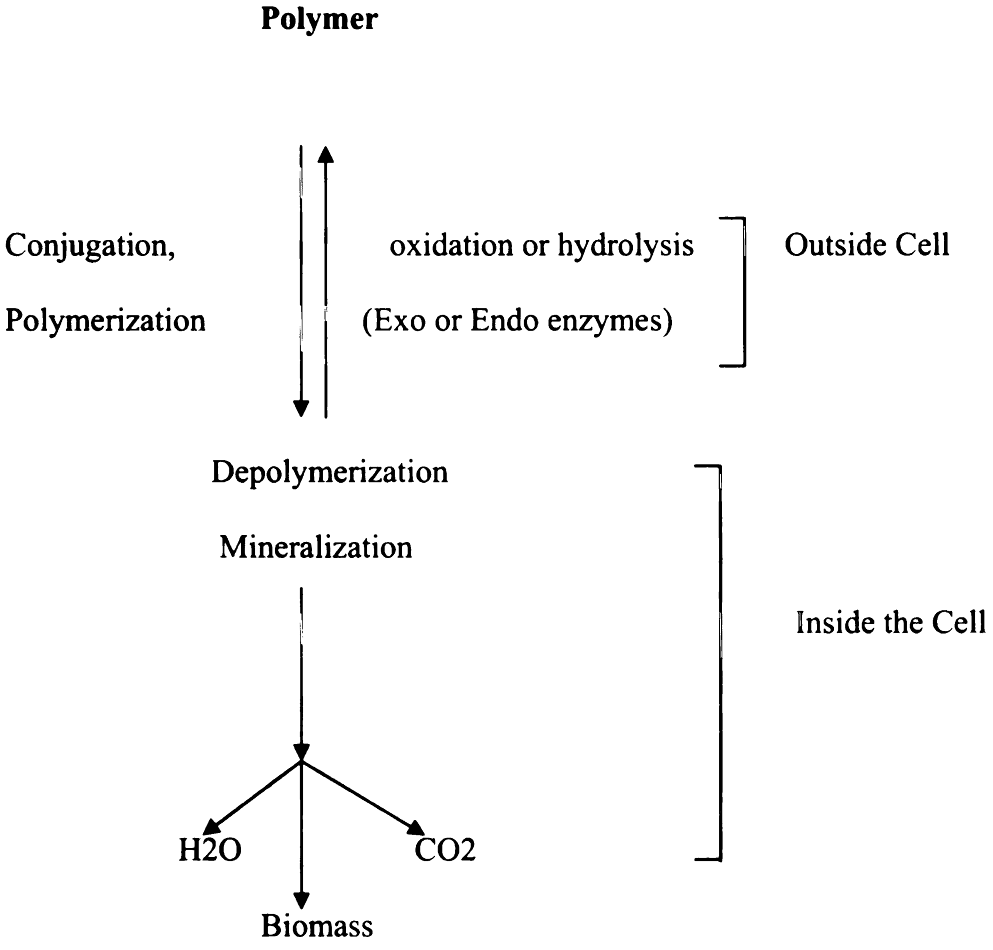


Figure 4. Schematic diagram for biodegradation of polymers

This process consists of two key steps: first, depolymerization or chain cleavage and second, mineralization. [14]

The first step normally occurs outside of the organism (usually bacteria or fungi due to the size of the polymer chain and insoluble nature of many of the polymers). In this step, extra cellular enzymes are responsible for acting either endo (random cleavage of the internal linkage of the polymer main chains) or exo (sequential cleavage of the terminal monomer units in the main chain). [14]

Sufficiently small oligomeric chains are formed and then transported into the cell where they are mineralized. The cell usually derives metabolic energy from the mineralization process and the products, apart from ATP, are gases (e.g. CO_2, CH_4, N_2), water salts, minerals and biomass [14].

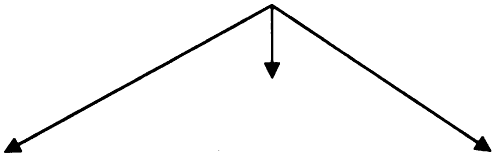
Traditional plastics cannot undergo biodegradation; the reason is because of their long polymer chains. These long chain polymers are too large and too tightly bonded such that they are very difficult to break apart, and thus can not be transformed into relatively simple components [16].

However, plastics based on natural plant polymers, such as wheat or cornstarch have molecules that are readily attacked and broken down by microbes [16].

1.41 Key Elements in Biodegradation

There are three key elements in the biodegradation process as shown in the following diagram. If any of the elements (below) is lacking, then the entire process will stop.

Biodegradation



Organisms

1) Appropriate enzymes
2) Appropriate enzymes Level
3) Co- metabolism
4) Aerobic,anaerobic,facultative
5) Enzymes kinetics
6) Inhibitors/inducers
7) Enzyme location (intra,extra-cellular)
8) Predators

Substrate

1) Chemical bond
2) Branching
3) Hydrophilicity/ Hydrophobicity
4) Stereochemistry
5) Molecular weight
6) Chain flexibility
7) Crytalinity
8) Interation with co polymer coatings
9) Surface area

Environment

1) Temperature
2) Oxygen
3) Moisture
4) Salts
5) Metals
6) Trace nutrients
7) PH
8) Redox potential
9) Stability
10) Pressur
11) Alternate carbon
12) Light

Figure 5. Key elements in the biodegradation process [14]

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1.42 Bioplastics:

Bioplastics are materials with plastic-like properties made from renewable resources such as corn, wheat, rice, soy and potato:

Biopolymer(s) + Plasticizer(s) + other additive(s) = Bioplastic.

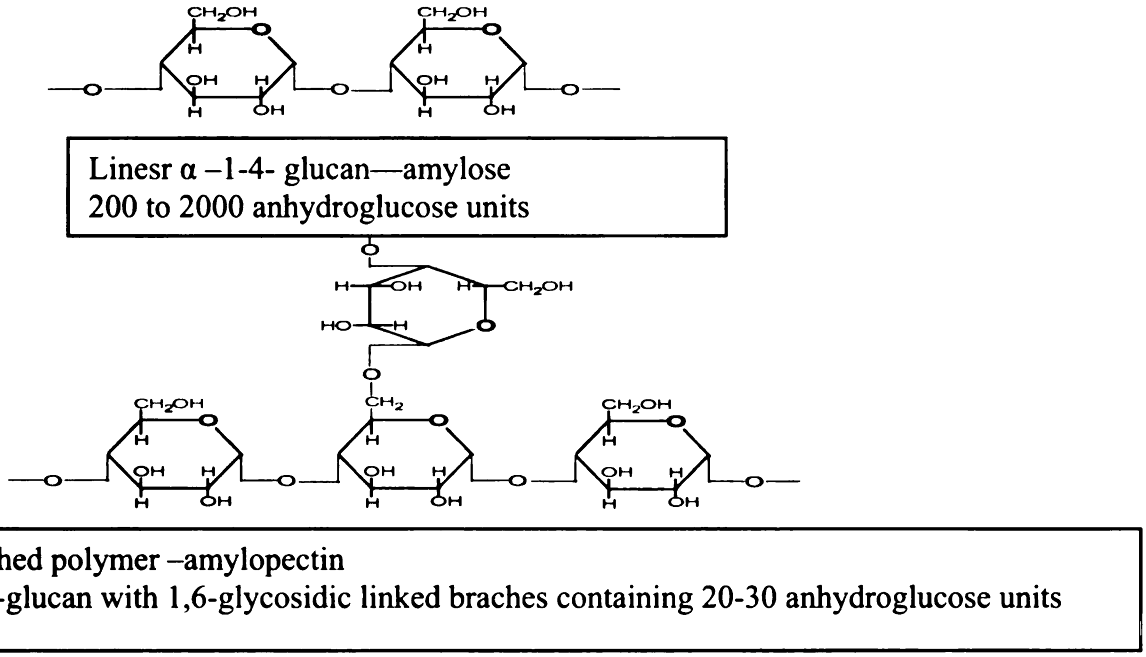
Biopolymers are inherently biodegradable. Biopolymers almost always have oxygen or nitrogen atoms in their polymer backbones. This particular feature is mainly responsible for their biodegradability [16].

There are three main new and important types of bio plastics material (carbohydrates, Lignins and Polyesters). They differ according to the means of commercially producing the resins from which the bioplastics are produced. There are also ready-made polymers existing in nature, which can be used in manufacturing bioplastics. Starch being the prime example [16].

Figure 6 shows the basic structure of a Starch Molecule. [49]

1.42.1 Starch

Structure of Starch Polymers



Linesr α -1-4- glucan—amylose
200 to 2000 anhydroglucose units

Branched polymer –amylopectin
α -1,4-glucan with 1,6-glycosidic linked braches containing 20-30 anhydroglucose units

Figure no. 6 The basic structure of a Starch Molecule

Starch is the main component of most human and animal diets. It is found in the storage organs of plants in the form of partially crystalline water-insoluble granules. [49] Starch is composed of anhydroglucose units, which are the major source of storage energy in various plants in nature. It can be widely found in cereal grain seeds (e.g. corn, wheat, rice, sorghum), tubers (e.g. potatoes), roots (cassava, sweet potatoes, arrowroot), legume seeds (e.g. peas beans and lentils), fruits and leaves (tobacco). [47]

The starch molecule consists of two master polymer components, amylose and amylopectin. Their structure and the relative amount of both populations play an important role in the starch properties. The amylose content and degree of polymerization

(DP) are important in the physical, chemical and technological properties of starch. [46]. Cornstarch typically consists of 28% amylase and 72 % amyl pectin but it can be genetically modified to have as much as 85%. [22]

Starch based material is important not only because it is the least expensive material but also it can be made into a thermoplastic when properly plasticised with water or other plasticizers. Therefore, starch formulations can be made into film or container by any method used for synthetic resins like extrusion, injection molding and thermo- forming [16]. The main limitations of starch-based formulations are physical/chemical properties such as poor water resistance and modest strength [16].

Starch based materials are being used for a number of applications and several major companies produce starch based resins. These resins further have been used to manufacture agriculture covers, compost bags and trash bin liners, house hold items such as disposable bowls, eating utensils and straws, single use disposable packaging film, diaper backing, disposable golf tees and personal hygiene articles like combs and disposable razors. [16]

1.43 Retrogradation

The aging of starch systems has a major effect on the quality of many products. Starch-based foods, such as bread and dough, stale with the passage of time. Low fat baked, or convenience foods are particularly susceptible. Furthermore in non-food uses of starches, for example in paper and adhesives applications, retrogradation affects the processing and final properties of the product. Similarly, one of the most important practical problems with recently developed starch plastics is their tendency to become brittle over time, a process analogous to the staling process in baked goods. [47] The basic definition of retrogradation is the returning to a former state or passing from a more complex to a simpler biological form. [30]

1.43.1 Retrogradation process of starch

When Starch is heated with water, it gelatinizes and the amylopectin is swelled. Starch particles then proceed to harden. This process is called retrogradation. [39]

F. Lionetto et all, in his paper [24] described the process of retrogradation. Starch consists of mainly two polysaccharides, amylose (linear polymer) and amylopectin (highly branched macromolecule). Amylopectin is believed to be the main contributor to the crystallinity of the starch granule [24].

The starch granules are made of concentric amorphous and semi-crystalline growth rings. Starch granules are insoluble in cold water, but, when heated in the presence of excess water, they swell. This swelling is reversible up to a certain temperature. This particular temperature is known as the gelatinsation temperature, where a more pronounced swelling takes place, accompanying the melting of the crystalline regions. Principally linear amylose becomes soluble and leaches out of the disrupted granule. In addition to thermal processing, the conversion of starch from its native partially crystalline granular structure to a polymeric solution/melt and subsequent molecular degradation can be driven by mechanical shear (e.g. in extrusion), chemical (e.g. through the use of solvents) and biochemical (e.g. through enzymatic hydrolysis) processes, etc [24].

Upon cooling, and the during early storage stage, amylose gelation or retrogradation occurs while in longer term storage (hours-weeks depending on composition and storage conditions), amylopectin retrogradation occurs, which leads to the partial recrystallisation of amylopectin producing an increase of firmness and a decrease of water-holding capacity [24].

Retrogradation occurs because gelatinized starch is often super cooled and stored below its melting temperature and therefore is not in thermodynamic equilibrium. Molecular packing and crystallization occurs during storage. Starch retrogradation is scientifically and technologically important since it leads to significant changes in the mechanical properties of starch-based products and thus greatly affects their sensory (e.g. texture and flavor perception), nutritional (availability) and processing (shredding, cutting, etc.) characteristics. [24]

This is further described by Zhenghoug Chen [50] in his dissertation; starch pastes may become cloudy and eventually deposit an insoluble white precipitate during storage. This phenomenon is caused by recystallization of starch molecules. Amylose is considered primarily responsible for the short –term retrogradation process due to the fact that the dissolved amylose molecules reorient in parallel alignment. But the long-term retrogadation is represented by slow recrystallization of the outer branches of amylopectin [50]. Basically the rate and the extent of retrogradation increase with an increasing amount of amylose. Retrogradation also depends on starch concentration, storage temperature, PH, process temperature, and the composition of the starch paste. Retrogradation is generally stimulated by high starch concentration, low storage temperature and PH values between 5-7. [50]

1.44 Thermal Insulation

Defining R-Value

The demand for quality building insulation has soared during the 1970's. At that time many new products were introduced with many conflicting claims pertaining to their insulating abilities. The federal Trade Commission with the participation and support of the insulation industry created an objective method to report the performance of residential insulating materials. This method was called the R-value Rule. [23]

Plastic foams are becoming more and more important in insulation. Price, performance and special design considerations are the most significant features, to consider in selecting any foam to be used for insulation. [12]

To reduce winter heat loss and summer heat gain, plastic foam is being more prominent than other materials because of their significant energy saving capability. Plastic foam insulation is the only viable method for building foundation walls and flat, steel deck roofs, and for packaging needs [23]

Other insulating materials like mineral wood and fiberglass are being used in the building industry as alternatives to foam board stock. Vacuum panels are also being used for building insulation applications. Insulation for flat roofs and below grade foundation walls requires compressive strength and the moisture resistance of closed cell foam. This cannot be found with other insulating materials. [12]

The R- value gives information regarding product labeling (R-value) and advertising, and mandates specific ASTM methods for thermal testing. The basic purpose of the R-value Rule is to create a level –playing field for competing insulating materials.

"The R-value Rule has been helpful in comparing different brands of the same type of insulating materials," said Betsy de Campos, executive director of EPSMA, " but as more sophisticated materials and higher technology construction systems are introduced into the building industry we find that the R- value of the material does not tell the whole story."[23]

R- value is based on the mathematical term known as R- factor. The term R- value was developed to represent the ability of an insulation material to restrict flow. Thermal resistance® of a material is its resistance to heat flow and is expressed as the reciprocal of the material thermal conductivity. Simply put, the greater the R-Value the better the insulation. [23]

1.45 Green Cell® Foam

Extruded starch foam is used as a loose fill packaging material (pallets or peanuts). Green Cell® foam is a commercially available, biodegradable foam material produced from a proprietary cornstarch. It has recently become available in a variety of laminations and constructions. Green Cell® foam can be used as a cushioning material and in applications where thermal insulation is essential [5].

KTM Industries, Inc. develops, manufactures and markets new bioplastic technologies for applications that incorporate proprietary, non-toxic, environmentally safe bio plastics like Green Cell® Foam. Large-scale production of these polymers is being developed because they have been found to have important commercial uses [5]. Typical current applications for the use of Green Cell® Foam can be seen in Figures 7 to 10.

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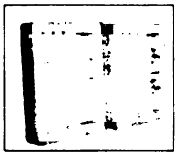

Figure 7. Die Cut

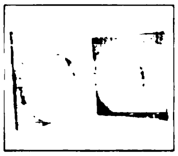

Figure 8. Die Cut Laminated End Cap

Figures 7 and 8. Green Cell® Foam is presently used as a Die Cut and as a Die Cut Laminated End Cap

Figure 9. Medical Shipper

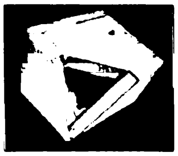

Figure 10. Shipping Coolers

Figure 9 and 10. The major uses of Green Cell® Foam are for Medical Shipper and for shipping Coolers purposes. [5]

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1.45.1 Composition of Green Cell® Foam.

1) Green Cell foam is made from Starch, HYLON VII (High Amylose, 70% Amylose) with an inherent moisture content of 11.2%.

2) Water used as the plasticizing agent, as well as the Blowing agent (10-12% of the dry feed) for all products.

3) BLOX (Dupont), to provide adhesion and durability resin with the flexibility and process ability of thermoplastic resins.

Green Cell® foam is made in thick nesses (t) of 1 and 2-inches. [5]

1.46 Foam Definition

According to S.T.Lee author of the foam extrusion book, "Foam can be defined as a gaseous void surrounded by a much denser continuum matrix, which is usually in a liquid or solid phase". This phenomenon widely exists in nature, in cellulose wood, and marine organisms. Foams can also be made using different synthesis processes (foamed plastics). [45]

Plastics foams can be classified in different ways, for instance, as flexible and rigid, as sheet or board, as low-density or high-density, as closed cell and open cell, and by cell size as foam and micro cellular. To minimize confusion, it is desirable to have a standard nomenclature for foam such as the one from IUPAC. In 1996, over six billion pounds (three metric tons) of synthetic foamed plastics were consumed in the United States. Today's, this material is widely used for a variety of packaging applications. [45]

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1.47 Types of commercial foams

Types of commercial foams are shown in the table No.1 and Major types of foam and their applications can also be seen in figure 11.

Table No.1. Major types of commercial plastic foam

Types of Foam	**Types of Foams**
Poly styrene foam	Pyranyl foam
Poly Urethane foam	Miscellaneous cellular plastics foams
Poly olefin foam	Synthetic rubber and silicon foam
Polyvinyl-chloride foam	Inorganic foams
Phenolic foam	Expanded beads and spheres
Urea-formaldehyde foam	Acrylonitrile and acrylate copolymer foams
Epoxy foam	

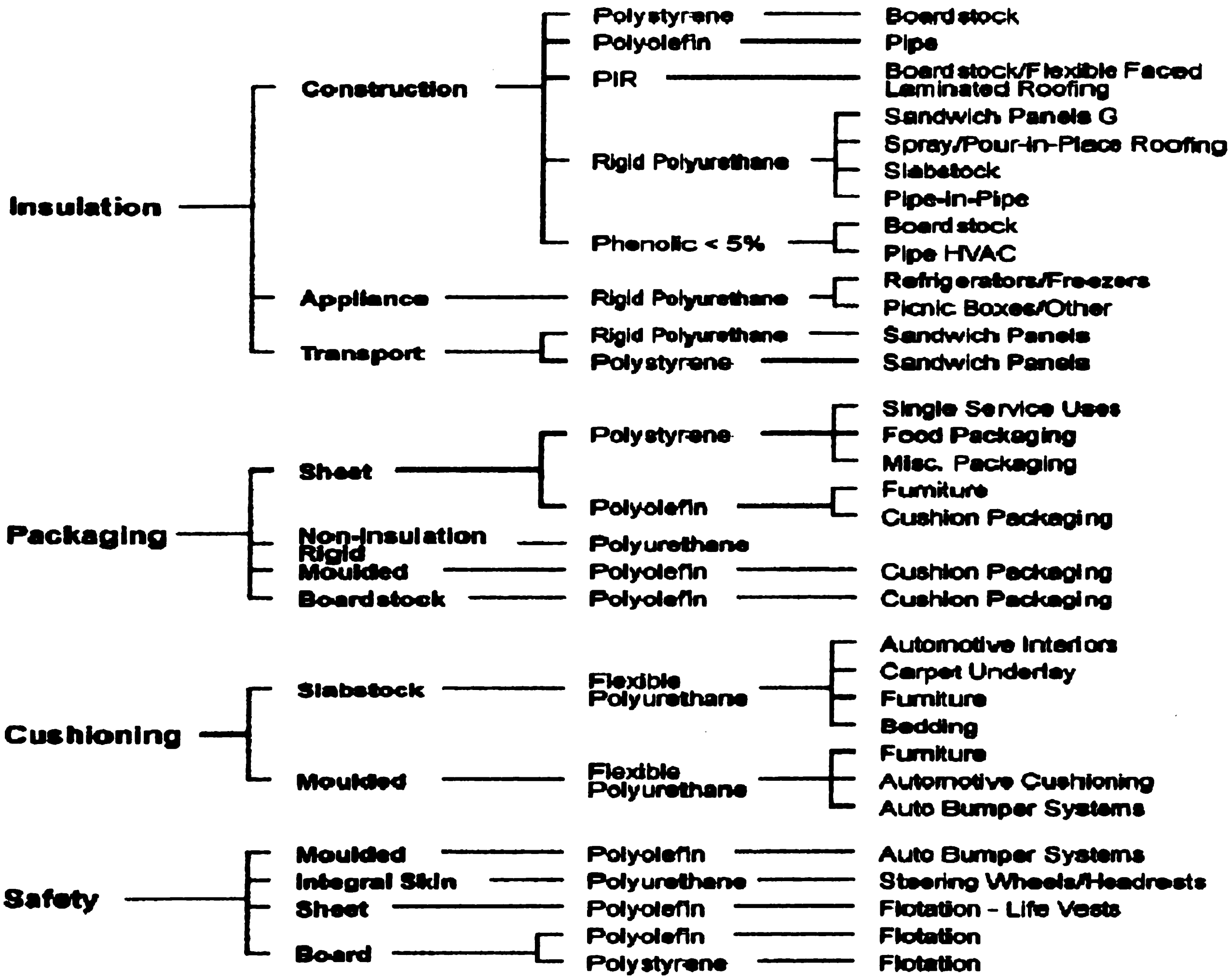

Figure 11. Major types of foam materials and their applications

A more description of these foams and these uses in packaging follows.

1.47.1 Polystyrene foam

Modern man has known about styrene for centuries. Styrene is present as a naturally occurring substance in many foods and beverages including wheat, beef, strawberries, peanuts and coffee beans. It is also found in the spice cinnamon. Its chemical structure is similar to cinnamic aldehyde (the chemical component that elicits cinnamon's flavor). Polystyrene foam is one of the rigid foams currently sold, and in fact dominates the market with urethane foam second. [13] Polystyrene foam was made first in Great Britain in 1943 but the early development was accomplished in Sweden during the mid 1930's. DOW Chemicals Company was first introduced as extruded polystyrene foam in the United States in 1943.The foam was used during world war II for construction of life rafts on troops transports and for floating equipment to shore. [13]

Styrene is a primary raw material and is a petroleum by-product. Styrene played a vital role during World War II. It was also used in the production of synthetic rubber during that time. After the war, the styrene utilization shifted towards the manufacturing of commercial polystyrene products. Synthetic styrene is also used in the manufacture of products such as automobile parts, electronic components, boats, recreational vehicles, and synthetic rubbers. [37]

Polystyrene (PS) meets tight (stringent) U.S. FDA standards for use in food contact packaging and is safe for consumers. Health organizations encourage the use of single-use food service products, including polystyrene, because they provide increased food safety. [37]

All packaging (glass, aluminum, paper, and plastic - including polystyrene) contain substances, which can "migrate," or transfer, to foods or beverages. The FDA (Food and Drug Administration) monitors and regulates residual levels of different components in food packaging to ensure safe packaging. [37]

Rigid thermoplastic polystyrene foam is available in densities ranging from 1pcf to over 20 pcf. PS foam can be purchased as a film, sheet and rod or as large slabs and containers made by steam molding techniques. Foamed film and sheet can be thermoformed into different low cost trays and for other uses in the packaging industry.

The thermal insulation properties and low cost of polystyrene foam make it competitive with other commercial insulating materials. Because of its closed cell structure, PS foam has excellent water resistance and low water vapor transmission. These properties make it possible to use as a support for floating docks and for other floatation applications. The closed cell structure and inert surface render polystyrene foams resistant to rot and mold growth. [13]

Manufacturing of poly styrene foam

Polystyrene foam can be produced either by direct extrusion and expansion of foamable beads and granules or by the injection of a blowing agent into the resin at high pressure, followed by expansion at atmospheric pressure. [13]

The two basic methods of manufacturing are being discussed below.

1) Dow Chemical Process: In this method, polystyrene and expanding agent, usually a low –boiling chlorocarbon such as methyl chloride, are blended together and extruded. [13]

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2) Badisch Anilin and Soda Fabrik process: In this method the styrene monomer and a low boiling hydrocarbon are polymerized together. The product is ground into chips and ultimately converted into low-density foam by extrusion. [13]

The production of polystyrene foam from expandable beads is as follows;

a) Preparation of expandable beads and pellets.
b) Pre expansion of beads.
c) Conditioning of the expanded beads.
d) Molding of the expanded beads.
e) Extrusion of expandable bead and pellets to form sheet and film.

The most important and the major step in producing foam sheet is Extrusion. Three major systems are used to produce polystyrene foam sheet and film for various applications. Two systems involve the extrusion of expandable high molecular weight polystyrene beads or pellets containing pentane as a blowing agent (6-7%) to produce a thin, low-density sheet and film. Pellets are being used more as a preferred feedstock than foamable beads because they give a more uniform feed. [13]

The third system incorporates two stages (bead preparation and extrusion expansion) into one step. In the one step system, high molecular weight crystals of polystyrene are used as a feedstock and produce foam sheet by addition of hydrocarbon or methyl chloride as a blowing agent during the extrusion process. This system produces a low-density sheet and / or film and is considered to have many economic advantages over the two-stage extrusion of expandable beads or pellets. [13]

Polyurethane foam has one major advantage over PS and that is that it can be "put in place" or "on the site placement". High temperature is a requirement in the manufa

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manufacturing of polystyrene foam, thus on the site foaming is not feasible. PS beads require a large quantity of heat to induce foaming, therefore, in place foaming is not possible. However, the low cost of PS foams (6-8c/bd ft) is a strong incentive for its use. [13]

Environmental concerns and blowing agents

Polystyrene foam products are 95 percent air and only five percent polystyrene. When polystyrene foam packaging is produced, a blowing agent is used in the process. Most polystyrene foam products were never made using chlorofluorocarbons (CFCs) as a blowing agent. The very few polystyrene products that were made with CFCs contained a very small portion of the nation's CFC use. According to the U.S. Environmental Protection Agency (EPA), only two to three percent of CFCs used in the United States in the 1980s went toward production of polystyrene packaging products. Polystyrene manufacturers exceeded government goals and timetables during the CFCs phase out period of in the late 1980s. Polystyrene foam products are now manufactured using primarily two types of blowing agents: Pentane and Carbon Dioxide. [37]

Pentane gas has no effect on the upper ozone layer, although, if not recovered, it can contribute to low-level smog formation. Therefore, manufacturers use state-of-the-art technology to capture pentane emissions. [37]

Some manufacturers use carbon dioxide (CO_2 or other hydrocarbons in some cases) as an expansion agent for polystyrene foam. CO_2 is a non-toxic, non-flammable gas. It does not contribute to low-level smog, and has no stratospheric ozone depletion potential. In addition, the carbon dioxide used for this technology is recovered from existing comm

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commercial and natural sources. As a result, the use of this blowing agent does not increase the levels of CO_2 in the atmosphere. [35]

However, there is still serious concern regarding the use of polystyrene products as a food packaging material. Due to present economic conditions, polystyrene food service packaging is generally not recycled. Polystyrene protective packaging and the packaging non-durables (i.e., video/audio cassettes, agriculture trays, etc.) are the primary forms of polystyrene collected for recycling. The amount of polystyrene food service packaging that is recycled has decreased during this period. Non-food service packaging is not contaminated with food and other wastes, as is food service polystyrene packaging. Therefore, it is more cost-effective to recycle. Presently, food service polystyrene packaging is not recycled because it is not economically sustainable. It is important to note that because of unfavorable economics, no other post-consumer foodservice disposable material, including paper and paperboard, is recycled in a measurable way [28].

Properties

Extruded polystyrene foam has been produced in densities ranging from 2.0pcf to 6.0pcf in many configurations. The properties and the quality of foam sheet depend on extrusion, pressure temperature, nucleating agent, polymer structure and other process variables. Low densities polystyrene foam is flexible and can be laminated to paper and high impact styrene sheet. [11]. Polystyrene foam is soluble in many organic solvents. Polystyrene foam is water repellent because of its aromatic structure and is unaffected by changes in RH. [28]. Figure 12 shows the basic structure of the polystyrene molecule.

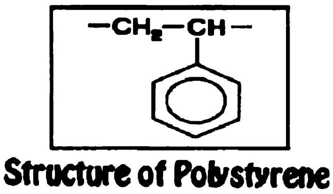


Figure 12. The basic structure of polystyrene

Since polystyrene foam is a thermoplastic, it has a well-defined softening point. The softening point of the foam is similar to that of the parent polymer and is independent of the volume fraction of gas present (density). The specific heat of the polymer depends on its structure. The specific heat of the cellular composite depends on both density and structure. The thermal expansion of the polystyrene foam mainly depends on polymer structure and is independent of density but affected by the closed cell structure. As polystyrene foam is an organic material, it can burn and since it is a thermoplastic it can melt. [12]

The molecular weight (molecular size) of polystyrene determines the structure of both extruded polystyrene foam and styrene foam beads. Decreasing the molecular weight of polystyrene increases its sensitivity to shrinkage. In general, the following rules apply regarding the molecular weight of the polymer.

1) Cell size decreases as the molecular weight of the resin increases.
2) The boundary between expanded beads (where the beads are fused to beads) is thicker for high molecular resins. [12]

1.47.2 Polyurethane Foam

The manufacturing of flexible polyurethane foams is a large business. Polyurethane foams play a vital role in every day life. The foam is used in houses, cars, schools, work places, airlines and for packaging applications. [31]

History

Mankind's curiosity, imagination and needs have pushed research and development to create a vast number of products. Once a basic product has been 'invented', then questions about its applications, uses and economical factors are considered.[38] Polyurethane was invented by Otto Bayer in the late 1930's. Early in the 1940's, some prestigious companies such as I.G. Farben of Germany, ICI of the United Kingdom and E.I. Dupont of the United States developed urethane systems for such applications as coatings for the Barrage balloon, synthetic bristles and submarine insulation/flotation. [38] Further development brought in new urethane products. These products greatly expanded the markets for flexible, rigid and energy-absorbing foams. This research led first to Poleset, then to Freon-free Poly-Set, and now our latest backfill system, Poly-Ground. [38]

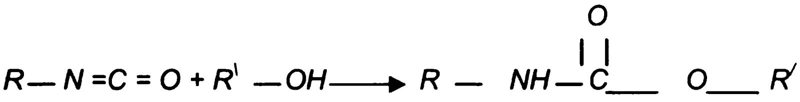
Forward Enterprises was a pioneer in the use of a rigid polyurethane foam to set direct-embedment utility structures. Numerous companies have investigated the effectiveness of the use of foam in areas of corrosion-protection and structural integrity for direct-embedment structures. [38]

The long-term effectiveness of polyurethane foams has been established by Forward Enterprises and by E. I. Dupont. Their research showed that partial embedment of foam-faced panels in soil for ten years "showed negligible deterioration of the foam and of the attached metal protected by the foam."[38]

Bayer has a vast variety of case studies of urethane foam applications for protecting metal structures from chemical attack, both above and below ground level. These show that urethane applications counteract the porosity of masonry structures. [38]

Manufacturing process;

The Urethane foam manufacturing process involves a series of complex chemical reactions. These reactions lead to the formation of many chemical bonds in addition to the urethane groups. The two most important reactions in the manufacturing of flexible urethane foam are the reaction between isocyanate and hydroxyl compounds (polyesters or polyester polyols) and the reaction between isocyanate and water. The former reaction is considered as the chain -propagating reaction and is shown below. [13]



$$R—N=C=O + R^{1} —OH \longrightarrow R — NH—\overset{\overset{O}{\|}}{C}—O—R'$$

(Urathane)

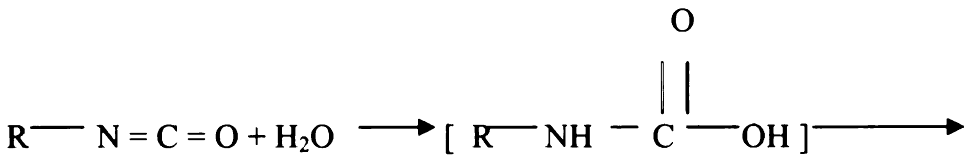
This reaction is common to both flexible and rigid polyurethane foam formation. [13]

An alcohol molecule first reacts with an isocyanate to form an active complex. This complex further reacts with another alcohol, forming an intermediately, which decomposes to produce the urethane group and free alcohol. The general expression for this type reaction may be written as follows:

$$R^{\backslash}NCO + \text{catalyst} \longrightarrow \text{complex} \longrightarrow \text{active hydrogen Compounds} \longrightarrow$$

$$\longrightarrow \text{products + catalysts}$$

The second reaction is called the **water –isocyanate** reaction. This reaction is responsible for foam formation and liberation of carbon dioxide. The first step is the formation of unstable carbamic acid, which decomposes to form an amine and carbon dioxide. The thermal conductivity of the encapsulated gas is very important in insulation and because of that the second step is minimized in the production of closed cell rigid urethane foam. The blowing agent Freon is used in the later case, and the expansion of the foam is the result of the volatilization of the fluorocarbon, caused by the exothermic isocyanate alcohol reaction which is shown below. [13]



$$R{-}N=C=O + H_2O \longrightarrow [\,R{-}NH{-}\overset{\overset{\displaystyle O}{\|}}{C}{-}OH\,] \longrightarrow$$

Carbamic acid

$$R{-}NH_2 + CO_2$$

The reaction mechanism is too slow to produce economical, commercial urethane foams. Catalysts are used to increase the reaction rate and to establish the proper balance between chain extension and the foaming reaction. It is essential to entrap the gas (CO2) efficiently and to provide sufficient strength in the cell walls and struts at the end of the

foaming reaction to maintain the structure without collapse. For rigid insulation foams, a proper balance between exothermic chain –propagating reactions and endothermic volatilization of the Freon blowing agents is essential. The objective is to produce a stable foam during final curing of the structure. [13]

A second important function of the catalysts in the foam reaction is to complete the reactions, resulting in a proper cure of the foam. Catalyst selection and concentration is governed by the type of foam to be made, the nature of the foaming process and the foam processing equipment and conditions available. [12]

The most commonly employed catalysts are tertiary amines and organmetallic catalysts. [12]

Types of polyurethane Foams:

Currently urethane foam is primarily available by three types.

1) Flexible foams:

These foams are based on a propylene oxide adduct of glycerol (3000 mol.wt.). The desired properties of the resulting foam are low density, high load bearing ability and low set.

2) Rigid Foams:

These are made by both prepolymer and one shot processes. The one-shot method produces low cost, high performance foams.

3) Semi rigid Foams;

Semi rigid foams are mainly used in the automotive industry where shock absorbing and elasticity are desired. [12]

Manufacturing Methods

Foam properties are generally dependent upon the mode of preparation and the mechanical processes used. In general, three methods are used:

1. Poured in place, this method is used for filling irregular voids with foam.
2. Slab stock; this method is used in applications where foam can be most economically cut to required shape.
3. Sprayed; used in applications where field moldability is required. [13]

Foam properties vary depending on how the foam is produced [13]

Flexible foam

Polyether polyols based on alkylene oxide adducts of simple polyhydric alcohols, highly active tin catalysts and alkyl silicon –polyoxyalkylene copolymer surfactants are the major components of one- shot urethane foam systems. These materials and other formulation components, together with processing variables, play a significant role in the successful production of foam. [13]

In the one-shot system, a polyol and a diisocyanate, water, catalysts and other processing materials are mixed. Chain extension, cross-linking and foaming reactions take places within seconds during the gas foaming step. As the molecules line up and form a network, viscosity increases, the carbon dioxide released is retained in the bubble and within a few minutes the foam has turned into a solid cellular mass. [13]

The major properties of flexible foam that influence its use are [32]

1. Density
2. Compression
3. Sag Factor
4. Fatigue loss
5. Hysteresis
6. Tensile
7. Elongation
8. Tear

Density levels started out at around 2.0 lbs/cu. ft. The density levels were lowered as the industry became more competitive. Currently, the most popular foam has a density of 1.2-lbs/cu. ft, though there is a trend to increase densities up to 3.5-lbs./cu. ft. In most cases, except for high quality, high price items, it is best to maintain a minimum of 1.4-lbs./cu. ft. density. [32]

Compression refers to a definition adopted by the American Society of Testing Materials (ASTM). By definition therefore, compression is "the load bearing capacity of a standard specimen indented by a circular compressor foot of 50 sq.in. at 25% deflection." The normally accepted standard is a piece of foam measuring 25 in. x 15 in. x 4 in. thick. Increasing the water in the formula and decreasing the amount of auxiliary blowing agent can increase compression during the production process. [32]

Sag Factor is the compression of a piece of foam at 65% deflection divided by the compression at 25% deflection and expressed as a pure numeric. The higher the density, the higher the sag factor, regardless of the type of foam. The higher the sag factor, the

better the foam. The sag factor range on most foam is from a low of 2.0 to a high of 3.0. Any foam having a sag factor less than 2.0 is usually poor quality foam, which indicates that it was poorly manufactured. [32]

Fatigue loss is a factor that describes what will happen to a cushion during service. Typically it predicts what the height loss and compression loss will be after it has been in service for some time. Inexpensive 1.32-lb./cu. Ft foam will have a height loss usually over 2 ½ % with a compression loss of about 30%, whereas a 2.0 lb. urethane density foam will have height losses as low as 1/2% and compression losses as low as 10%. [32]

Hysteresis loss is relative to compression readings. The lower the hysteresis loss (higher the resilience) the better the foam quality. No foam should have a hysteresis loss greater than 40%. If it does, generally there is something wrong with the foam. [32]

Tensile, Elongation and tear are three material tests used to determine foam quality and are simple to perform. Tensile strength is the force required to pull apart a piece of foam and is expressed in pounds per square inch. Elongation is the amount the of foam will stretch before it pulls apart. Tear strength is the force required to actually tear the foam. The value is expressed in pounds per linear inch. [32]

Rigid foam

Rigid polyurethane foam has versatility in both directions because of its physical strength and mechanical properties. These qualities enable it to be used in a wide variety of multi-functional building products, which combine insulation with load bearing, sealing, impact resistance, weight and space saving, and ease of maintenance. [13] Rigid polyurethane foam provides a high level of compression and shear strength, which is further enhanced by bonding with facing materials such as metal or plasterboard. [48]

Low thermal conductivity

Rigid polyurethane foam has one of the lowest thermal conductivity ratings of any insulant, which allows efficient retention of heat or, alternatively, maintenance of a refrigerated or frozen environment. [48] Effective insulation in all types of buildings is important in the conservation of non-renewable fossil fuels. [48]

Adhesion

The adhesion strength of polyurethane foam is extremely high. This strength develops during the short period between mixing and the final curing process. Due to its high adhesive strength, rigid polyurethane foam can be effectively bonded to a wide range of building facings. The adhesion is so strong that the bond strength is usually higher than the tensile or shear strength of the foam. [48]

Compatibility/Stability

Rigid polyurethane foam is compatible with a large number of building and packaging facings, including paper, foil, glass fiber, aluminum, plasterboard, plywood and bitumen. These materials add to the inherent strength of the foam, which enable its use as semi-structural panels and cladding and allowing foam to accept a variety of finishes so that it can operate effectively as a moisture barrier in conditions of high humidity. The water vapor permeability of rigid polyurethane foam is low and is enhanced in most building applications by the incorporation of a moisture barrier of polyethylene film or aluminum foil. [48] Rigid polyurethane foam provides excellent resistance to a wide range of chemicals, solvents and oils. [32]

Heat and Fire properties

Like all organic building materials - wood, paper, plastics, paints - rigid polyurethane foam is combustible, although its ignitability and rate of burning can be modified to suit a variety of building applications and it can be formulated to meet the relevant national regulations. [48] Rigid polyurethane foam can be used in applications which experience exceptional extremes of temperature, from -200°C to +100°C.

Density

At low densities (e.g. 30kg/m3), the volume of polyurethane polymer in rigid polyurethane foam is around 3 per cent. The remaining 97 per cent of the foam is gas trapped within the cells, which provides the low thermal conductivity properties. The lightness of the foam is an important aspect in terms of transportation, handling and ease of installation. [48]

1.47.3 Polyolefin foam

Polymer Foams are used in many different types of applications and it is hard to find an area where they are not utilized. [28] Polyolefin Foams are a relatively recent development compared to the other types of foam. "Olefins" or "alkenes" are defined as unsaturated aliphatic hydrocarbons. Ethylene and propylene are the main monomers used for polyolefin foams, but dienes such as polyisoprene are also be included. The copolymers of ethylene and propylene (PP) are included, but not polyvinyl chloride (PVC), which is usually treated as a separate polymer class. The majority of these foams have densities <100 kilograms per cubic meter, and their microstructure consists of closed, polygonal cells with thin faces..." [32]

The tremendous growth of polyolefin resins is well known to the plastic technologist or anyone else connected with the plastic industry. From its beginning in Europe in the early 1940's, the production of low density polyethylene has risen to phenomenal heights (over 3.7 billion pounds in 19670.In the early 1950's plastic foams based on polyolefin resins first appeared commercially. Since then the market has increased, but not at the phenomenal rate of growth that polystyrene and polyurethane foam have enjoyed. The primary reason for this relatively slow growth is high process costs that result in an unbalanced cost/performance ratio. [13]

History:

The earliest patent, which was issued for the preparation of expanded polyethylene, was granted to Calendar's cable and construction Co. Ltd. in 1945 and described the physical expansion of polyethylene using carbon dioxide. Other patents have been issued dealing with the physical expansion of polyethylene by using volatile liquids or gas pressurized into the polymer melt, with subsequent depressurization to produce cellular polyolefin. These processes were commercially not successful since they did not produce cellular products of acceptable cost/performance ratio. However, similar methods using volatile liquids or expanding agents have been successfully developed and commercialized. [13]

Polyolefin Foams are a relatively recent development compared to the other types of foam. Polyolefin foam processes were developed in the 1960s and 1970s. [32]

Methods of preparations:

In general, cellular plastics or composites based on polyethylene and polypropylene can be produced by both physical and chemical methods. Each process produces a specific structure that depends on polymer properties, volume fraction present in the foam and cell morphology.[13]

At present, there are four methods involving chemical foaming agents that are used commercially;

1. Direct extrusion expansion.
2. Compression molding using organic peroxides.
3. Pressure molding (Engelite and U.C.process)
4. Atmospheric expansion of radiation – cured sheet.

Polyolefin foam properties;

Low density chemically cross linked PE foam made by the high pressure molding process and by atmospheric pressure expansion of procured materials has been evaluated by Kadowaki and compared with other foams and found out that it is more flexible, strong and semi rigid than other foams. It has shock absorbing characteristics and water absorption is low than other plastic foams. It has a superior chemical resistance and electrical properties. It is harmless to human beings and does not corrode any surface metal. Polyolefin's process ability is good. Cross-linking polyethylene has further advantages like Very foam uniform closed cells (1-6 mils). It has excellent esthetic appeal and acceptable heat insulation properties. Cross- linking polyolefin has a density as low as 1pcf. and an excellent ultra violet and weather resistance

1.5 MANUFACTURING METHODS FOR PLASTIC FOAMS

There are many processes to make plastic foams. Selection of a process depends on many factors, for example

1) Quantity and production rate
2) Dimensional accuracy and surface finish
3) Form and detail of the product
4) Nature of material
5) Size of final product

Typically, plastics processes have three phases:

1. Heating - To soften or melt the plastic resin
2. Shaping / Forming - Under constraint of some kind
3. Cooling - So that it retains its shape [8]

The most common processes are injection molding and extrusion processes. A brief overview of these processes is given below. The most universal and efficient for creating a uniform thick and equally dense skin is the rotational molding or roto molding process. [31]

1.51 Injection molding

. The most common way of producing foam parts is injection molding. Different classification systems exist. The classification described by Fydor A.Shutov [26] into four groups is mentioned below

1) Low pressure (LP) processes, up to 20 MPa
2) High pressure (HP) processes, up to 100Mpa or more

3) Gas counter pressure process and
4) Two- (or more) component processes. [26]

Basic Principle.

Plastic foam injection molding is similar to conventional injection molding. [26]

Injection Molding is the process of forcing melted plastic in to a mold cavity. The part can be ejected after the plastic has cooled. Sometimes injection molding is used in mass-production and prototyping. Injection molding is a relatively new way to manufacture plastic foam. The first injection molding machines were built in the 1930's. [31] There are six major steps in the injection molding process:

1.Clamping

An injection-molding machine consists of three basic parts; 1) the mold, 2) the clamping and 3) injection units. The clamping unit is used to hold the mold under pressure during injection and cooling. Basically, it holds the two halves of the injection mold together. [31]

2. Injection

Plastic material in the form of pellets is loaded into a hopper on top of the injection unit during the injection phase. The pellets feed into the cylinder where they are heated until they become molten. A motorized screw within the heating cylinder mixes the molten pellets and forces them to the end of the cylinder. Once enough material has accumulated in front of the screw, the injection process begins. The molten plastic is inserted into the mold through a sprue, while the pressure and speed are controlled by the screw. Some injection molding machines use a ram instead of a screw. [31]

3. Dwelling, Cooling, Ejection

The dwelling phase consists of a pause in the injection process. The molten plastic has been injected into the mold. Pressure is applied to make sure all of the mold cavities are filled. The plastic is then allowed to cool to its solid form within the mold. The clamping unit is opened, which separates the two halves of the mold. An ejecting rod and plate eject the finished piece (plastic foam) from the mold. Foam formation takes place following injection, either as a result of mold expansion or due to regression of plastic material from the mold. [26]

1.52 Extrusion

Extrusion methods to produce plastic foams are readily available. The main advantages of these methods include continuous and high productivity, simple equipment and precisely sized articles. Solid and hollow profiles made of plastic foam can be successfully substituted for wooden articles (without any further machining) and profiles made of unformed plastics reduce feed stock consumption by 15 to 40 percent. Extrusion is particularly economical for fabricating finished articles that do not require any secondary processing. [26]

Basic principle

Extrusion occurs when a solid plastic (also called a resin), in the form of beads or pellets, is continuously fed into a heated chamber and the product is carried along by a feed screw. The feed screw is driven via drive/motor machine. Tight speed and torque control are critical steps in producing quality product. The product is compressed, melted, and forced out of the chamber at a steady rate through a die. Dies have been engineered and machined to ensure that the melt flows in a precise desired shape. There is almost always downstream processing equipment that is fed by the extruder. Depending on the end product, the extrusion may be blown into film, wound, spun, folded, and rolled, and a number of other possibilities. [40]

Plastics are very commonly extruded. Rubber and foodstuffs are also quite often processed via extrusion processes. Occasionally, metals such as aluminum are extruded plus trends and new technologies are allowing an ever-widening variety of materials and composites to be extruded at continually increasing through put rates. [40]

Foam formation takes place when the polymer contains blowing agents which cause foaming at the extruder exit (or die) [26]. Figure 13 represents the basic extrusion machine structure.

Basic Extruder Machine

The feed screw, barrel, and temperature controller form a section of the extruder called the plastication unit. Plastication is defined as the conversion of a thermoplastic to a melt. This is critical to successful extrusion processes. [40]

The major components in an extruder are following.

Feed screw

The job of the feed-screw is to move the resins through the barrel chamber in a steady and predictable manner. There are three main defined sections in a basic feed screw.

The feed zone takes resin from the hopper and conveys it along. Resin pellets encounter friction from feed screw surfaces, barrel surfaces, and each other. This mechanical friction provides about 85% of the required heat, so it is critical that the drive equipment, which turns the screw, must have the HP (horse power) capabilities to overcome friction and

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and turn the feed screw at a steady and controlled rate. Some extruders can continue to plasticate materials long after their external heat sources are shut down. [40]

The compression zone is next. The channel depth between screw flights diminishes and the result is to pressurize melting resin. Friction, barrel heating, and compression complete the melting process. Two important design parameters are associated with this zone.

- The compression ratio is measured the channel depth at the end of this zone. Different compounds or operating pressures require different compression ratios.
- The length of the compression zone affects the rate of compression. These two parameters will be different for different compounds. [40]

The metering zone has a constant channel depth and primarily exists to further mix molten resin. The end result is a smooth consistent melt with uniform temperature. [40]

Devolatizing section.

4. In some processes, a de-gassing or devolatizing section is required. This is a shorter zone that immediately follows the compression zone (See figure 13). Channel depth is suddenly increased, and the resulting pressure drop causes a release of gas, which can be vented or drawn off via a vacuum pump. The remaining melt is re-compressed and metered. The following figure 13 show a basic Extruder machine. [40]

Figure No. 13

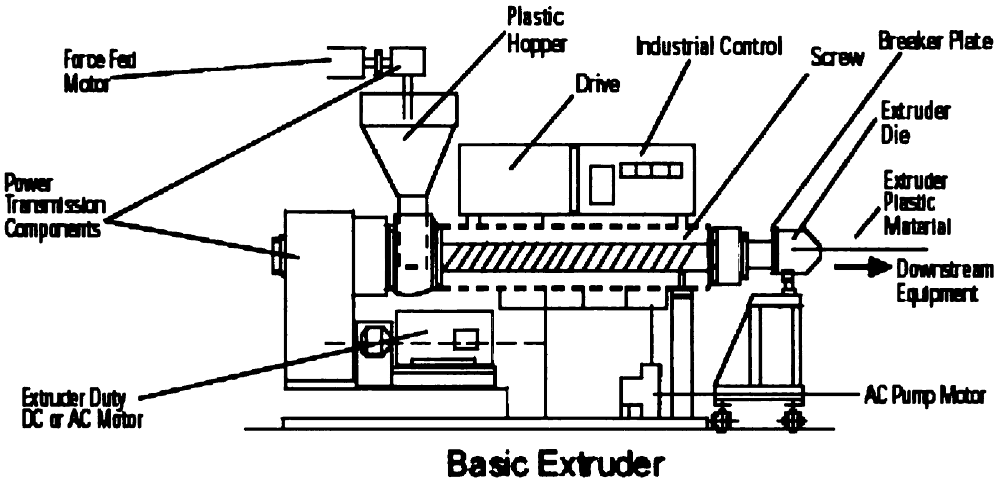

Figure 13. Basic diagram of Extruder machine

1.53 Other processes

a) Rotational Molding

The most universal and efficient method for creating uniform thick and equally dense foam is rotational molding [26] In this process; plastic powder is scooped into a mold. The mold is rotated over a large gas burner. As the mold gets hot, the plastic melts and sticks to the mold. This method is used to make large hollow objects like water tanks and barrels.

b) Compression Molding

Compression molding is used for thermoset resins. Dry powder is put in a mold, which is squeezed and heated until the plastic melts and cured. This is used for making ashtrays, cups and plates, and some electrical switches.

c) Reaction injection Molding

In this process, two chemicals are mixed together and squirted into a mold and the chemicals react together. This is used to they make car bumpers, some disposable cups and plates, and meat trays.

d) Vacuum forming

In vacuum forming process a sheet of plastic is clamped in a frame and heated until it becomes stretchy. It is then sucked into a mold. This process is used to make the inside of your refrigerator, bath and hand basin. It is also used to make a lot of packaging for cosmetics, chocolates, biscuits, some yogurt containers and disposable cups.

e) Fabrication

Some thermoplastics are fabricated like sheet metal. Sheets of plastic are cut to the desired shape. They can then be folded by heating a narrow line through the plastic. When it is soft, the sheet will bend along the heated line. Sheets can be joined together by gluing, or by welding. The joint is heated with hot air and a thin filler rod is forced into the gap. These fabrication methods are used to make acrylic signs and displays, and industrial tanks and equipment. They can also be used to manufacture laboratory fume cupboards and exhaust fans. Thin flexible plastic sheets are used for making folders,

wallets, swimming pool liners, inflatable toys and raincoats. The seams are welded using ultrasonic vibration.

f) Styrene Foam.

To make blocks of styrene foam, or complicated shapes like a cycle helmet, pallets are scoop into a mold and heated with steam. The steam makes the pellets swell and stick together. [1]

CHAPTER 2

MATERIALS AND METHODS

Chapter 2 covers the material and methods section for the research " Performance properties of biodegradable foam (Green Cell® foam) .The following M&M are presented

2.0 Twin Screw extrusion process

2.1 Cushioning characteristics

2.2 Dimensional stability

2.3 Moisture sorption

2.4 Thermal insulation

2.0 Green Cell® Foam is produced by twin Screw extrusion process

Materials:

The type of starch used was hydroxypropylated high amylose cornstarch (70% amylose content). The starch was purchased from National Starch and Chemicals (Indianapolis, IN), under the trade name of HYLON 7. The inherent moisture content of the starch was 11.2% under ambient conditions.

Water was used as the plasticizer as well as the blowing agent. Water content was maintained at 7-10% of the starch used. Talc (Magnesium Silicate), used as the nucleating agent, was obtained from Luzenac (Ontario, Canada). It has a specific gravity of 2.

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of 2.76 and a bulk density of 150 kg/m^3. The talc content was maintained at 1% for all the experiments.

Poly (hydroxyamino ether) (PHAE) is an additive, which offers the adhesion and durability of epoxy resins with the flexibility and process ability of thermoplastic resins. PHAE was purchased from Dow Chemicals (Midland, MI), under the trade name BLOX 110. PHAE has a melt temperature of 75°C, and is produced by reacting liquid epoxy resin (LER) with hydroxy functional dinucleophilic amines and resorcinol diglycidyl ethers (RDGE) [45].

Experimental Setup:

EQUIPMENT FOR GREEN CELL

1) Thick material. Twin Screw Co –Rotating Food Extruder: Wenger TX-80. (D=80 mm, L/D=20)
2) Positive displacement pump: For injecting water.
3) Screw Feeders1&
4) An Annular Die: 2.5mm width
5) Down stream equipment for cutting and rolling or laminating foam sheets.
6) Figure 2 represents a process flow diagram of making Green Cell foam.

The experimental setup used in this study was a twin-screw extrusion system (fig. 14). The twin-screw extrusion system consisted of an extruder driver with a speed control gearbox, a Werner Pfleiderer ZSK-30 twin-screw co-rotating extruder with a screw diameter of 30 mm, an L/D of 32, a positive displacement pump for injecting water into the extruder, accurate single-screw feeders for feeding starch, and PHAE and talc could be fe

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be fed individually or as a mixture. A cylindrical filament die 2.7mm in diameter and 8.1 mm in length, with a cooling sleeve was assembled to the extruder. The sensors were mounted on the die to measure the temperature and pressure of the melt. A high-speed cutter was used to get cylindrical foam samples of required size.

Basic principle

The foam sheets are being produced on an industrial scale twin-screw food extruder, Wenger-80, having a screw diameter of 80mm and an L/D of 16. An annular die of width 2mm is used. Talc is not used in the production of starch foam sheets in order to get the minimum density product. Also, the addition of talc rendered the product more brittle.

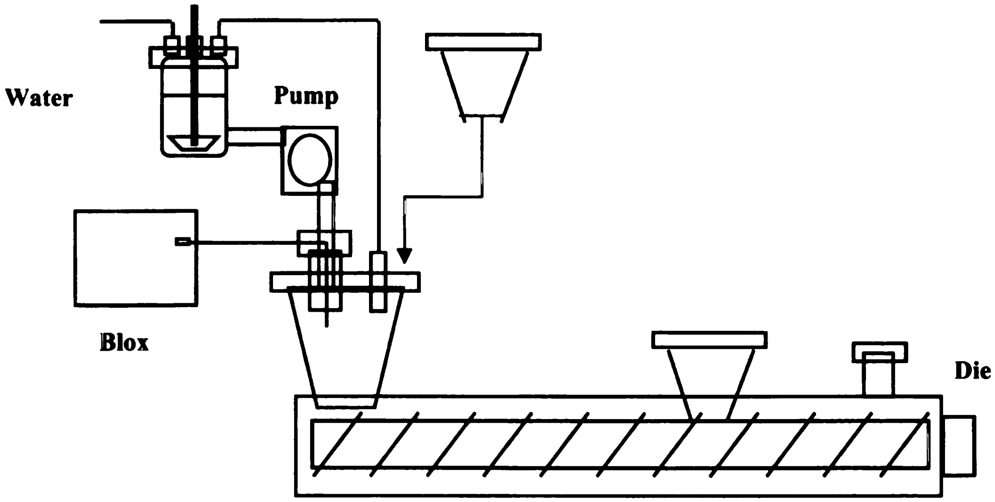

Figure 14. Process Flow Diagram of Green Cell Foam.

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2.1 Cushioning Characteristics of Green Cell® Foam.

The cushioning characteristics of Green Cell® Foam were determined, and compared with the G values of different plastic foams commercially available. The effect of relative humidity and time on the G value of Green Cell® foam was also evaluated.

2.11 Instrumentation (Lansmont drop tester)

G value of one and two inch thick GCF were determined using Lansmont drop tester, (Monterey CA) at the controlled temperature 22°C and 50% RH .The instrument consists of the following components.

1) Instrumentation and shock sensors
2) A dropping platen

The dropping platen must have a mechanism to attach additional mass for adjusting its total mass to a desired value.

3) Reaction Mass

Reaction mass would be attached to the testing machine. Reaction mass would be sufficiently heavy and rigid so that no more than 2% of the impact acceleration is lost to the reaction mass while conducting dynamic tests. The reaction mass must be in contact with the ridged impact surface so that the two bodies move as one.

4) Accelerometer

The accelerometer is a data storage system and is required to monitor acceleration versus time histories. The instrumentation system needs the following minimum requirements. Frequency response range from 2Hz or less to at least 1000Hz.

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Accuracy reading to within 5 % of the actual value

Cross axis sensitivity less than 5 % of full scale, and the instrumentation are required to measure the impact velocity to an accuracy of

±2% of the true value.

Test material

KTM Industries, Inc. develops, manufactures a bioplastic Green Cell® Foam. The type of starch used was hydroxypropylated high amylose cornstarch (70% amylose content). The inherent moisture content of the starch was 11.2% under ambient conditions. Green Cell® Foam is produced by twin Screw extrusion process. 25 pieces each of Green Cell® foam having dimensions of 8"x8"x1" and 8"x8"x2"were used.

20 pieces each of Green Cell® foam having dimensions of 6"x 6"x 1" and 6"x 6"x 2" were used

2.12. Methods.

Conditioning

The Material was conditioned at standard conditions (25°C and 50% relative humidity) prior to do the cushion testing. [3]

Determining dynamic shock cushioning characteristics.

The specimen was loaded onto a rigid plate or onto the machine platen to 0.025 psi (17.55 kg/m^2) on the top surface area. After a 30 sec interval, the thickness to an accuracy of 1/32 inch was measured by averaging the thickness measurements of the four corners of the specimen. This value was recorded as the specimen thickness.

The top surface area of the specimen was measured with an apparatus yielding values accurate to 1/32 in. The mass of the specimen was measured with an apparatus yielding values accurate to 30g. [3]

The test specimen was centered on the impact surface face and the platen was positioned to strike the cushion on its top surface area. The specimen was subjected to a series of five drops at a pre-determined static loading and impact velocity allowing a minimum of 1 min between each drop. A complete acceleration time record for each drop was recorded and the impact velocity of the platen was measured just before impact to ensure that it was representative of the impact velocity equated to the desired free drop height. To obtain dynamic data for a given cushion, it is necessary to repeat the five test drops on new specimens varying some aspect of the test such as static loading impact velocity or cushion thickness. [3]

2.13 Calculation

The density of a test specimen was calculated using the following equation.

$$\mathbf{D = (3.81x\ M)/\ (L_1xL_2xT)}$$

D= density (lb /ft^3)

M = mass of the specimen (g)

L1 = length of the specimen (in)

L2 = width of the specimen (in)

T = original thickness of the specimen in

For free fall height, the following equation was used

$$\mathbf{H = Vi^2 /2g}$$

and impact velocity can be calculated using the following equation.

$$\mathbf{V_i = \sqrt{2gh}}$$

H = free fall drop height (in)

Vi = measured impact velocity in/sec

G = acceleration due to gravity 386 in/sec^2

Dynamic set can be calculated using the following equation

$$\textbf{Dynamic set \% = [(T-F)/T] x 100}$$

T = original thickness of the specimen (in)

F = thickness of specimen after test (in) [3]

2.14 Effect of % RH and temperature on G values

Method.

To determine the effect of relative humidity on GCF's G value, 2- inch thick material was tested to determine its G value according to ASTM standards D-1596. Seven pieces of GCF were determined based upon 1st impact and then these seven pieces of Green Cell®

foam were held under seven different relative humidity conditions at 30° C for two months.

After two months, GCF pieces were again tested to determine their G value at the same static load, drop height and weight.

2.15 Effect of Time on G values.

1-inch thick material and 2-inch thick material were tested at different times during three months of storage. The G value of 1-inch foam was 80.80(average) initially. The same batch of material was then tested after two months at ambient conditions (humidity and temperature conditions varied according to the external weather conditions). 2nd set of fresh material was then received and was tested again to determine the G values at same the drop height, bearing area of foam and static load. Fresh material had a G value of 80.804(average of five drops).

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2.2 Dimensional Changes

Dimensional changes (length, width and thickness) of GCF and net weight loss /gain of the product (Green Cell®) at 30°C/ several different humidity conditions was determined. An experiment was set up using samples of Green Cell® foam and saturated salt solutions. Salt solutions were prepared according to ASTM standard E104 [2]. Detailed can be seen in appendix E.

Dimensional changes and weight loss/gain were measured periodically until equilibrium conditions were achieved. Effects of ambient conditions on GCF were also determined.

Materials and Methods,

Materials.

Dimensional changes at different relative humidity (%RH) conditions and 30°C

- 14 pieces of Green Cell® Foam having dimensions of 2"x 2" x 1"
- Seven RH chambers
- Digital vernier caliper (supplies)

Material behavior at ambient conditions

- Three pieces of Green Cell foam having a dimension s of 8" x 8"x 2" were used to examine the Green Cell® behavior at ambient conditions.

Change in thickness under load

- Several pieces of Green Cell® foam having a dimensions of 8"x8"x2" and 8"x8"x1" were used to examine the effects in thickness under load conditions.

- Vernier caliper
- Dematerialized water
- 8 one gallons of bottles
- 8 wooden blocks 8"x 8"x ½"

Methods:

Dimensional changes at different relative humidity (%RH) conditions and 30°C.

Salt solutions were prepared according to ASTM standard E104 (Appendix E). Green Cell® foam material was cut into 2x2x1 inch pieces. The dimensions were measured using a digital vernier caliper and weight was measured using an analytical balance. All the pieces were placed into the HDPE buckets containing different salt solutions to create specific humidity conditions. All the HDPE buckets were placed inside an environmental chamber at 30°C.

Each piece was marked as to its length width and thickness. Dimensional change in each piece was measured by vernier caliper and weight was checked by analytical balance each day for the first week and then at a time interval of 1-3 days until the weight of the product became constant. Each piece was marked at one specific location when taking the first reading and all subsequent readings were taken using this as reference. One piece of material was removed from the bucket and measurements, at a time, measured quickly as the product is sensitive to moisture. Latex gloves were used to avoid any contamination or hand moisture.

Material behavior at ambient conditions.

1" and 2" Green Cell® foam was kept under observation in the experimental lab where temperature and relative humidity conditions change according to the weather conditions for about three months.

The Change in thickness of Green Cell® Foam under Specific load

a) At 50%RH and 25°C

b) At ambient conditions

Two sets of experiments were conducted to determine the change in thickness under load. One set of experiments was conducted in a room where temperature and relative humidity conditions varied according to ambient conditions. Another set of experiments was conducted in a controlled conditioned room where temperature and relative humidity conditions were maintained at 25°C and 50% RH. One gallon Plastic bottles were filled with water and placed on top of the Green Cell® foam pieces which had been covered with wooden blocks. Wooden blocks were placed over the Green Cell® foam to provide uniform weight distribution over the foam pieces.

Thickness of GCF was measured periodically with using a digital vernier caliper. Thickness was determined at the same location each time to minimize error.

2.3 Sorption isotherm

Sorption isotherm was developed at different RH% conditions and net weight changes at 30°C and different RH %conditions were measured.

2.31 Sorption isotherm at different %RH and 20°C,25°C and 30°C

2.32 Net weight changes at 30°C and different %RH conditions

2.31 To determine the moisture sorption isotherm of the product at 20°C, 25°C 30°C

Empty aluminum dishes were weighed and approximately 0.5-2 grams of product was added to each dish. Green Cell® foam was cut into small pieces to increase the surface area of the product to allow it to reach equilibrium conditions. Dishes were reweighed. Triplicates were prepared for 7 or 8 humidity conditions. Aluminum dishes containing GFC were then placed over saturated salt solution prepared at different relative humidity conditions. Three replicates were prepared. Storage temperatures used were 20°C, 25°C and 30°C.Weight readings were taken every day for the first week, then at a time interval of 1-3 days until the weight of the product became constant. The equilibrium moisture content of the samples, was determined using the following formula:[18]

$$Me = \frac{W_e}{W_i(M_i+1)-1}$$

Where,

W_e. Equilibrium or final weight of the product

W_i. Initial weight of the product

Mi. Initial moisture content of the product

Sorption isotherms were then plotted at the three temperatures used GCF.

The GAB model was used to obtain the best fit for the product. Graphs were plotted between aw/Me and Me to obtain various constants (α, β, γ) for each temperature to develop the GAB model. Comparison was made between experimental values and the GAB model values. RMS values were then calculated. The best fit was determined using the RMS value, the lower the RMS value, the better fit.

Determination of the Initial Moisture Content (Mi) of the product by Gravimetric method:

Initial moisture content was determined using the AOAC official method 934.06. as modified. [4]

Three empty aluminum dishes were weighed and 1-2grams of product added and reweighed. The product was then placed in a Laboratory National vacuum oven at 75-80°C under 22-25in Hg for 8-9 hours to determine the moisture loss from the product. Initial moisture content of the product (dry basis) was then calculated using the following formula: [4]

$$\text{Initial Moisture content of the product} = \frac{W_i - W_d}{W_d} \times 100$$

Where,

W_i = initial weigh of the product

W_d = Final weigh of the product

2.32 Net weight changes

Salt solutions were prepared according to ASTM standard E104 [2]. Detailed calculations can be seen in appendix E. Green Cell® foam material was cut into 2 x 2 x 1 inch pieces. The weight was measured using an analytical balance. All the pieces were placed into the HDPE buckets containing different salt solutions to create specific humidity conditions. All the HDPE buckets were placed inside an environmental chamber at 30ºC.

Weight was checked by analytical balance each day for the first week and then at a time interval of 1-3 days until the weight of the product became constant. One piece of material was removed from the bucket and measurements were taken quickly to avoid extra moisture absorption/desorption. Latex gloves were used while taking the reading to avoid any contamination or hand moisture.

2.4 The package insulating ability (R -Value) and bulk density of Green Cell® foam.

A modified version of ASTM D3103 (ice melt method) [10] was used to quantify the insulating ability of a package by specifying a means for calculating its thermal resistance (R -value). Density of the foam was calculated .In order to calculate the R- value R-value, a cooler measuring 11 x 10 x 9 $^{1/8}$ inches was fabricated from GCF and used as the test specimen. EPS and Green Cell® coolers were made to have the same dimensions. To compare the R- value of Green Cell® with EPS, experiments were performed at the same time, in the same environments with the same equipment and the same amount of ice. Experiments were performed in two different environment, 30°C and 80% RH and 25°C and 50% RH. [5 a]

2.41 Materials.

- For density calculations three pieces of Green Cell® foam having dimensions 8"x8"x2" and three pieces of Green Cell® foam having dimensions 8"x8"x1"were taken.
- Ruler
- Analytical balance
- **Ice Melt method [10]**

Regular cubed ice or crushed store ice can be used. The amount of ice was used was based on the available inside volume of the coolers (EPS and GCF). Approximately, 1/2 of the inside volume was filled with ice.

- Package:

- Green Cell® cooler. A GCF cooler was made by using couurugated fiberboard as a frame. Hen placed into the fiberboard Slabs of GFC were then placed into the fiberboard box.
- b) EPS Coolers:

An EPS cooler was made of $1^{1/2}$-inch thick EPS foam.

- Bucket:

Plastic buckets was used the coolers it. Metallic buckets can interfere with the calculation of the package R-value by providing a reflective surface not associated with the coolers itself. Same size and same color buckets were used for GCF and EPS coolers.

- Duct tape or any sealing adhesive tape:

Sealing is a very important step. Stray air currents can flow in and out even through the smallest of openings. This can carry enough heat to render the best insulator ineffective.

- Ruler: to measure the dimensions.
- Thermometer: graduated cylinder or weight scale [10]

2.42 Methods

Density of the Green Cell® Foam:

Density of Green Cell® foam were calculated .Two Green Cell® foam dimensions were used to determine it's density, 8"x8"x2" and 8"x8"x1".

Weight of the material was measured using an analytical balance. Length, width and thickness were measured using a measuring tool (ruler). Averaged density was calculated from three replicates.

Calculation

The density of the specimen was determined according to the following formula

$$\mathbf{D = \frac{(3.81x\ M)}{(L_1xL_2xT)}}$$

D= density (lb /ft^3)

M = mass of the specimen (g)

L1 = length of the specimen (in)

L2 = width of the specimen (in)

T = original thickness of the specimen in

R-value

Ice Melt method.

This test closely resembles the situation in which an insulating container would be used be used & it is also similar ASTM D3103: Standard Test method for thermal Insulation Quality of a Package [10].

In the ice melt test a quantity of regular cubed or crushed ice is placed in a non- metallic bucket (preferably plastic made of HDPE) inside the package. The package was sealed with duct tape to avoid any air circulation from the outside environment into the package or vice versa. This assembly was stored at 50%RH and 25°C (77°F). A second trial was done at 80% RH and 30°C (86°F). The amount of ice used, was selected to fill at least half of the available volume. The ice was then allowed to melt for several hours, after which the bucket was removed, and the water drained out and discarded. This was a preconditioning procedure intended to ensure that the ice was uniformly at its melting temperature, (32°F) before the actual test would begin. This then maintained a constant temperature difference across the package wall.

Metallic buckets must not be used because they could interfere with the calculation of the package R value by providing a reflective surface not associated with the package itself [10].

The buckets were then placed back inside the package near the center and the package was sealed with tape to make it relatively airtight. Sealing is very important. Stray air currents may flow in and out through the smallest of openings and carry enough heat to render even the best insulator ineffective [10].

The day and time were recorded and the package was immediately placed in a draught free constant temperature environment, at 50% RH and 25°C, on a shelf or other surface off the floor. The package was then allowed to sit in this environment for at least one day and possibly two or three days depending upon the package. The aim is to get most, but not all, of the ice to melt. The experiment was replicated three times as specified in ASTM [10].

The day and the time were recorded at the end of this time period. The box was opened, the bucket removed, and the water was drained out. The water collected during this procedure was weighed, since it takes 144 Btu of heat to melt 1 lb of ice (the latent heat). The heat transfer rate in Btu /h into the package was the melt rate multiplied by the latent heat. This can then be depicted as a system R- value using the following formula.

$$\textbf{System R- value} = \frac{\textbf{(box area) (Temperature difference)}}{\textbf{(Melt rate) (Latent heat)}}$$

The R- value mainly depends on the wall construction, and not the size of the package and is a reciprocal of the effective coefficient of heat transfer. The box area term is the inside surface area of the package. The temperature difference term is the temperature difference between the outside air and the ice. The melt rate term is the rate at which ice melts during the experiments and is equal to the weight of the water (melt ice) collected divided by the exposure time.

The same experiment can be done with dry ice (solid CO2). Since dry ice goes directly from a solid to a gas, the melt rate would be calculated as the difference between the starting & ending weights of the block of dry ice, divided by the exposure time.

The temperature difference must be based on an ice temperature of –180.4°F instead of 32°F, & latent heat of 240 Btu/lb instead of 144 cal. Whichever method is used the R-value should be the same [10].

The summary of research on the performance properties of Green cell Foam (GCF) can be seen in figure no.15

Research overview

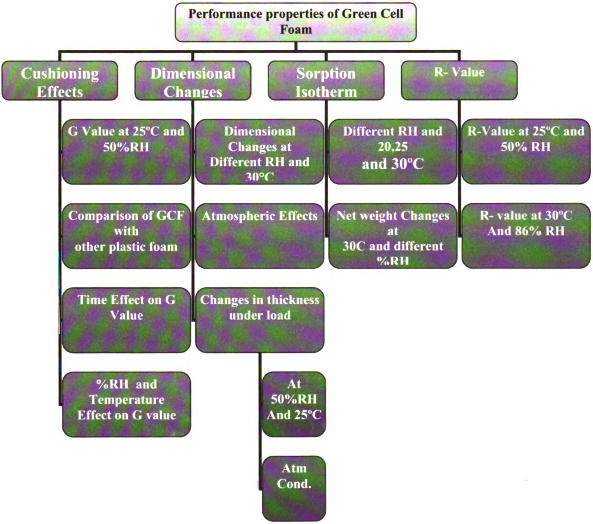


Figure No 15. Overall Research overview of the Performance properties of Green Cell Foam.

CHAPTER 3

RESULTS AND DISCUSSION

The results and discussion are divided into different sections as follows.

3.1 Cushioning characteristics

- 3.11 G value at 25°C and 50%RH and comparison of G values
- 3.12 Time Effect on G values
- 3.13 Effect of relative humidity on G value

3.2 Dimensional stability

- 3.21 Dimensional changes at different relative humidity (%RH) conditions and 30°C
- 3.22 Material behavior at ambient conditions
- 3.23 Changes in thickness under load
    - 3.23-a at 50%RH and 25°C
    - 3.23-b at ambient conditions

3.3 Moisture sorption

- 3.31-a Sorption isotherm at different %RH and 20°C, 25°C and 30°C
- 3.31-b Net weight changes at 30C and different %RH conditions

3.4 Thermal insulation

- 3.41 Density calculations
- 3.42 R- value at 25C and 50% RH
- 3.43 R- value at 86%RH and 30C

Results and Discussion

3.1 Cushioning Characteristics of Green Cell Foam.

The cushioning characteristics of Green Cell® Foam was determined and the G values of Green Cell® foam were compared with the G values of different plastic foams commercially available. Effect of relative humidity and time on the G value of Green Cell® foam was determined.

Packaging designers face many challenges in predicting the performance of cushioning materials, when designing protective package .The prime objective is to choose the proper cushioning material that will protect the product from the hazards of the distribution environment, such as shock and vibration. It is also to achieve the most cost effective package. Classically, shock attenuation characteristics of cushioning material have been considered a material characteristic. Shock attenuation is commonly presented as a cushioning curve, which is a plot of peak acceleration in G's vs static loading and is used to compare and qualify materials. [41]

Peak acceleration is represented by G; such forces are basically a shock of very short duration, and high deceleration. [42]

By definition, deceleration is the rate at which an object slows down, and can be written as

$$G = \frac{\text{deceleration}}{g}$$

G is a dimensionless number and important in designing a package because it is proportional to the impact force on the product and impact force is what damages the product [42].

Fundamental information about the product is necessary to develop a precise and low cost package for product protection. Thus, fragility level is the most vital parameter to determine. [41]. Gorman [41] defines fragility as "The maximum acceleration and velocity change the product can withstand before damage occurs". Typical fragility levels for different products is presenting in the following table 2 [42]

Extremely fragile	Missile guidance systems, precision aligned test instruments.	15-25 G's
Very delicate	Mechanically shock mounted instruments and electronic equipment, Disk drives.	25-40 G's
Delicate	Aircraft accessories, Computers, Laptops, Flat Panel monitors, Standard Monitors, Printers, Scanners.	40-60 G's
Moderately Delicate	Television Receivers, Aircraft accessories	60-85 G's
Moderately Rugged	Major Appliances	85-115 G's
Rugged	Industrial Machinery	115 G's and above

Table 2. Typical Fragility Levels for Different Products [42]

This information is then charted to form a damage boundary curve (DBC). A Damage boundary curve is drawn between the critical velocity change (ΔV) and critical acceleration (ΔG) and is obtained from drop tests. From the DBC curve, the fragility of the product can be determined. [11].

Classically, cushion curves are used to identify a material thickness and loading range based on a pre-determined drop height and required acceleration level. By comparing cushion curves of various materials (generated using the same test method), a cushioning material with the least amount of surface area and thickness can be chosen [41].

Cushion characteristics can be determined by plotting cushion curves. A cushion curve is a graphic representation of a transmitted shock (G) over a variety of static loading conditions (psi or kg/m2) for a specific cushioning material thickness at a specific equivalent free fall drop height [11].

G values of the Green Cell® Foam (two inch and one inch thickness) were determined at different static stresses (psi) by keeping the same drop height (24- inches) and then comparing these G values for the same thickness and drop height with commercial foams (tables 3 and 4).

It was also found that GCF could not bear the total reaction mass 63.3lbs. Green Cell® Foam tore as shown in the figure 16.

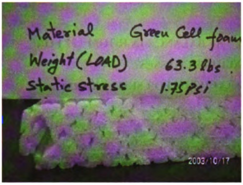


Figure 16. Material damage at 1.75psi, determine G value, 1st impact

Table 3: Comparison of the G value of Green Cell Foam® two inch thick with the G values of commercial materials.* (2" thickness,24 in Drop height) [5-a]

Static stress	PE	(1.25pcf)	(2.20pcf)	(2.2pcf)	(2.2pcf)	(3.357pcf)	Stdev
psi	G value	EPS	EPE(Dow)	EPE(Arco)	EPE(Dow)	GCF ,G's	(GCF)
0.355	66	70	55	63	43	37	3.1
0.578	47	51	37	40	42	35	2.7
0.656	43	48	35	38	41	32	1.7
0.7344	41	42	32	38	40	34	2.1
0.8125	38.5	39	30	37	39	34	3.9
1.444	37	32	45	42	38	42	8.8
1.583	36.5	31.5	33	43	40	33	8.9
1.722	36.5	30	37	42	42	41	7.5
1.758	36	28	38	44	43	37	

The G values of commercial material were taken from the literature [15]. At lower static stress, Green Cell® foam had low G values as compared with the other materials while at higher static stresses the material behave about the same as the market competitors [5-a]. This results shows that G values of 2-inch thick Green Cell foam is competitive with the other foams as for as G values are concerned. Graphical representation of the comparison of the G values can be seen in figure 18.

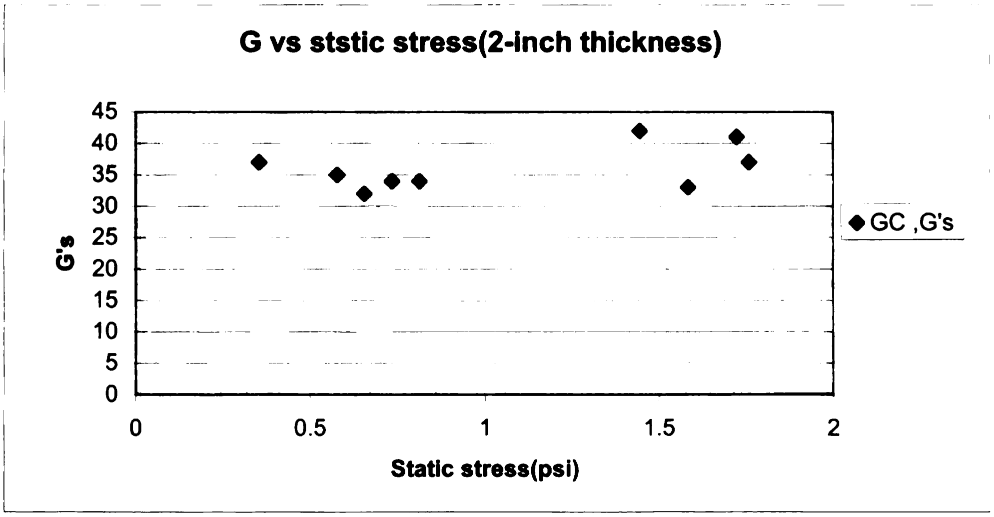


Figure 17. G values of Green Cell® foam Vs Static Stress (psi) * 2-inch thick GCF

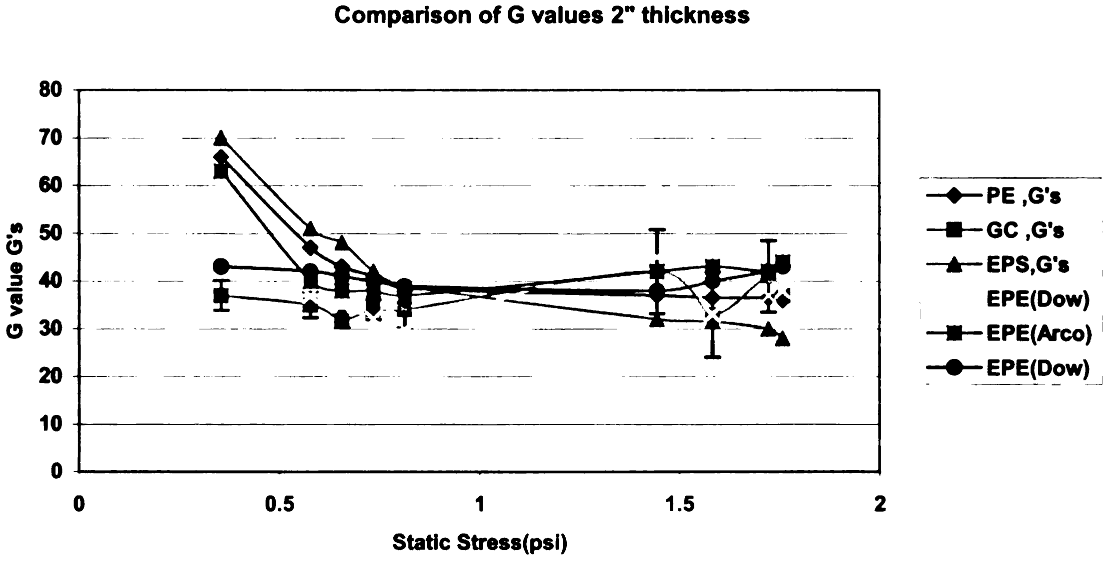


Figure 18 Comparison of the G values of 2 in thick GCF with the G values of commercial materials. * (2" thickness 24" Drop Height)

1-inch thick Green Cell® foam was also tested to determine its G values and these values were compared with the G values of other foams.

At lower static stress, Green Cell® foam had lower G values as compared with other materials, but at higher static stress, had higher G values as compared to the competititive foams [5-a]. This comparison can be seen in table 2 and graphical representation is shown in figure 19.

Table 4. Comparison of the G values of Green Cell® foam with the G values of other commercial materials(1" thickness 24" Drop Height).

	PE	(1.25pcf)	(2.20pcf)	(2.2pcf)	(2.2pcf)	Green Cell	
Static stress	G value	EPS	EPE(Dow)	EPE(Arco)	Dow	(3.4pcf)	
S.S psi	PE ,G's	EPS,G's	EPE(Dow)	EPE(Arco)	EPE(Dow)	GC ,G's	Stdev
0.2	120	116	81	92	100	56.6	4.6
0.355	105	87	65	81	64	63.0	1.1
0.403	73	80	63	73	63	72.0	3.1
0.8	64	63	59	95	60	81.0	1.2
1.305	75	65	90		73	117.0	0.0
1.44	83	70	97		80	116.0	4.5
1.58	90	78	105		83	117.0	2.0
1.722	105	84	110		87	131.0	1.6

Graphical representation of the comparison of the G values can be seen in figure 19.

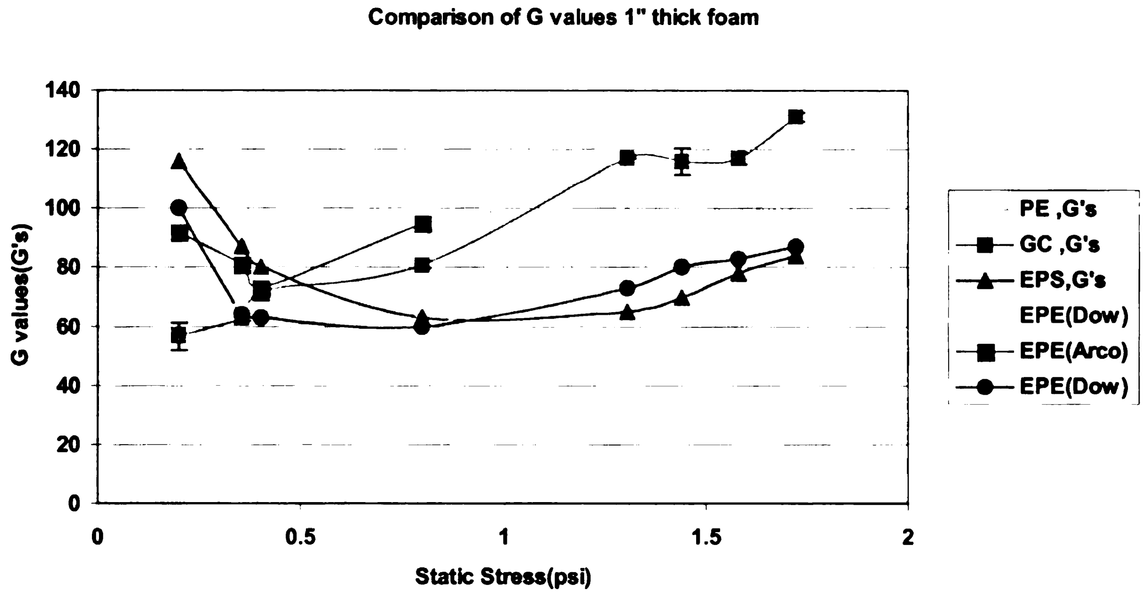


Fig19. Graphical representation of the G value of *Green Cell® foam with the G values of other commercial materials. *(1" thickness 24" Drop Height)

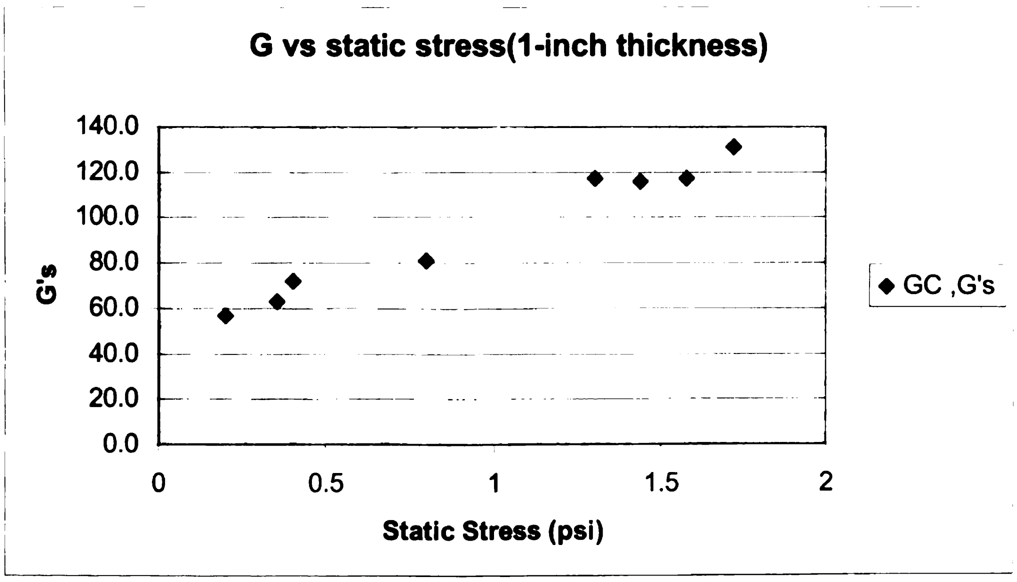


Figure 20. Graph between G values of GCF Vs Static stress (* 1-inch thick GCF)

3.11 Effect of Time on G values:

The G values of GCF decreased with time.

1-inch thick material and 2-inch thick material were tested at different times during three months of storage. It was observed that the G value of 1-inch foam was 80.8(average) when material was received. The same batch of material was tested two months later. The material was kept in an ambient air-conditioned environment where humidity and temperature conditions varied according to the weather conditions. The G value was found at that time to be 51.6. A 2nd set of fresh material was then received and tested to determined the G values at same the drop height (24 inches), bearing area of foam (64 in^2) and static load (51.0 lbs). Static stress was kept constant (0.81psi). The fresh material had a G value of 80.8(average of five drops

This behavior can be seen in table 5.

Table 5: Comparison of G value of *GCF with respect to time
Thickness 1- inch Green Cell® foam

Type of material	**G value**	**s.dev**
Fresh material 1^{st} set	80.0	2.2
Two months later-1^{st} set	51.7	3.3
Fresh material 2^{nd} set	50.3	1.7
Two months later-2^{nd} set	80.8	2.2

Similarly, two-inch thick foam was tested and showed the same pattern. The first set of fresh material was tested and had a G value of 34.9 with the st. dev of 3.8. It was then kept at ambient conditions where temperature and humidity conditions varied according to the weather conditions. Two months later it had a G value of 24.2(st dev. 1.3). A 2nd set of fresh material was tested at the same drop height (24 inches), bearing area of foam (64 in^2) and static load (51.00lbs). Static stress was kept constant (0.81psi).

Fresh material had a G value of 35(average of five drops) with the st.dev of 1.02.

3.12 Effect of relative humidity on G value:

Relative humidity had a significant effect on the G values of Green Cell® foam. Green Cell Foam® at 11% and 43% had an increased G value (from 39.97 to 51.84) and (from 43 to 45.2) [5-a]. No significant increase in weight was observed.

There was no distinct change observed in G values at 54%, 75%and 86% RH.

But at 89%RH and 96% RH, an increase in G values were observed along with significant increase in weight [5-a]. Expansion in the thickness direction was observed at 75% RH, 30°C. This behavior can be seen in figure 20. Fungus was also observed on the material at 89% RH and 96% RH, contracted significantly and lost its shape. The bearing area of the Green Cell® foam decreased. As toughness and bearing area decrease, G value increases. These results are shown in the following figures (21-30) and tables. (6 and 7) Detailed calculations and material physical changes are shown in appendix A

Table 6. G value and change in weight (Δw) of Green Cell® foam with respect to time.

		Fresh material	**Two months later**	**Fresh material**	**Two months later**	**Δw**
s.no	**RH**	**G value**	**G value**	**wt.**	**wt.**	**net wt. gain**
	%			**(g)**	**(g)**	**(g)**
1	11	39.97	51.84	51.62	52.68	1.06
2	43	38.58	45.21	52.65	52.64	-0.01
3	54	32.18	38.29	54.58	54.7	0.12
4	75	39.22	36.53	51.86	53.96	2.1
5	86	32.9	37.25	56.34	62.03	5.69
6	89	39.15	50.63	51.51	60.59	9.08
7	97	38.42	76.77	52.38	67.31	14.93

Table 7: Comparison of impact time and impact velocity before and after keeping the material at specific %RH conditions.

		Fresh material	Two months later	Fresh material	Two months later
s.no	RH	time	time	velocity	velocity
	%	(ms)	(ms)	(in/sec)	(in/sec)
1	11	22.8	17	177.25	182.63
2	43	23	18.1	170.57	174.4
3	54	25.2	21	158.19	171.59
4	75	22.9	22.6	172.57	169.08
5	86	25.8	18.8	164.47	153.64
6	89	22.1	16.4	169.92	163.43
7	97	22.8	12.4	169.86	184.1

Figures 21-30. Show the Green Cell Foam kept at 25°C/ 50%RH, at 30° C 75% RH,30 °C /84%RH,30 °C /89%RH and 30°C /96% RH.

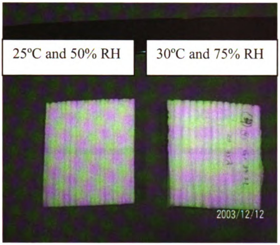


Figure 21 (Front view) Comparison of Green Cell® foam kept at 25ºC, 50%RH and 30ºC, 75% R

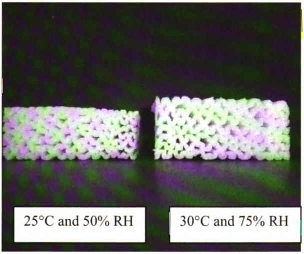


Figure 22 (Side view) Comparison of Green Cell® foam kept at 25ºC, 50%RH and 30ºC, 75% RH [5-a]

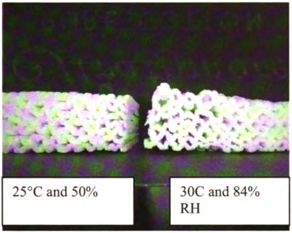
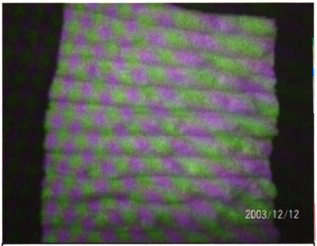


Figure 23. (Side view) Comparison of Green Cell® foam kept at 25ºC, 50%RH and 30ºC, 84% RH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Material became soggy, lost its shape and

And showed marks of deterioration

Figure 24 GCF kept at 84% RH and 30°C

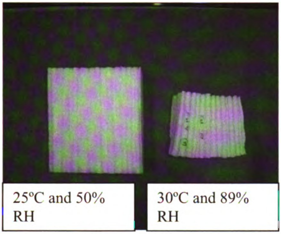

Figure 25 (Front view) Comparison of Green Cell® foam kept at 25°C, 50%RH and 30°C, 89% RH [5-a]

Figure 26. Material kept at 89% RH and 30ºC

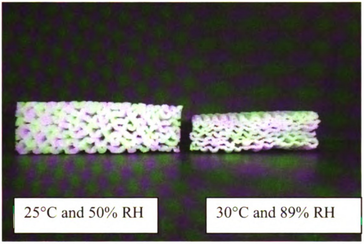

Figure 27 (Side view) Comparison of Green Cell® foam kept at 25ºC, 50%RH and 30ºC, 89% RH

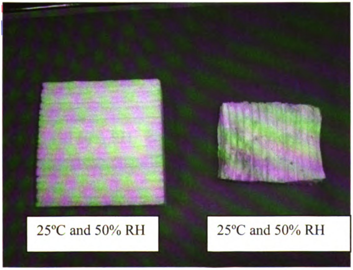

Figure 28 (Front view) Comparison of Green Cell® foam kept at 25ºC, 50%RH and 30ºC, 96% RH

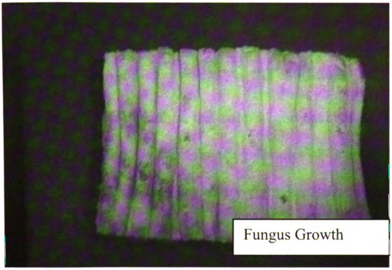

Figure 29. Material kept at 96% RH and 30ºC

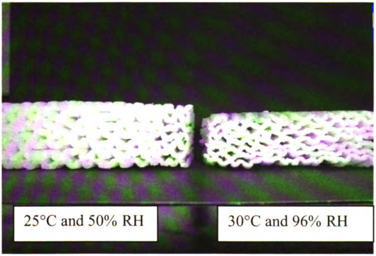

Figure 30 (Side view) Comparison of Green Cell® foam kept at 25ºC, 50%RH and 30ºC, 96% RH

3.2 Dimensional stability

The dimensional stability of Green Cell® Foam was determined. Dimensional changes (length, width and thickness) and net weight loss /gain of the product (Green Cell®) at 30°C and different humidity conditions were determined.

Dimensional changes at 30°C at several % RH conditions

A 4.3-6.0 kg weight was placed on the material and changes in thickness were observed periodically. An experiment was set up using samples of Green Cell® foam and saturated salt solutions. Dimensional changes and weight loss/gain were measured periodically until the equilibrium conditions reached.

Change in thickness:

The most expansion accrued at 75% and 84% and this behavior can be seen in Figs 21-25. The material expanded 0.400 inches during 408 hrs at 84% RH and 30°C, and 0.332 inches during 408 hrs at 75 % RH and 30°C [5-a]. Detailed calculations are shown in appendix B-Dimensional Changes.

Negligible change in thickness was observed (0.03-0.075 inches) at 11%, 43% and 56% RH% at 30°C.The material contracted slightly ((–0.053, - 0.055) inches) at 89%RH and 95% RH%.

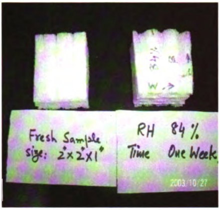

Figure 31. Comparison of GCF maintained at 84% RH/30°C and 50%RH /25°C. (Front view)

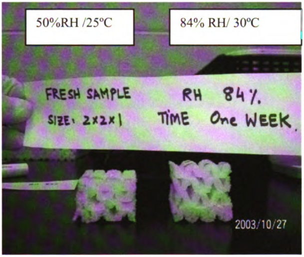

Figure 32. GCF maintained at 84% RH/ 30°C and 50%RH /25°C
GCF pieces were compared after one week of time period. (Side view).

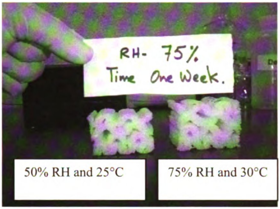

Figure 33. Comparison of samples maintained at 75% RH/ 30ºC and 50%RH/25ºC. (Side View)

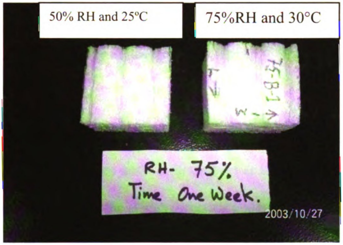

Figure 34. Comparison of samples maintained at 75% RH/ 30ºC and 50%RH /25ºC. (Front View)

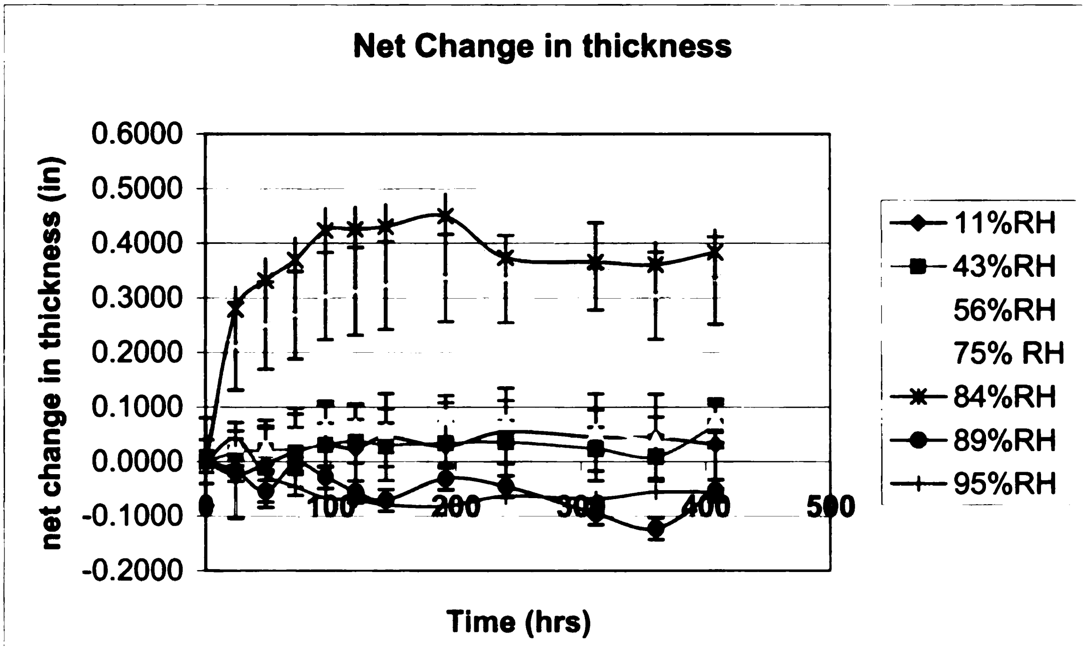

Figure 35. Net Change in thickness of GCF at 30°C at different humidity conditions

Width:

Significant change in width was observed at 89% and 95%. Material shrunk in the width dimension (–0.60 inches and –0.50 inches) at these two RH% conditions. At 84 % RH, material contracted in the width dimension slightly " –0.132 inches". At the remaining, RH% conditions (11%, 43%, 56% and 75%), only slight (0.02- 0.04 inches) change was observed in width during the storage study period. Change in width can be seen in the following graph.

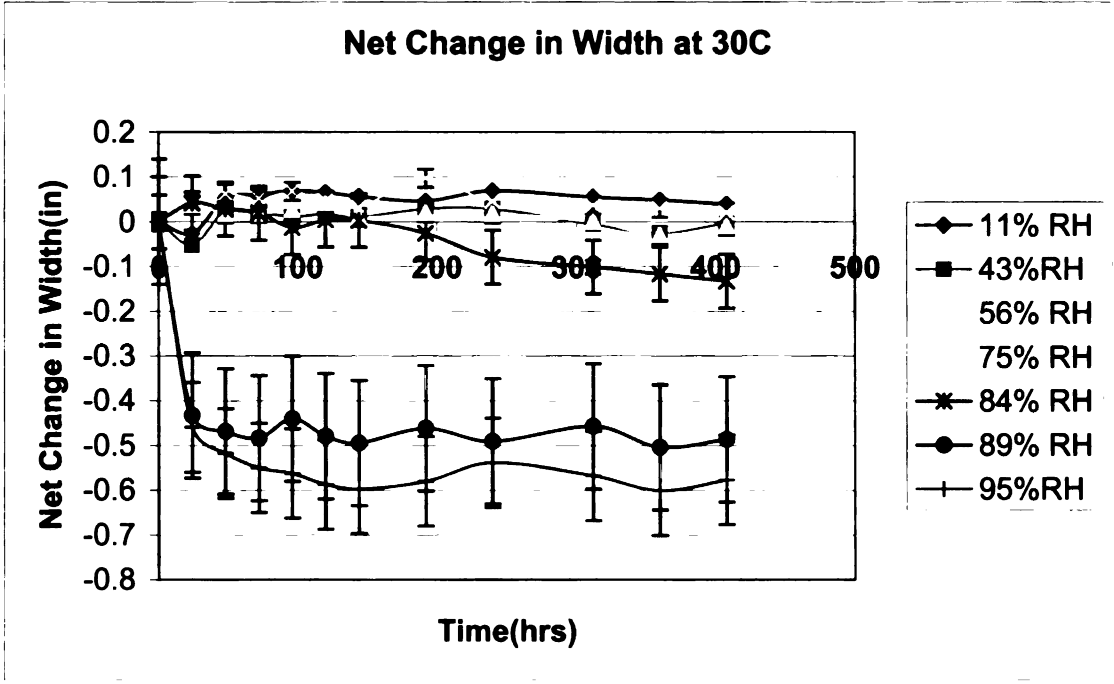

Figure 36. Change in width of GCF at 30°C at different humidity conditions.

Length

Significant change was also observed in length at higher humidity conditions (95% and 89%). The material shrunk almost 0.90 inches in the length direction. At 84%RH material contracted in the length direction only 0.23 inches. This behavior of the material can be best seen in figure 6.

No significant change was observed at 11%, 43%, 56% and 75% RH.

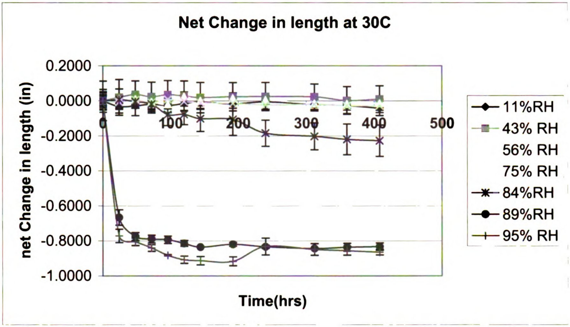

Figure 37. Change in length of GCF at 30°C and different humidity conditions.

Figure (a)

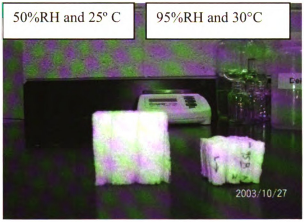

Figure (b)

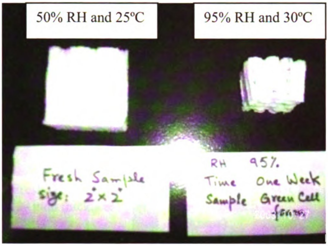

Figure No.38 (a and b): Comparison of GCF samples kept at 95% RH, 30°C and 50%RH and 25°C. (Front View)

3.21 Material behavior at ambient conditions:

1" and 2" Green Cell foam was kept under observation in an air conditioned lab but not controlled where temperature and relative humidity conditions changed according to the weather conditions for about three months. Physically it was observed that material increased in thickness. This behavior can be seen in the following figures 39 and 40.

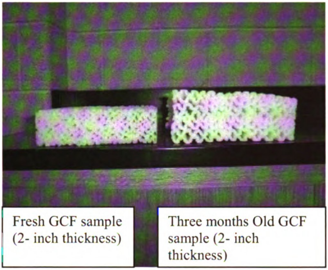

Figure 39 (side view). Comparison of 2” fresh and three month old GCF material [5-a]

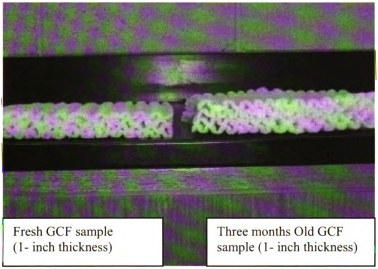

Figure 40. Comparison of 1-inch fresh and three month old material

3.22 The Change in thickness of Green Cell® Foam under constant load at controlled conditions (50% RH and 25° C)

The effect of load over time on the thickness of GCF was also determined. Both 1-inch and 2- inch foams decreased slightly over time under load at 25 °C and 50%RH.

No significant change was observed during the storage period in thickness under load. A weight of 4.3-4.5 kg weight was placed on the top of the foam pieces for 53 days. Only 0.0230 inches of net change in thickness was observed for 2-inch thickness material during the storage period. While only 0.068 inches decrease in thickness was observed for 1-inch thickness material. No physical, change was observed during the study period. This behavior of material can be best seen in the following figures and tables

Table 8. Relationship between change in Thickness under load at 25°C and 50% RH (1- inch thick sample)

Time days	**Thickness (in)**	**Thickness (in)**	**Thickness (in)**	**Average thickness**	**s dev**
0	1.23	1.1965	1.2455	1.2240	0.03
1	1.205	1.1865	1.208	1.1998	0.01
2	1.209	1.208	1.223	1.2133	0.008
4	1.1885	1.1905	1.155	1.1780	0.02
6	1.188	1.176	1.145	1.1697	0.02
8	1.187	1.1725	1.144	1.1678	0.02
10	1.2245	1.1925	1.1715	1.1962	0.03
12	1.2035	1.174	1.1685	1.1820	0.02
15	1.2065	1.1955	1.1785	1.1935	0.01
17	1.171	1.1605	1.147	1.1595	0.01
19	1.202	1.1635	1.1645	1.1767	0.02
27	1.172	1.1495	1.164	1.1618	0.01
35	1.179	1.152	1.186	1.1723	0.02
48	1.1535	1.1385	1.1735	1.1552	0.02
			Net change	-0.0688	

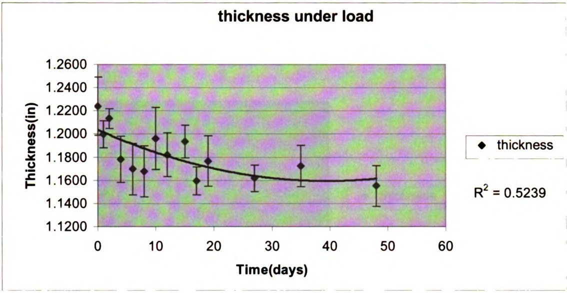

Figure 41. Graph of Time (days) Vs Thickness of Green Cell® foam (1-ich thick GCF) at 25°C and 50%RH at constant load

Table 9. Relationship between change in Thickness under load at 25°C and 50% RH (* 2-inch Green Cell® foam)

Time (days)	Thickness (in)	Thickness (in)	Thickness (in)	Average thickness	s.dev
0	2.07105	2.2324	2.0695	2.1243	0.1
1	2.0775	2.2385	2.106	2.1406	0.09
2	2.0855	2.2412	2.1255	2.1507	0.08
3	2.089	2.2425	2.131	2.1541	0.08
4	2.134	2.2615	2.134	2.1765	0.07
5	2.0925	2.22	2.108	2.1401	0.07
7	2.0985	2.2455	2.1605	2.1681	0.07
9	2.0855	2.2297	2.1285	2.1479	0.07
11	2.1115	2.2305	2.1335	2.1585	0.06
13	2.0935	2.228	2.1245	2.1486	0.07
15	2.126	2.231	2.2105	2.1891	0.05
17	2.097	2.214	2.177	2.1626	0.06
20	2.1005	2.2395	2.15	2.1633	0.07
22	2.0475	2.225	2.1125	2.1283	0.09
24	2.1015	2.2245	2.1165	2.1475	0.07
32	2.045	2.2045	2.1145	2.1213	0.08
40	2.091	2.2055	2.1215	2.1393	0.06
53	2.1115	2.2075	2.123	2.1473	0.05
			Net change	0.0230	

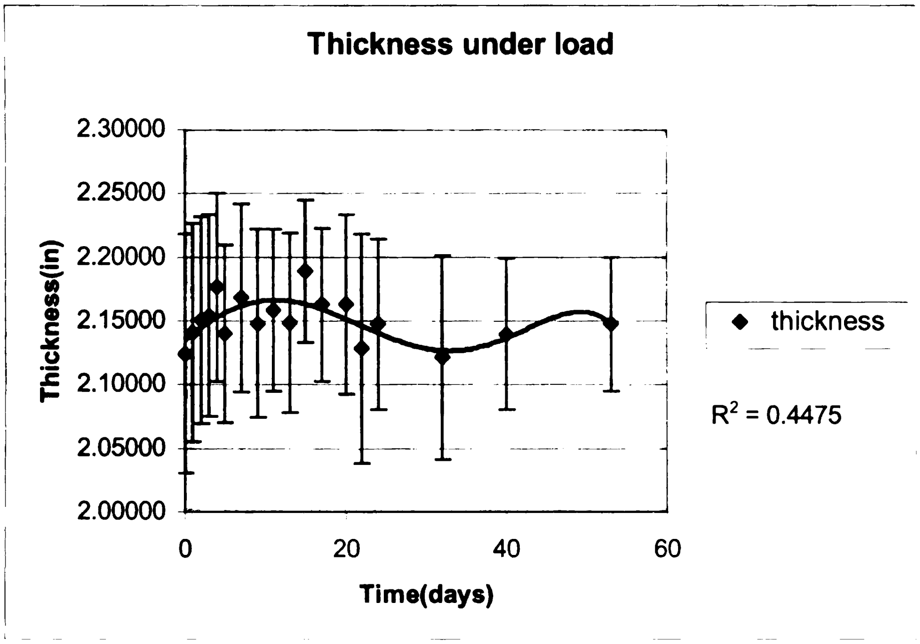

Figure 42. Graph between Time (days) Vs Thickness of Green Cell® foam at 25°C and 50%RH at constant load(* 2-inch Green Cell® foam)

Combined results of 1-inch and 2-inch thick Green Cell® Foam can be seen in figure 43.

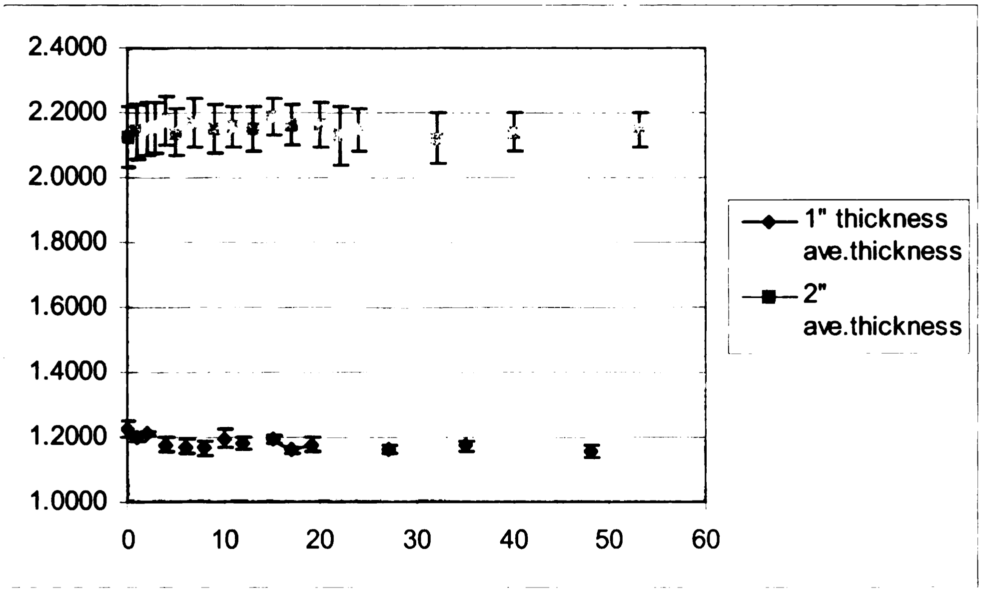

Figure 43. Change in thickness under load at 25°C and 50%RH for 1 inch and 2-inch GCF

3.23 Change in Thickness under load at ambient conditions:

Not significant change was observed during the storage period in thickness under load at ambient conditions. This experimental set up was placed in air-conditioned room but not controlled conditions (temperature and relative humidity conditioned varied). Total 5.9 kg weight was placed over the foam piece. Experiment was kept in progress for 23 days. Inconsistence decrease and increase in thickness was observed during the observation/study time. Only "-0.2.0 inches" of net change in thickness was observed for 2- inch thick GCF sample on the 24th day. While total 0.023 inches change in thickness was observed on 24th day of storage study for the 2- inch thick GCF sample, which was kept at controlled conditions (50% RH and 25°C).

Physically appearance of the foam was detoriated, material become soggy (because of absorption of moisture from the environment) and slight change of shape was observed. This behavior of material can be best seen in the following figure and tables.

Table 10. Relationship between change (Δ) in Thickness under ambient conditions.
(* 2-inch Green Cell® foam)

days	thickness(in)
0	2.135
1	2.181
2	2.13
3	2.137
4	2.071
6	2.048
7	2.129
9	2.067
17	2.042
23	1.945
Net change	-0.19

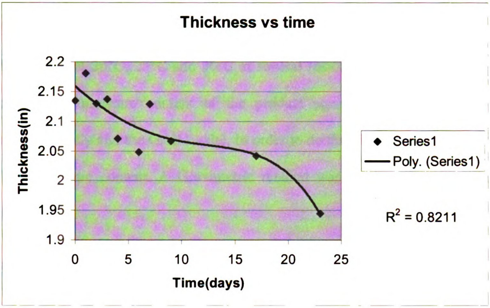

Figure 44. Relationship between change Thickness under constant load at 25°C and 50% RH(* 2-inch Green Cell® foam)

3.3 Moisture Sorption

Moisture Sorption Isotherm.

Sorption isotherms of the biodegradable starch based foam (Green Cell®) were determined at 20°C, 25°C and 30°C at several relative humidity conditions, by plotting equilibrium moisture content of the product against water activity of the product experimentally and the GAB model. In order to do this, it was necessary to determine the foam moisture content. A Gravimetric method was used to determine foam moisture content .

Sorption isotherm at different %RH and 20°C, 25°C and 30°C.

Since Green Cell® foam is biodegradable, it absorbs moisture, which affects its packaging performance properties. Moisture sorption isotherms at three temperatures were developed to determine the moisture sensitivity of the product.

Gesamtverband der Deutschen versicherungswirtschaft e.v defines the term hygroscopity as the "capacity of a product to react to the moisture content of the air by absorbing or releasing water vapor. Of decisive significance for the absorption or release of water vapor is the water of a product"[27].

Further the sorption isotherm is defined, as "A sorption isotherm is the graphic representation of the sorption behavior of a substance. It represents the relationship between the water content of a product and the relative humidity of the ambient air (equilibrium) at a particular temperature".

Sorption behavior of a hygroscopic product is related to its ability to absorb or release water vapor from air (or into the air) until equilibrium is reached.

Sorption isotherms were plotted to determine the moisture sensitivity of the Green Cell® Foam. Initial moisture content (Mi) of the foam was determined to be 1.26%. Moisture sorption isotherms were determined at three different temperatures 20°C; 25°Cand 30°C. The GAB model was then used to obtain the best fit of the data. Quadratic regression analysis was performed by plotting aw/Me vs Me to obtain various model constants.

The material was much more hygroscopic at higher temperatures as compared to lower temperature. Green Cell® foam was shown to have a hygroscopic nature. The sorption isotherm profile is a characteristic of the hygroscopic nature of a product. The sorption behavior of a product is dependent on temperature. Highly hygroscopic products exhibit a steep sorption isotherm, while sparingly hygroscopic products exhibit flat sorption isotherms [27]. The hygroscopic nature of a product can be judged by the magnitude of the increase or decrease of a product's water content as a function of relative humidity or water activity at a certain temperature. Weakly hygroscopic products exhibit no or only a slight change in their water content as a consequence of variations in relative humidity. In strongly hygroscopic products, water content may vary widely [27], which was found to be the case for Green Cell® foam.

Types of Sorption isotherm:

Generally in the literature three types of sorption isotherm are considered.

1) Sorption isotherm in which the product shows strong hygroscopic nature. As shown in Figure 45,this product exhibits a steep rise in product moisture content as a function of %RH.

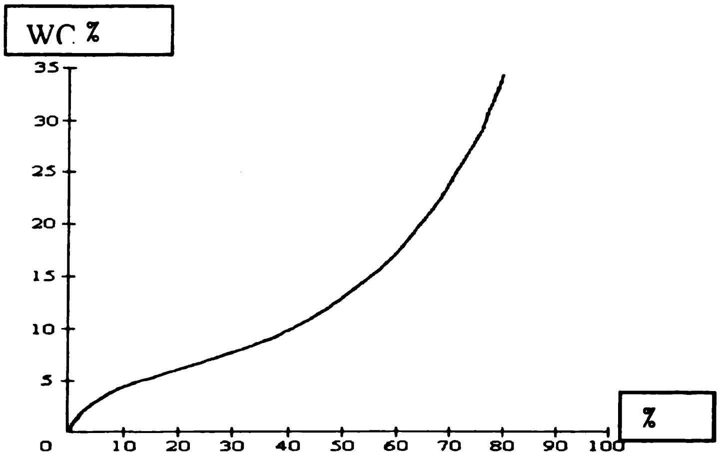

Figure 45. Plot between the moisture content (%) and relative humidity RH (%)

2) Sorption isotherm, in which the product exhibits an S-shaped profile, as, shown in Figure 46

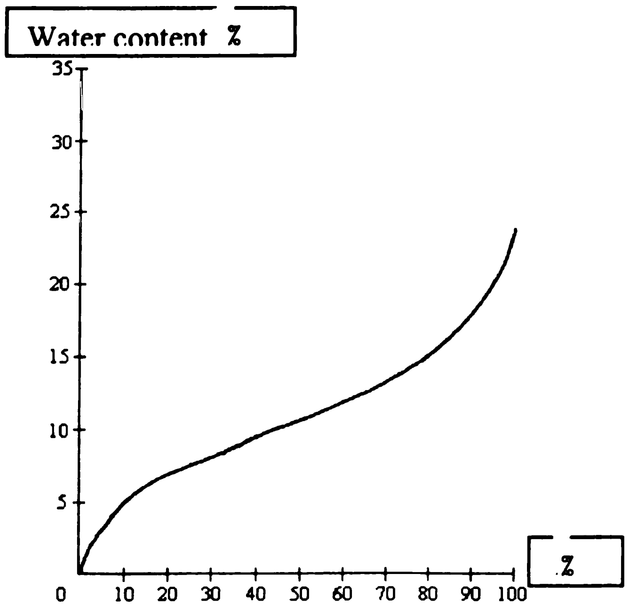

Figure 46. Plot between the moisture content (%) and relative humidity RH (%)

The flat linear portion of this graph represents the most stable form of the product. Above and below this region, harmful changes may occur in the product. [27]

3) Anhydrous product generally exhibits low hyrosocopicity, however, once the flow moisture point has been reached, the product rapidly absorbs large amounts of water vapor, its exhibits a deliquesce (hydrous form), as shown in figure 47. Many crystalline products (salt, sugar, potash, tartaric acid) exhibit this behavior. [27]. Equilibrium sorption isotherm provides information about the hydroscopic nature of material. [19]

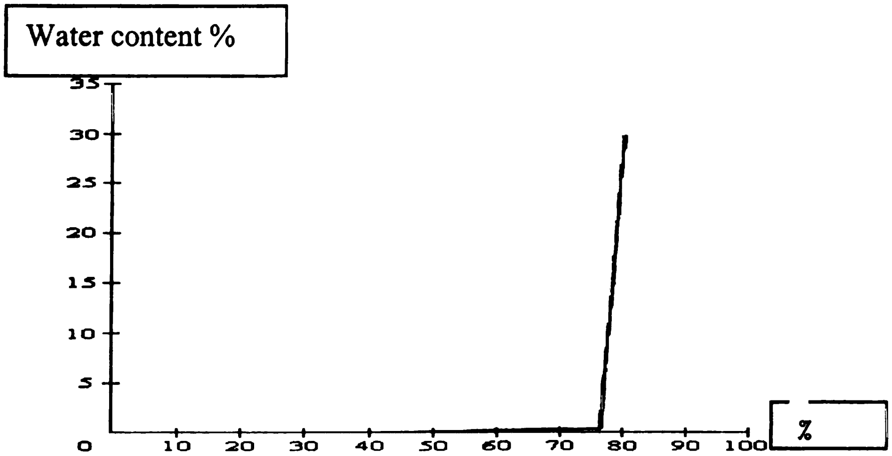

Figure 47. Plot between the moisture content (%) and relative humidity RH (%)

Sorption behavior of Green Cell® Foam was found to more closely resemble with type two at 20°C, 25°Cand 30°C as shown Figure No. 48. 49 and 50.

Sorption isotherm was determined using a liner method and graphical representation is shown in the following figures 48-50.

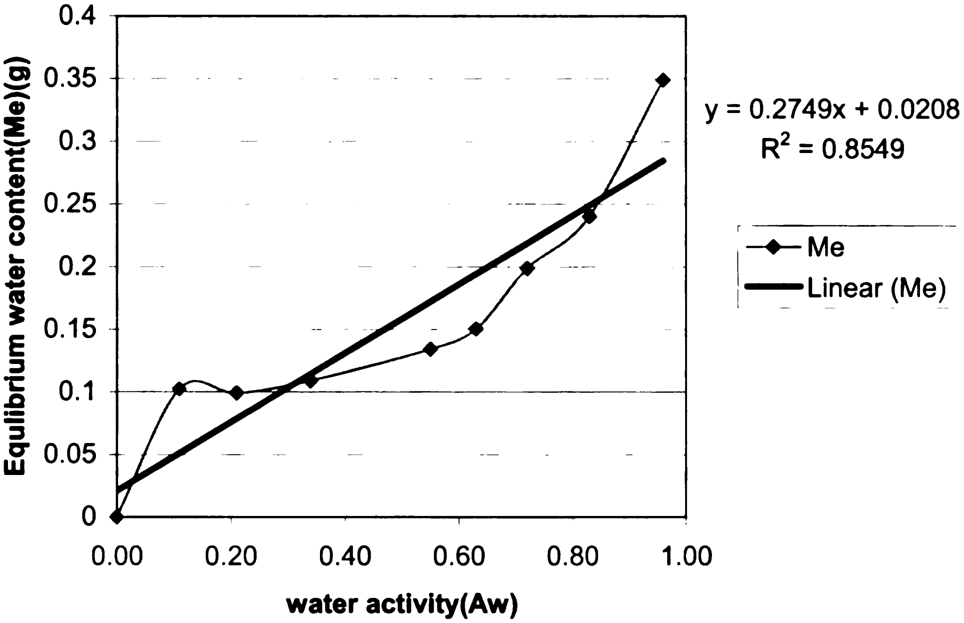

Figure 48. Sorption isotherm of GCF at 20°C

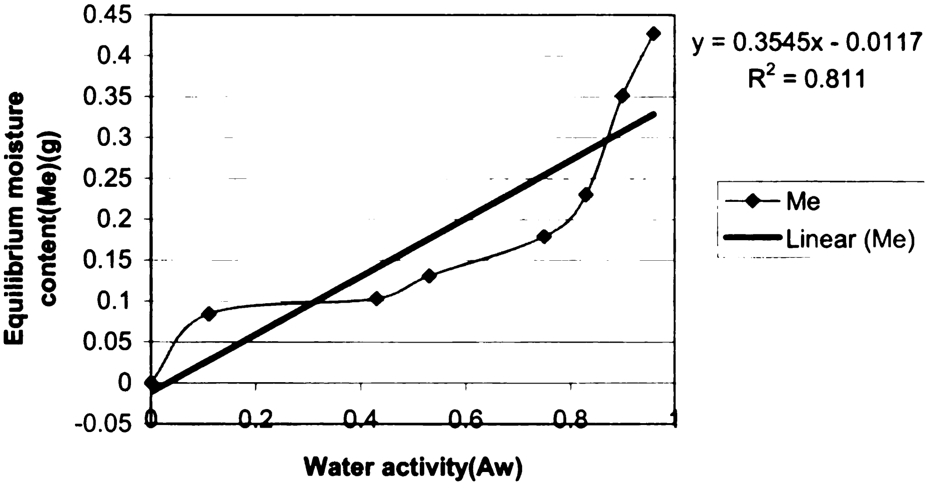

Figure 49. Sorption isotherm of GCF at 30°C

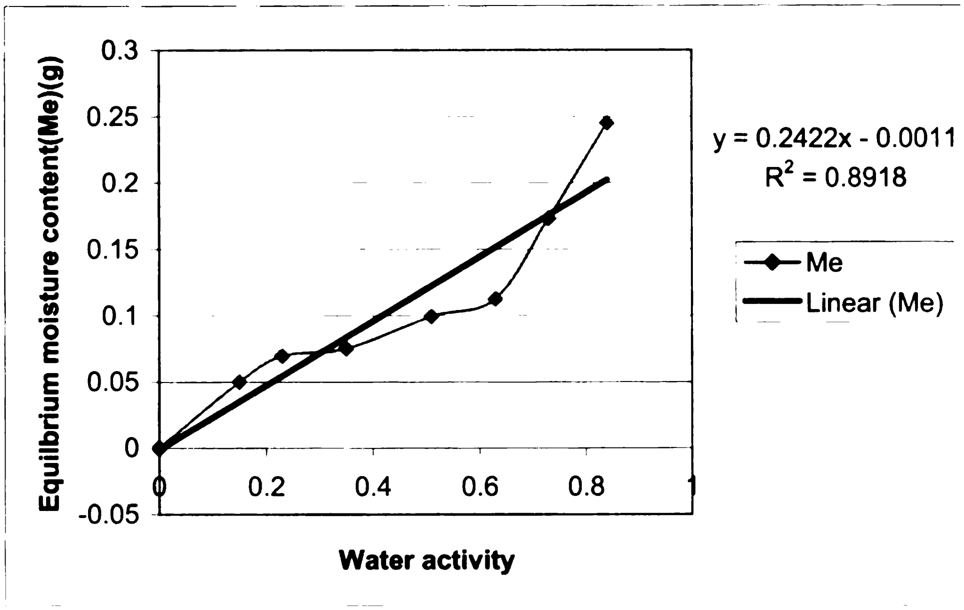

Figure 50. Sorption isotherm of GCF at 25°C

Since the product did not follow a linear relationship between the a_w and Me, the GAB model was selected to represent the sorption isotherm.

GAB (α, β, γ) constants were taken from slope of the line for aw/Me vs. a_w and calculating T, C, W_m and K to get the calculated GAB value. T, C, W_m and K (GAB constants) were calculated using the following formula. Detailed calculations can be seen in appendix-C, moisture sensitivity of Green Cell® Foam.

$$T = \frac{\beta^2}{-\alpha\gamma} + 4$$

$$C = \frac{T \pm (T^2 - 4T)^{1/2}}{2}$$

$$W_m = 1/\beta \, [1 - 2/C]$$

$$K = 1/\gamma * 1/CW_m$$

Calculation of Me (cal) can be achieved using the following expression

$$\frac{M}{Wm} = \frac{CkAw}{(1-kA_w)(1-kA_w+CkA_w)}$$

Substituting the values into the above equation and solving for M/Wm, gives a value of Me (cal) at different water activities.

The RMS values are calculated using the following formula.

$$RMS = \sqrt{[\Sigma\{(Mexp - Mcal)/Mexp\}^2 / N]} * 100$$

Sorption isotherm by GAB Model:

GAB model (α, β, γ) constants were taken from the slope of the following Graph(figure 51) in order to get the calculated Me (GAB) values at 20°C

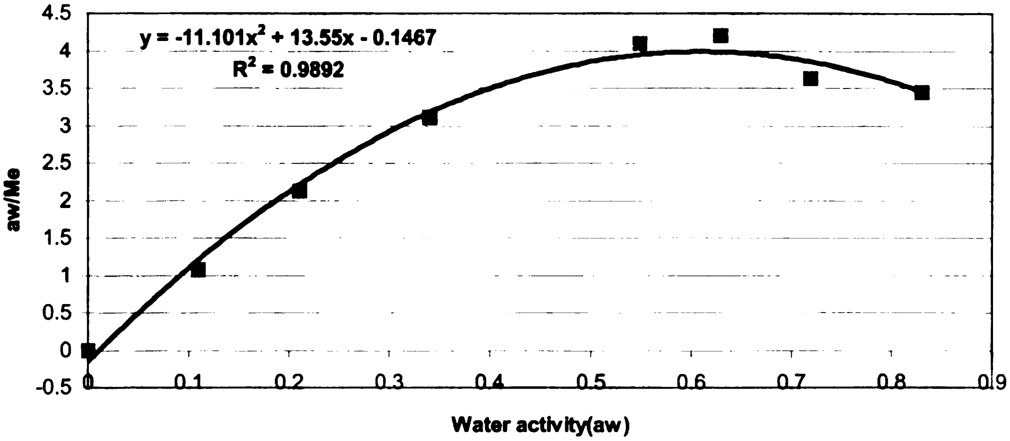

Figure 51. Plot of a_w/Me and water activity at 20°C

Comparison of GAB model (calculated values) and experimental values of Me are shown. Detailed calculations are shown in appendix-C, Moisture sensitivity of Green Cell® Foam.

The RMS value was calculated to be 5.00.

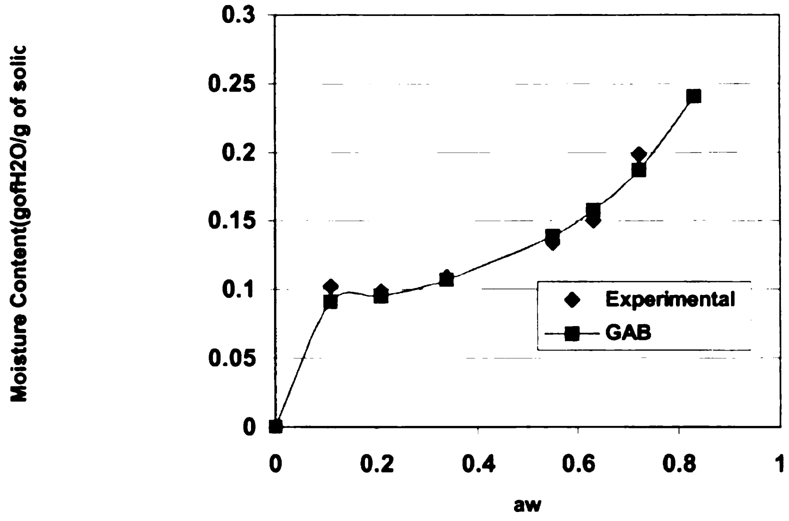

Figure 52. Comparison of Moisture sorption isotherm for Green Cell Foam based on experimental data and GAB model at 20°C [5-a].

To plot the sorption isotherm using the GAB model at 25° C

GAB model (α, β, γ) constants were taken from the slope of the following Graph (figure 53) to get the calculated Me values.

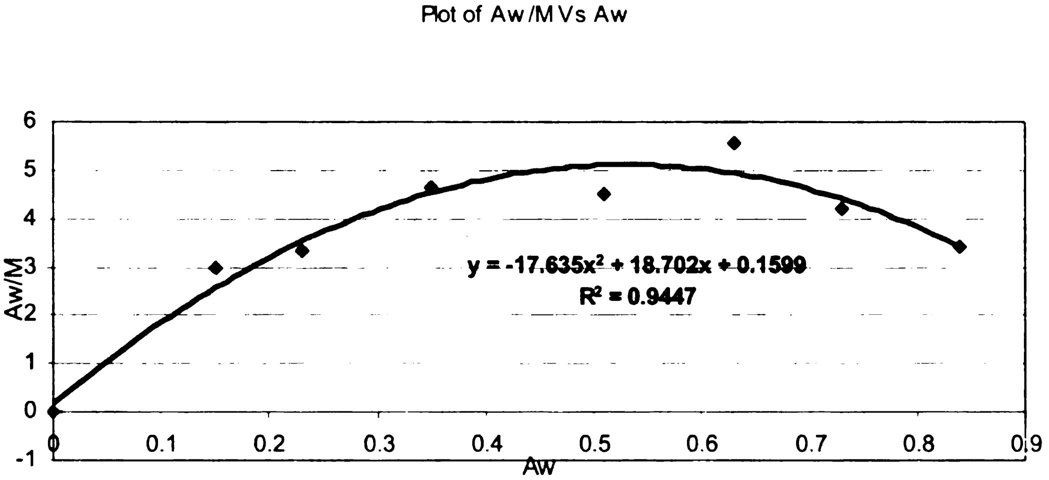

Figure 53. Graph between aw/Me and water activity at 20°C

The GAB isotherm and experimental values at 25°C is presented in figure 54.

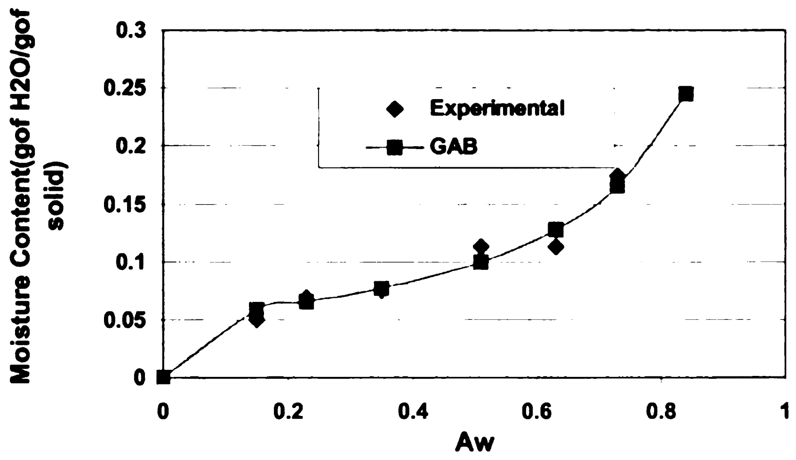

Figure 54. Moisture sorption isotherm of Green Cell® foam at 25°C.

Detailed calculations are presented in appendix-C, Moisture sensitivity of Green Cell® Foam.

The RMS value was found to be 8.53 [5-a].

To plot the sorption isotherm at 30 C using the GAB model

GAB model (α, β, γ) constants were taken from the slope of the Graph (figure 55) to get the calculated Me values using the GAB model.

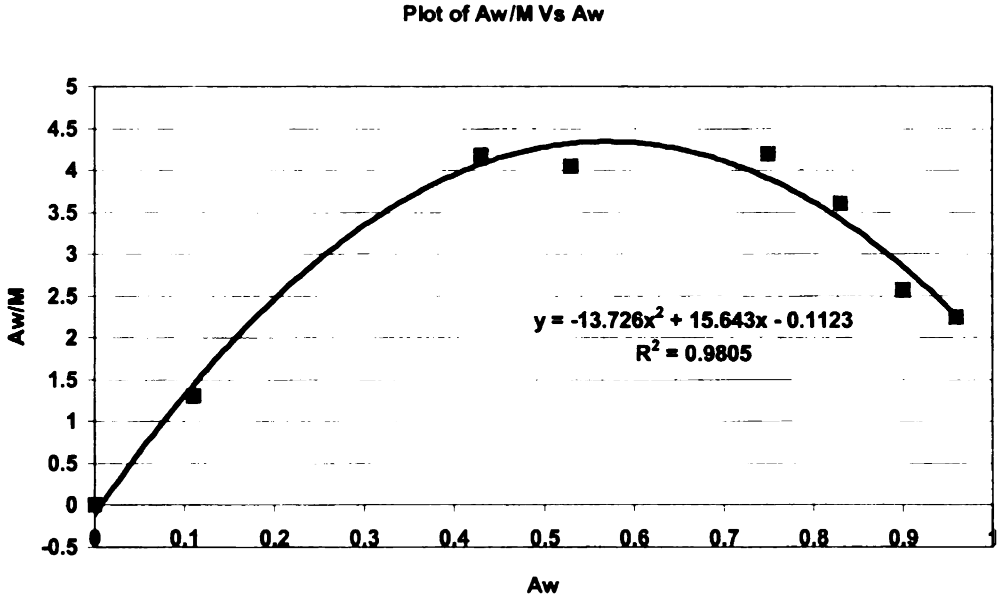

Figure 55. Plot of a_w/Me and water activity at 30°C

Comparison of the GAB predicted isotherm and the experimental isotherm is shown in figure 56.

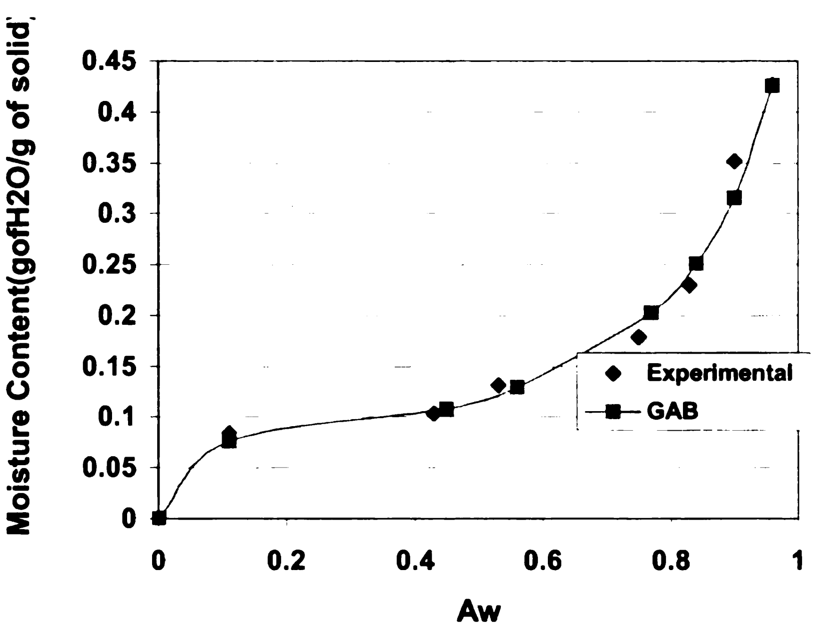

Figure 56. Comparison of the moisture sorption isotherm (GAB and experimental) of Green Cell® Foam at 30°C [5-a].

Detailed calculations can be seen in appendix-C, Moisture sensitivity of Green Cell® Foam.

RMS value was found to be 8.6847. [5-a]

Moisture loss or gain

Moisture absorbing/desorbing behavior under different humidity conditions at 20° C,25°C and 30°C is shown in the figures 57 and 59.

Moisture gain/loss behavior at 20°C followed the same pattern as GCF at 25°C and 30°C but at a slower rate. Fungus was observed on the GCF at 96%RH after 35 days of storage.

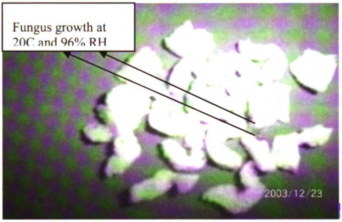

Figure 57. Fungus on GCF at 20 C and 96% RH

Most significant weight changes were obserevd at 75%, 84% and 96%. At 75%and 84% RH, material expanded during the first week of storage and gained moisture. At higher humidity conditions like 96% RH, material lost its shape and contracted during the first few days of storage but gained moisture. After the first week of storage, the material again started to expand but never regained its shape. After one month of storage, it was observed that mold was growing on the material which was kept at 96% RH.

At 25°C the most significant change can be seen at 75% and 84% .At 75%RH, material expanded during the first week of storage study and gained moisture. No significant physical change was observed at 51%, 35% and 23% RH.

At 75% and 84% material gained moisture and also expand. This behavior is shown in the following Figures 58 and 59.

Sample kept at RH75%
And 30 C

Fresh sample

Figure 58. Comparison of fresh sample and material kept at RH75% and 30°C

Fresh sample

Sample kept at 95% RH
and 30C

Figure 59. Comparison of fresh sample and material kept at RH 95% and 30°C

At higher Relative humidity conditions (89% and 95%) material lost its shape, contracted but gained moisture. Retrogradation may affect Green Cell® foam at higher humidity conditions and may be why it lost its shape and became brittle. At 43% and 54% no significant change was observed during the storage.

The material absorbed moisture at 75%, 84%, 89% and 95% RH at 30°C. At 95% RH, the material absorbed the maximum quantity of moisture as compared to 89% RH, 84%RH and 75% RH. At 95% RH, material absorbed 0.844 grams of moisture during 408 hrs of storage [5-a]. At 89%, material absorbed 0.74 grams, at 84% RH 0.32 grams and at 75% RH 0.177grams.At 11% RH the material lost moisture (-0.10 grams).

At higher Relative Humidity conditions (89% and 95%) material shrunk but gained moisture. At 43% and 54% no significant changes were observed At 56% RH the material absorbed only 0.0001 grams of moisture and thus it is concluded the ideal relative humidity conditions for Green Cell® Foam.

This behavior is shown in the following graph [5-a].

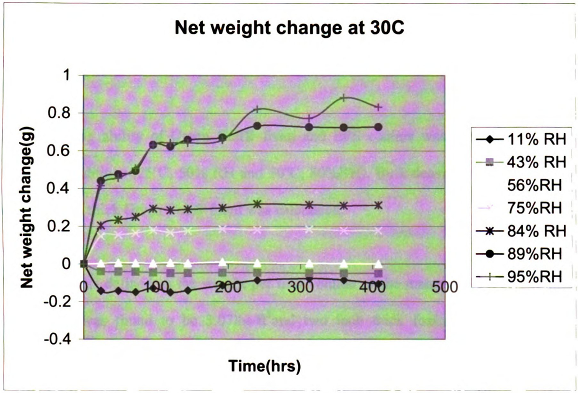

Figure 60. Net Change in weight at 30°C and different humidity conditions.

At 11%, 43% and 54%, no significant changes were observed. Detailed calculations can be seen in appendix B- dimensional changes. The most ideal conditions for the material is at 30°C was 56% RH .L, x W, x T change (–0.01 x –0.01 x0.075) inches) respectively. Ideal conditions for Green Cell® Foam is 56% relative humidity. Net moisture gain at 55% RH and 20°C was only 0.01 grams after 35 days of storage, while at 25°C and 51% RH, net moisture gain was only 0.0008 grams after 15 days of storage. This leads to the conclusion that the ideal storage condition for this material is 50-56% RH at 25°C.

The product showed the same pattern of absorbing/desorbing behavior under the different temperature conditions of 20° C, 25°C and 30°C as this pattern.

3.4 Thermal insulation

Package insulating ability (R Value) and bulk density of Green Cell foam.

The insulating ability of Green Cell® foam and EPS coolers was determined at two different conditions (25°C, 50% RH and 30°C, 80%RH). Bulk density of one inch thick and two-inch thick Green Cell® foam was calculated.

Bulk density

Bulk density is defined as the weight per unit volume of the material [9] .For one-inch thick foam was found to be 3.07lbs/ft^{3}and two inch thick foams was found to be 3.3571lbs/ft3 [5-a]. Density values were calculated from triplicate measurements and detailed calculations can be seen in appendix D, R-value and density calculations.

Traditionally, expanded polystyrene (EPS) has been the sole foam packaging material used for coolers.

The bulk density of Green Cell® foam, is much higher than expanded polystyrene foam and other commercial foams. Total weight of the package would increase substantially because of the higher density of the GCF. Bulk densities range from 1.25 pcf to 2.2pcf,density for EPS, PE, ARCEL512, and polyurethane.

R-value:

"The R-value Rule has been helpful in comparing different brands of the same type of insulating materials" said Betsy de Campos, executive director of EPSMA, " but as more sophisticated materials and higher technology construction systems are introduced into the building industry we find that R- value of the material does not tell the whole story."[23]

The R- value is based on the mathematical term known as the R- factor. The term R-value was developed to represent the ability of an insulation material to restrict flow. Thermal resistance of a material is its resistance to heat flow and is expressed as the reciprocal of the material's thermal conductivity. Simply put, the greater the R-Value the better the insulation. [23]

Traditionally, expanded polystyrene (EPS) was the sole foam packaging material [12]. Polystyrene foams are considered to have excellent balance between cost and performance for the insulation and packaging fields. Polystyrene also has superior shock absorbing properties. [13] This, therefore; was the basic reason to compare the R- value of Green Cell® coolers with EPS coolers.

EPS and Green Cell® coolers were made to have the same dimensions. Identical buckets (same size and same color) were used in the EPS and Green Cell® coolers. To compare the R- value of Green Cell® cooler with the EPS coolers, experiments were performed at the same time, in the same environments with the same equipment and the same amount of ice. The conditions used a) 50%RH and 25°C b) 30°C and 80% RH

It was found that the EPS cooler had a 10% higher R- value than GC at 50% RH and 25°C and at the higher temperature and relative humidity the EPS cooler had 20% higher R –value as compared to Green Cell® cooler. This indicates that Green Cell® degraded with increase in humidity. It absorbed moisture, which increased its thermal conductivity and thus lowered it's R- value.

Thermal conductivity of cellular plastic is directly affected by factors like density, cell size, polymer composition and gas phase. [12] Thermal conductivity of cellular plastic and elastomers is defined by the K factor, which is defined by Fourier's equation for conduction through homogeneous materials. Total K factor (M$_C$ Intire and Keddedy, 1948) is separated into components of different modes of heat transfer .As shown in the following equation.

$$K= ks+kg+kr+kc$$

Where

k_s = conduction through solid

k_g = conduction through gas

k_r = radiation

k_c = convection in the gas

These factors can affect the R-value of cellular plastic foams.

As density increases, k_r (thermal conductivity due to radiation) decreases but in this case no mode of radiation and convection existed only conduction was available, which is responsible for the R- value. The overall change in k usually decreases with increase in density to a minimum at 2pcf(lbs per cubic feet) [12] and then increases with increasing density of the foam above 2 pcf. Since the R- value is the reciprocal of K factor [12], thus Green Cell® will have a lower R- value than the EPS cooler because of its higher density. (3.3pcf).

At higher relative humidity conditions Green Cell® shows a greater discrepancy than EPS (about 20%) as the material has a more hygroscopic nature as compared to EPS and picks up moisture at a faster rate.

At higher humidity conditions, the carbohydrates in Green Cell® foam can absorb more moisture than EPS, thus causing a decrease in the R-value. Green Cell® polymer composition and cell size at different humidity conditions effect R-values.

It is difficult to extrapolate, based on these studies, R-values of Green Cell® foam at other temperatures, because of the direct effect of relative humidity. R-value is not linear with temperature and RH increase.

Table 11. R-values of EPS cooler and Green Cell cooler at different conditions [5-a].

Temp.	**RH**	**Time**	**EPS**	**Green Cell®**	**R-Value**
°F	**%**	**hr**			**Unit**
77	50	24	14.2019	13.24	ft^2*hr*°F/BTU
77	50	48	12.8250	11.918	ft^2*hr*°F/BTU
86	80	26	10.0455	7.803	ft^2*hr*°F/BTU

* Dimensions of EPS cooler and Green Cell cooler: $11^{14/16}*10^{1/8}*9^{1/8}$

CHAPTER 4

CONSLUSIONS

Biodegradable packaging materials will find niche markets as long as their properties are comparable to currently used synthetics.

Dimensional stability is an important parameter for plastic foams. It represents the ability of a material to retain its original shape and size in varying environmental conditions. Since GCF is a hygroscopic material it was not able to retain its dimensions at high RH and temperature conditions. Cushioning characteristics of Green Cell® Foam are also affected by high temperature, high RH and long storage time. Green Cell® Foam can be used for those products such as electronics which are not moisture sensitive and have fragility level 30-45 G. One-inch foam can be used for rugged appliances when these items are shipped and stored in controlled environments for a short period of time.

Thermal insulation properties of Green Cell® Foam showed comparable results with EPS at standard RH and temperature (25 °C, 50% RH) conditions. Green Cell® coolers could be an effective package for pharmaceuticals when these items are shipped and stored in controlled environments for short periods of time.

Green Cell® Foam is a hygroscopic material whose properties change substantially at high RH. For high RH applications, and for the packaging of produce and other perishables, this will need to be addressed to create more opportunities for its use as packaging foam.

4.2 RECOMMENDATIONS

Polymer composition and cell size of Green Cell® at different humidity conditions should be investigated and affect of these factor upon R-values are those points which are recommended for further study.

Molecular structure of Green Cell® Foam would be studied in depth to investigate its hydroscopic nature.

APPENDIX A

CUSHIONING CHARACTERISTICS

- Tables G 1 to G 7 represent the information about the shock characteristics of Green Cell® foam having thickness of 1 inch.

Table G1. Shock characteristics

Shock characteristics 1" thickness

Weight = 12.8lbs
Area=64in2
Static pressure=0.2 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	56.76	17	187.06
2	55.56	17.2	187.6
3	56.29	16.9	186.07
4	57.41	17.5	196.37
5	57.09	17.7	193.69
Ave.	56.622	17.26	190.158
s.dev	0.7241	0.3362	4.5803

Table G2. Shock characteristics

Shock characteristics 1" thickness

Weight = 12.8lbs
Aear=36in2
Static pressure=0.355 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	59.39	17.3	195.45
2	64.92	16.1	197.76
3	61.28	16.4	196.31
4	65.04	15.8	198.03
5	64.29	15.9	195.96
Ave.	62.984	16.3	195.02
s.dev	2.5249	0.6042	1.1352

Table G 3. Shock characteristics

Shock characteristics 1" thickness

Weight = 51lbs
Aear=64in2
Static pressure=0.8 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	79.6	12.9	196.35
2	78.12	12.9	193.67
3	80.93	12.6	194.22
4	84.26	12	193.37
5	81.11	12.4	193.69
Ave.	80.804	12.56	195.02
s.dev	2.2752	0.3782	1.2078

Table G4. Shock characteristics

Shock characteristics 1" thickness

Weight = 47lbs
Aear=36in2
Static pressure=1.305 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	117	10.3	226.42

Table G5. Shock characteristics

Shock characteristics 1" thickness

Weight = 52lbs
Aear=36in2
Static pressure=1.44
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	122.12	9.5	219.94
2	107.93	10.3	211.13
3	117.37	9.9	216.71
Ave.	115.8067	9.9	215.9267
s.dev	7.2230	0.4	4.4569

Table G 6. Shock characteristics

Shock characteristics 1" thickness

Weight = 57lbs
Aear=36in2
Static pressure=1.58
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	114.18	10.6	219.51
2	124.69	9.6	223.1
3	112.62	10.4	219.62
Ave.	117.1633	10.2	220.7433
s.dev	6.5648	0.5292	2.0417

Table G7.Shock characteristics

Shock characteristics 1" thickness

Weight = 62lbs
Aear=36in2
Static pressure=1.722
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	131.47	9.6	229.4
2	130.92	9.3	228.96
3	130.23	9.5	226.49
Ave.	130.8733	9.4667	228.2833
s.dev	0.6213	0.1528	1.5686

- Tables G 8 to G16 represent the information about the shock characteristics of Green Cell® foam having thickness of 2- inch.

Table G8. Shock characteristics

Shock characteristics 2" thickness

Weight = 12.8lbs
Area =36in2
Static pressure = 0.355 psi
Gate time =3.67
Height = 24in
Filter = 156

s.no	G value	time	Velocity
1	39.97	22.8	177.25
2	38.58	23	170.57
4	39.22	22.9	172.57
6	39.15	22.1	169.92
7	38.42	22.8	169.86
ave.	39.0680	22.7200	172.0340
st dev.	0.6127	0.3564	3.1158

Table G 9. Shock characteristics

Shock characteristics 2" thickness

Weight = 37lbs
Area = 64in2
Static pressure = 0.578
Gate time = 3.67
Height = 24in
Filter = 156

s.no	G value	time	Velocity
1	34.61	21.5	164.56
2	38.3	20.7	166.49
3	37.99	20.5	167.81
4	34.1	21.8	165.1
5	31.96	21.9	162.47
Ave.	35.392	21.28	165.286
s.dev	2.7049		

Table G 10. Shock characteristics

Shock characteristics 2" thickness

Weight = 42lbs
Aear=64in2
Static pressure=0.65625
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	34.65	22.5	169.45
2	31.75	22.9	165.88
3	31.16	22.9	166.67
4	34.59	22	170.05
5	31.79	22.9	165.86
Ave.	32.788	22.64	167.582
s.dev	1.6910		

Table G11. Shock characteristics

Shock characteristics 2" thickness

Weight = 51.00lbs
Aear=64in2
Static pressure=0.8125
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	37.14	21.1	168.34
2	38.23	23	168.26
3	34.54	21.6	175.91
4	29.56	25.7	161.83
Ave.	34.8675	22.85	168.585
s.dev	3.8621		

Table G12. Shock characteristics

Shock characteristics 2" thickness

Weight = 52lbs
Aear=36in2
Static pressure=1.444 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	40.03	23.9	174.2
2	40.96	21.8	171.93
3	40.01	21.7	170.31
4	48.65	20.6	189.95
5	40.31	21.8	167.7
Ave.	41.992	21.96	174.818
s.dev	3.7417	1.1971	8.7848

Table G 13. Shock characteristics

Shock characteristics 2" thickness

Weight = 57lbs
Aear=36in2
Static pressure=1.583 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	36.97	21	158.4
2	36.63	22.3	162.21
3	31.55	22.6	143.42
4	31.7	22.8	142.45
5	31.31	24.1	148.79
Ave.	33.632	22.56	151.054
s.dev	2.8978	1.1104	8.8861

Table G 14. Shock characteristics

Shock characteristics 2" thickness

Weight = 62lbs
Aear=36in2
Static pressure=1.722 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	39.57	21.5	164.46
2	43.13	22.3	178.81
3	39.75	20.8	163.49
4	41.15	21.4	174.37
Ave.	40.9	21.5	170.2825
s.dev	1.6459	0.6164	7.5159

Table G 15. Shock characteristics

Shock characteristics 2" thickness

Weight = 63.3lbs
Area=36in2
Static pressure=1.758 psi
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
1	37.52	21.8	161.13

Table G16. Shock characteristics

Shock characteristics 2" thickness

Weight = 12.8lbs
Aear=36in2
Static pressure=0.355
Gate time=3.67
Height =24in
Filter = 156

- Table G17 represents the shock characteristic information before storing at different humidity conditions and 30°C and table G 18 represents shock characteristic information after the storage study at different humidity conditions and 30°C.

Table G17. Shock characteristic information before storing at different humidity conditions and 30°C.

Date: 10/21/2003

s.no	G value	time	Velocity	Wt. of sample
	G's	ms	in/sec	g
1	39.97	22.8	177.25	51.62
2	38.58	23	170.57	52.65
3	32.18	25.2	158.19	54.58
4	39.22	22.9	172.57	51.86
5	32.9	25.8	164.47	56.34
6	39.15	22.1	169.92	51.51
	38.42	22.8	169.86	52.38
Ave.	37.203	23.51429	168.976	
s.dev	3.2311	1.3981	6.0859	

Table G18. Shock characteristic information after the storage study at different humidity conditions and 30°C.

s.no	RH %	G value	time	velocity	wt. Of sample
	%	G's	ms	in/sec	g
1	11	51.84	17	182.63	58.68
2	43	45.21	18.1	174.4	52.64
3	54	38.29	21	171.59	54.7
4	75	36.53	22.6	169.08	53.96
5	86	37.25	18.8	153.64	62.03
6	89	50.63	16.4	163.43	60.59
7	97	76.77	12.4	184.1	67.31

- Table G19 (a, b and c). Shows the comparison of shock characteristics of Green Cell® foam before the storage study and after the storage study at different relative humidity (%RH) conditions and 30°C.(Table G19-a)

Table G19 (a)

		10/21/03	12/23/03	10/21/03	12/23/03	Δw
s.no	RH	G value	G value	wt.	wt.	net wt. gain
	%			(g)	(g)	(g)
1	11	39.97	51.84	51.62	52.68	1.06
2	43	38.58	45.21	52.65	52.64	-0.01
3	54	32.18	38.29	54.58	54.7	0.12
4	75	39.22	36.53	51.86	53.96	2.1
5	86	32.9	37.25	56.34	62.03	5.69
6	89	39.15	50.63	51.51	60.59	9.08
7	97	38.42	76.77	52.38	67.31	14.93

(Table G19-b)

Date			10/21/2003	12/23/2003	10/21/2003	12/23/2003
	s.no	RH	time	time	velocity	velocity
		%	(ms)	(ms)	(in/sec)	(in/sec)
	1	11	22.8	17	177.25	182.63
	2	43	23	18.1	170.57	174.4
	3	54	25.2	21	158.19	171.59
	4	75	22.9	22.6	172.57	169.08
	5	86	25.8	18.8	164.47	153.64
	6	89	22.1	16.4	169.92	163.43
	7	97	22.8	12.4	169.86	184.1

Table G19. Comparison of G values of Green Cell® foam at different relative humidities and time (days)

(Table 19-c)

Time	RH 11%	RH 45%	RH 56%	RH 77%	RH 8400%	RH90%	RH 96%
10/21/03	39.97	38.58	32.18	39.22	32.9	39.15	38.42
12/23/003	51.84	45.21	38.29	36.53	37.25	50.63	76.77

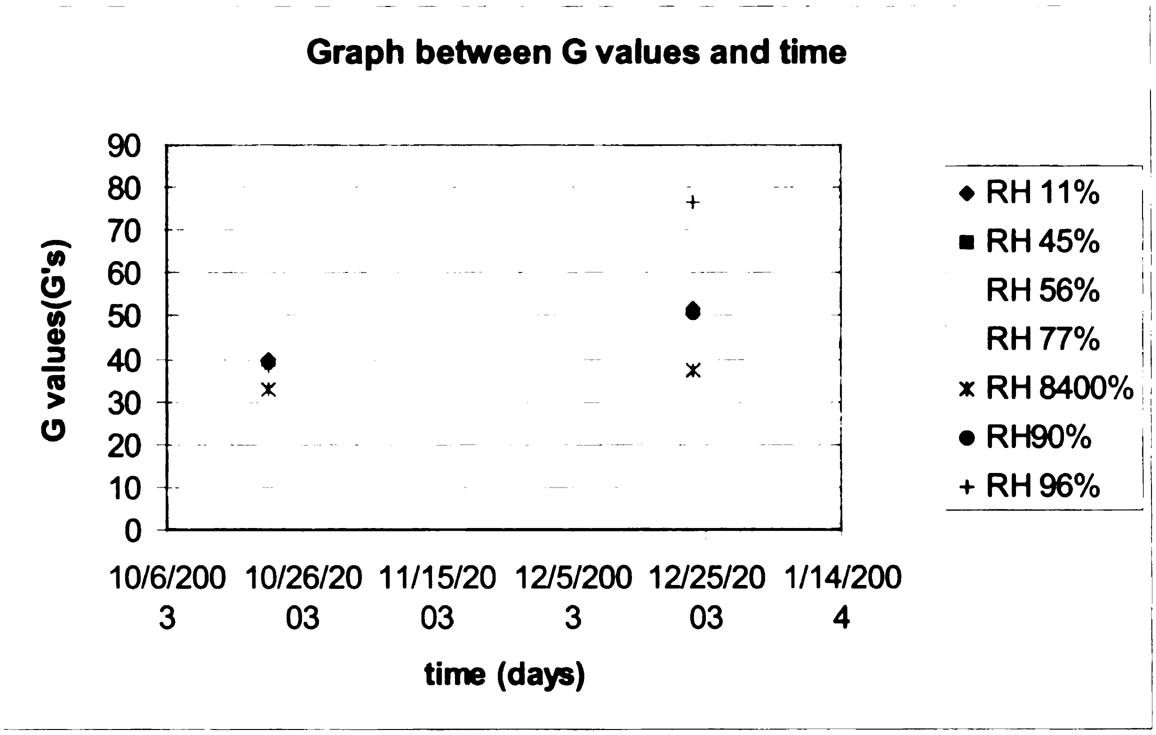

Figure G1. Graph between G value and Time (days)

Table G 20. Comparison of G values of Green Cell® foam at different relative humidities with respect to time

RH %	10/21/2003	12/23/2003
11	39.97	51.84
45	38.58	45.21
56	32.18	38.29
77	39.22	36.53
84	32.9	37.25
90	39.15	50.63
96	38.42	76.77

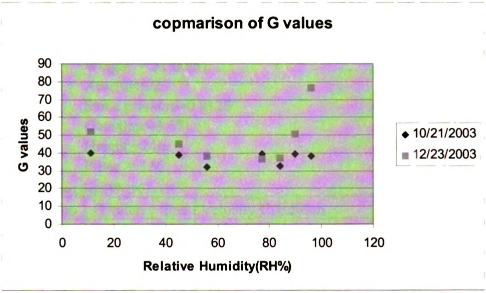

Figure G 2. Graph between G values and Relative Humidity conditions (RH%)

Shock characteristics and time effect

Table G 21. Shock characteristics of Green Cell® foam

Shock characteristics 2" thickness
Weight = 51.00lbs
Aear=64in2
Static pressure=0.8125
Gate time=3.67
Height =24in
Filter = 156

Time: July 09,2003

s.no	G value	Time	Velocity
1	37.14	21.1	168.34
2	38.23	23	168.26
3	34.54	21.6	175.91
4	29.56	25.7	161.83
Ave.	34.8675	22.85	168.585
s.dev	3.8621		

Table G 22. Shock characteristics of Green cell foam

Shock characteristics 2" thickness

Weight = 51.00lbs
Aear=64in2
Static pressure=0.8125
Gate time=3.67
Height =24in
Filter = 156

Time : Sept.19,2003

s.no	G value	time	Velocity	Condition
1	22.05	30.1	130.95	Platen donot bounces back
2	24.28	28.2	130.67	Platen donot bounces back
3	24.28	28.5	134.34	Platen donot bounces back
4	24.88	27.6	133.59	Platen donot bounces back
5	25.6	27	137.1	Platen donot bounces back
Ave.	24.218	28.28	133.33	Platen donot bounces back
s.dev	1.3282			Platen donot bounces back

Table G 23. Shock characteristics of Green cell foam

Time oct. 21,2003

2nd set of material fresh samples

Weight = 51.00lbs
Aear=64in2
Static pressure=0.8125
Gate time=3.67
Height =24in
Filter = 156

s.no	G value	time	Velocity
		ms	in/sec
1	34.28	21.1	166.34
2	37.32	23.2	168.34
3	34.54	21.6	173.91
4	37.14	24.7	161.83
5	35.38	23.02	169.29
Ave.	36.095	22.724	167.942
s.dev	1.3567	1.424739	4.4021438

Table G24. Shock characteristics of Green cell foam

Shock characteristics 1" thickness

Weight = 51lbs
Aear=64in2
Static pressure=0.8 psi
Gate time=3.67
Height =24in
Filter = 156

Time : July 15, 2003

s.no	G value	time(ms)	Velocity(in/sec)
1	79.6	12.9	196.35
2	78.12	12.9	193.67
3	80.93	12.6	194.22
4	84.26	12	193.37
5	81.11	12.4	193.69
Ave.	80.804	12.56	195.02
s.dev	2.2752	0.3782	1.2078

Table G 25. Shock characteristics of Green cell foam

Shock characteristics 1" thickness

Weight = 51lbs
Aear=64in2
Static pressure=0.8 psi
Gate time=3.67
Height =24in
Filter = 156

Time : Sept 19,2003

s.no	G value	time(ms)	Velocity(in/sec)
1	55.84	14.8	173.52
2	51.41	15.7	166.83
3	47.59	16.6	167.4
4	51.89	15.2	165.76
Ave.	51.683	15.575	168.3775
s.dev	3.3740	0.7762	3.4951

Table G26. Shock characteristics of Green cell foam

Another attempt
Weight = 51lbs
Aear=64in2
Static pressure=0.8 psi
Gate time=3.67
Height =24in
Filter = 156 Time sept.20,2003

s.no	G value	time(ms)	Velocity(in/sec)
1	48.24	16.6	163.12
2	51.39	15.6	167.73
3	52.08	15.2	168.48
4	49.65	16.5	168.78
Ave.	50.34	15.975	167.0275
s.dev	1.7336	0.6850	2.6422

Table G27. Shock characteristics of Green cell foam

Shock characteristics 1" thickness

Weight = 51lbs
Aear=64in2
Static pressure=0.8 psi
Gate time=3.67
Height =24in
Filter = 156

Oct.21,2003

s.no	G value	time	Velocity
1	79.6	12.9	196.35
2	78.12	12.9	193.67
3	80.93	12.6	194.22
4	84.26	12	193.37
5	81.11	12.4	193.69
Ave.	80.804	12.56	195.02
s.dev	2.2752	0.3782	1.2078

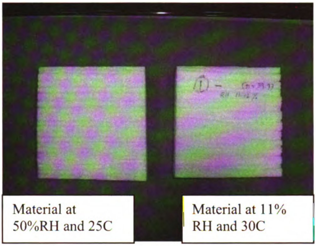

Figure G 3. Comparison of Green Cell® foam material kept at 50% RH ,25°C and 11% RH ,30°C.(Front view)

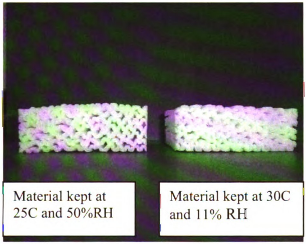

Figure G 4. Comparison of Green Cell® foam material kept at 50% RH, 25°C and 11% RH, 30°C.(Side view)

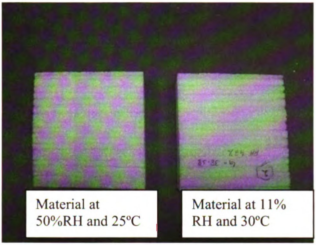

Figure G 5. Comparison of Green Cell® foam material kept at 50% RH , 25°C and 43% RH ,30°C.(Front view)

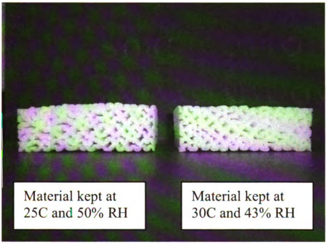

Figure G6. Comparison of Green Cell foam material kept at 50% RH, 25C and 43% RH ,30C.(Side view)

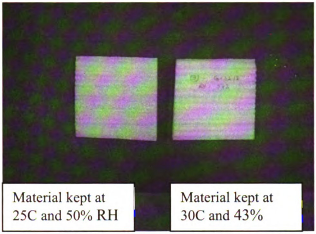

Figure G 7. Comparison of Green Cell foam material kept at 50% RH, 25C and 43% RH ,30C.(Front view)

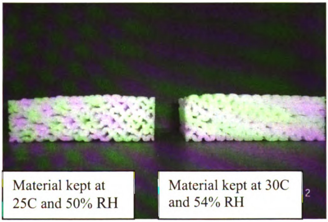

Figure G 8. Comparison of Green Cell foam material kept at 50% RH, 25C and 43% RH, 30C.(Side view)

APPENDIX B

DIMENSIONAL CHANGES AND MOISTURE GAIN/LOSS

Dimensional Changes and Moisture gain/loss with respect to time at 11% RH and 30°C.

Table D 1. Dimensional change data of sample no. "1"

	S.No.1				
Date	Time	Length	Width	Thickness	Weight
	hrs	(L) in	(W) in	(T) in	(wt) g
10/22/2003	0	2.1105	2.019	1.1785	4.1529
10/23/2003	24	2.077	2.0045	1.166	4.016
10/24/2003	48	2.1075	1.978	1.1585	4.0182
25-Oct	72	2.109	2.013	1.1785	4.0091
10/27/2003	96	2.0915	2.03	1.1935	4.0378
10/28/2003	120	2.099	2.016	1.19	4.0094
10/29/2003	144	2.122	2.014	1.197	4.0195
11/31/2003	192	2.1025	1.994	1.187	4.0605
11/2/2003	240	2.107	2.005	1.2095	4.0715
11/5/2003	312	2.0755	1.996	1.2	4.08
11/7/2003	360	2.083	2.007	1.207	4.0728
11/9/2003	408	2.057	1.987	1.19	4.053
	Ave.	2.0951	2.0053	1.1880	4.0501

Table D 2. Dimensional change data of sample no. "1-A"

	S.No 1-A				
Date	time	Length	Width	Thickness	Weight
	hrs	(L) in	(W) in	(T) in	(wt) g
10/22/2003	0	2.1025	2.097	1.2865	4.4403
10/23/2003	24	2.0865	2.062	1.2508	4.291
10/24/2003	48	2.093	2.112	1.2985	4.2882
25-Oct	72	2.1025	2.128	1.323	4.2842
10/27/2003	96	2.092	2.113	1.3325	4.2978
10/28/2003	120	2.0975	2.1155	1.3235	4.2802
10/29/2003	144	2.1002	2.0915	1.3585	4.2915
11/31/2003	192	2.0985	2.0902	1.334	4.3047
11/2/2003	240	2.114	2.122	1.3645	4.3478
11/5/2003	312	2.1085	2.0995	1.3545	4.3576
11/7/2003	360	2.105	2.0865	1.346	4.3493
11/9/2003	408	2.0915	2.082	1.338	4.3273
	Ave.	2.0993	2.0999	1.3259	4.3217

Table D 3. Averaged Dimensional Changes (thickness, length and width) data

Time (hrs)	Length (in)	st.dev	Length net change (in)	Width in	Width net change (in)	st.dev.	1" Thickness (in)	Net Wt. Change(g) (in)	st.dev.
0	2.0834	0.0269	0.0000	1.9474	0.0000	0.1317	1.2325	0.0000	0.0764
24	2.0505	0.0364	-0.0329	1.9210	-0.0264	0.1319	1.2084	-0.0241	0.0600
48	2.0543	0.0553	-0.0292	2.0001	0.0527	0.1257	1.2285	-0.0040	0.0990
72	2.0634	0.0493	-0.0200	2.0078	0.0604	0.1231	1.2508	0.0183	0.1022
96	2.0571	0.0413	-0.0263	2.0164	0.0690	0.1067	1.2630	0.0305	0.0983
120	2.0677	0.0384	-0.0158	2.0128	0.0654	0.1040	1.2568	0.0242	0.0944
144	2.0775	0.0417	-0.0060	2.0036	0.0562	0.1012	1.2778	0.0453	0.1142
192	2.0660	0.0402	-0.0174	1.9932	0.0458	0.1120	1.2605	0.0280	0.1039
240	2.0770	0.0392	-0.0064	2.0161	0.0687	0.1189	1.2870	0.0545	0.1096
312	2.0630	0.0368	-0.0204	2.0020	0.0546	0.1172	1.2773	0.0448	0.1092
360	2.0561	0.0450	-0.0273	1.9960	0.0486	0.1135	1.2765	0.0440	0.0983
408	2.0410	0.0413	-0.0424	1.9863	0.0389	0.1132	1.2640	0.0315	0.1047
Ave.	2.0631	0.0410		1.9919		0.1166	1.2569		0.0975

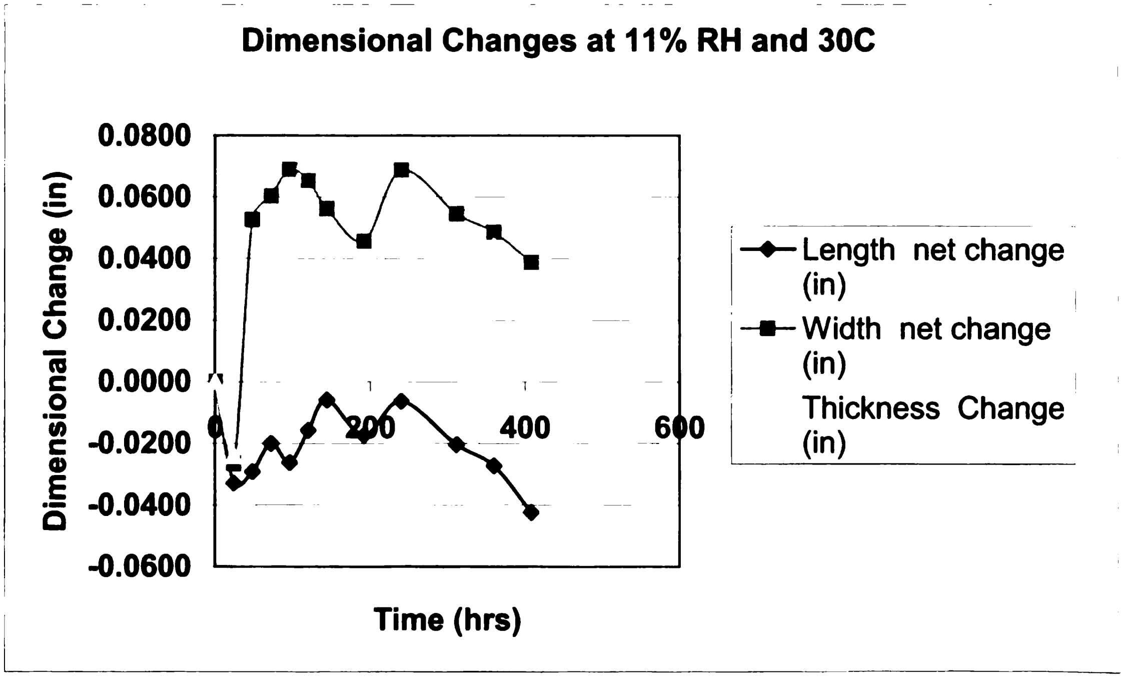

Figure D1-a. Dimensional changes at 11% RH and 30°C.

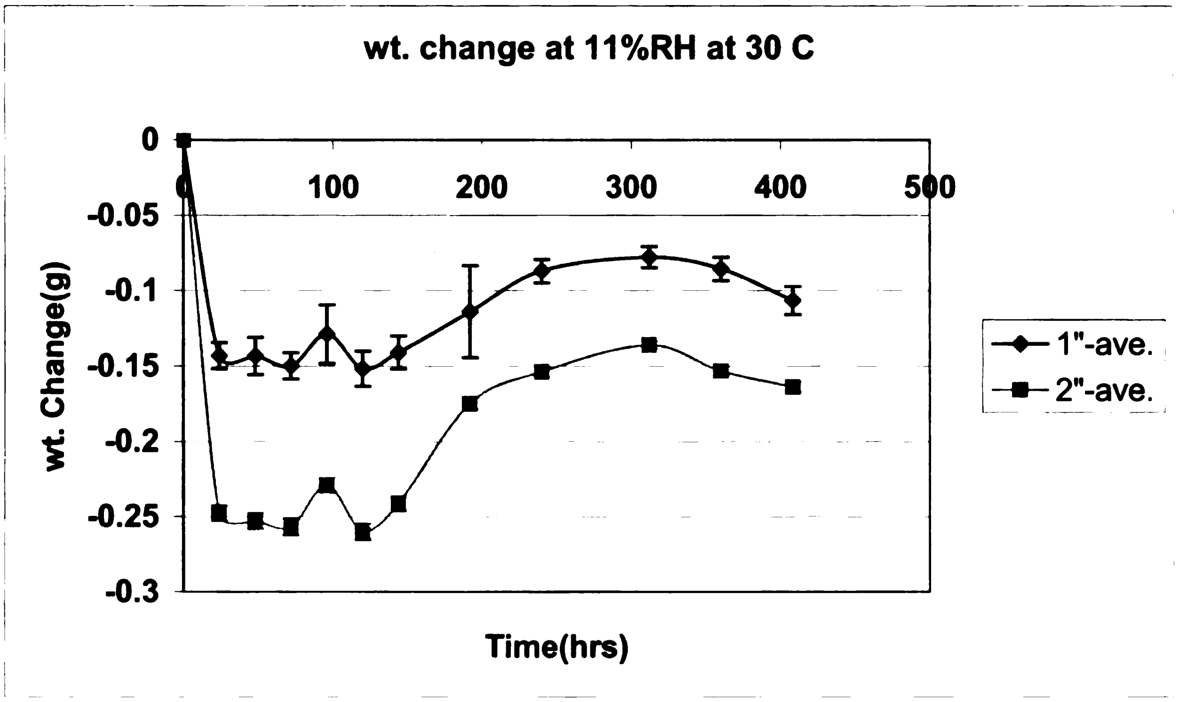

Figure D1-b. Weight changes at 11% RH and 30°C.

Dimensional Changes and Moisture gain/loss with respect to time at 43% RH and 30°C.

Table D 4. Dimensional Changes data at 43% and 30°C.

Length

	Date	10/22/03	10/23/03	10/24/03	25-Oct	10/27/03	10/28/03
S.no.	hrs	0	24	48	72	96	120
43-B		2.096	2.108	2.107	2.098	2.108	2.1045
43-B-1		1.936	1.964	1.9965	1.9805	1.994	1.983
Ave.		2.016	2.036	2.05175	2.03925	2.051	2.04375
	st.dev	0.1131	0.1018	0.0781	0.0831	0.0806	0.0859

Width

	Date	10/22/03	10/23/03	10/24/03	25-Oct	10/27/03	10/28/03
s.no	hrs	0	24	48	72	96	120
43-B		1.918	1.9435	1.9445	1.9535	1.936	1.964
43-B-1		2.0735	2.049	2.094	2.081	2.077	2.0615
Ave.		1.99575	1.9435	2.01925	2.01725	2.0065	2.01275
	st.dev	0.1100	0.0746	0.1057	0.0902	0.0997	0.0689

Thickness

	Date	10/22/03	10/23/03	10/24/03	25-Oct	10/27/03	10/28/03
s.no	hrs	0	24	48	72	96	120
43-B		1.258	1.2625	1.275	1.2765	1.287	1.2925
43-B-1		1.187	1.2155	1.212	1.2145	1.219	1.2275
Ave.		1.2225	1.239	1.2435	1.2455	1.253	1.26
	st.dev	0.0502	0.0332	0.0445	0.0438	0.0481	0.0460

wt. change

	Date	10/22/03	10/23/03	10/24/03	25-Oct	10/27/03	10/28/03
s.no.	hrs	0	24	48	72	96	120
43-B		4.1342	4.0945	4.0908	4.0915	4.0865	4.0835
43-B-1		3.9382	3.9011	3.8989	3.8974	3.8951	3.8919
Ave.		4.0362	3.9978	3.99485	3.99445	3.9908	3.9877
	st.dev	0.1386	0.1368	0.1357	0.1372	0.1353	0.1355

(continued from Table D4)

Length

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
S.no.	hrs	144	192	240	312	360	408
43-B		2.0955	2.096	2.097	2.09	2.0735	2.0795
43-B-1		1.9735	1.982	1.983	1.987	1.9615	1.971
Ave.		2.0345	2.039	2.04	2.0385	2.0175	2.02525
	st.dev	0.08626703	0.0806102	0.08061017	0.072832	0.07919596	0.07672109

Width

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	hrs	144	192	240	312	360	408
43-B		1.9475	1.9535	1.9555	1.935	1.9205	1.944
43-B-1		2.0635	2.095	2.093	2.0445	2.016	2.0395
Ave.		2.0055	2.02425	2.02425	1.98975	1.96825	1.99175
	st.dev	0.0820	0.1001	0.0972	0.0774	0.0675	0.0675

Thickness

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	hrs	144	192	240	312	360	408
43-B		1.291	1.2865	1.2873	1.28	1.267	1.2805
43-B-1		1.2165	1.226	1.229	1.2115	1.1955	1.295
Ave.		1.25375	1.25625	1.25815	1.24575	1.23125	1.28775
	st.dev	0.0527	0.0428	0.0412	0.0484	0.0506	0.0103

wt. change

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no.	hrs	144	192	240	312	360	408
43-B		4.0834	4.0843	4.0848	4.083	4.0825	4.0815
43-B-1		3.8924	3.8953	3.8952	3.8915	3.8908	3.8905
Ave.		3.9879	3.9898	3.99	3.98725	3.98665	3.986
	st.dev	0.1351	0.1336	0.1341	0.1354	0.1356	0.1351

Table D 5-D8: Net Dimensional changes and weight loss/gain at 43% RH and 30°C.

Length

Table D5: Change in length with respect to time

				Net change
Date	hrs	Length	st.dev	Length
10/22/2003	0	2.0160	0.1131	0
10/23/2003	24	2.0360	0.1018	0.020
10/24/2003	48	2.0518	0.0781	0.036
25-Oct	72	2.0393	0.0831	0.023
10/27/2003	96	2.0510	0.0806	0.035
10/28/2003	120	2.0438	0.0859	0.028
10/29/2003	144	2.0345	0.0863	0.019
11/31/2003	192	2.0390	0.0806	0.023
11/2/2003	240	2.0400	0.0806	0.024
11/5/2003	312	2.0385	0.0728	0.023
11/7/2003	360	2.0175	0.0792	0.002
11/9/2003	408	2.0253	0.0767	0.009

Width

Table D 6. Change in Width with respect to time

				Net change
Date	hrs	Width	st.dev	Width
10/22/2003	0	1.9958	0.1100	0
10/23/2003	24	1.9435	0.0746	-0.0523
10/24/2003	48	2.0193	0.1057	0.0235
25-Oct	72	2.0173	0.0902	0.0214
10/27/2003	96	2.0065	0.0997	0.0107
10/28/2003	120	2.0128	0.0689	0.0170
10/29/2003	144	2.0055	0.0820	0.0097
11/31/2003	192	2.0243	0.1001	0.0285
11/2/2003	240	2.0243	0.0972	0.0284
11/5/2003	312	1.9898	0.0774	-0.0060
11/7/2003	360	1.9683	0.0675	-0.0276
11/9/2003	408	1.9918	0.0675	-0.0041

Thickness

TableD7. Change in Thickness with respect to time

				Net change
Date	hrs	Thickness	st.dev	Thickness
10/22/2003	0	1.2225	0.0502	0
10/23/2003	24	1.2390	0.0332	0.0165
10/24/2003	48	1.2435	0.0445	0.0210
25-Oct	72	1.2455	0.0438	0.0230
10/27/2003	96	1.2530	0.0481	0.0305
10/28/2003	120	1.2600	0.0460	0.0375
10/29/2003	144	1.2538	0.0527	0.0313
11/31/2003	192	1.2563	0.0428	0.0338
11/2/2003	240	1.2582	0.0412	0.0357
11/5/2003	312	1.2458	0.0484	0.0233
11/7/2003	360	1.2313	0.0506	0.0088
11/9/2003	408	1.2878	0.0103	0.0653

Weight Change

TableD 8. Moisture gain/loss with respect to time

				Net change
Date	hrs	wt.(g)	st.dev.	wt. Change
10/22/2003	0	4.0362	0.1386	0.0000
10/23/2003	24	3.9978	0.1368	-0.0384
10/24/2003	48	3.9949	0.1357	-0.0414
25-Oct	72	3.9945	0.1372	-0.0418
10/27/2003	96	3.9908	0.1353	-0.0454
10/28/2003	120	3.9877	0.1355	-0.0485
10/29/2003	144	3.9879	0.1351	-0.0483
11/31/2003	192	3.9898	0.1336	-0.0464
11/2/2003	240	3.9900	0.1341	-0.0462
11/5/2003	312	3.9873	0.1354	-0.0489
11/7/2003	360	3.9867	0.1356	-0.0496
11/9/2003	408	3.9860	0.1351	-0.0502

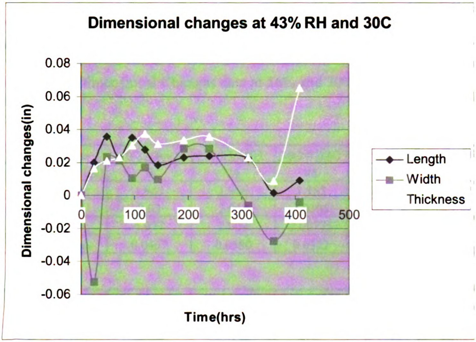

Figure D 2. Dimensional changes at 43% RH and 30°C.

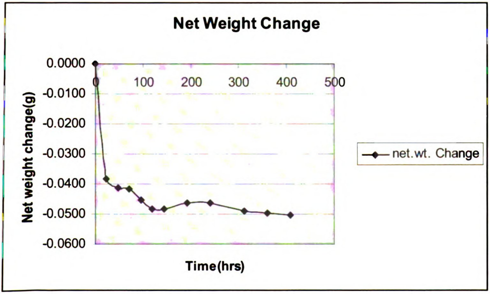

Figure D 3. Moisture gain/loss at 43% RH and 30°C.

Dimensional Changes and Moisture gain/loss with respect to time at 56% RH and 30°C.

Table D 9. Dimensional Changes data at 56% and 30°C.

Length

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
S.no.	Time(hrs)	0	24	48	72	96	120
56-B		1.964	1.966	1.985	1.973	1.969	2.0025
56-B-1		2.03	2.048	2.0305	2.0085	1.986	2.04
Ave.		1.997	2.007	2.00775	1.9907	1.9775	2.02125
	st.dev	0.0467	0.0580	0.0322	0.0251	0.0120	0.0265

Width

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no	Time(hrs)	0	24	48	72	96	120
56-B		2.085	2.0888	2.09	2.0805	2.096	2.1005
56-B-1		2.0185	2.045	2.0485	2.0595	2.061	2.0885
Ave.		2.05175	2.0888	2.06925	2.07	2.0785	2.0945
	st.dev	0.0470	0.0310	0.0293	0.0148	0.0247	0.0085

Thickness

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no	Time(hrs)	0	24	48	72	96	120
56-B		1.2455	1.2835	1.2615	1.2945	1.317	1.321
56-B-1		1.229	1.255	1.2635	1.275	1.2845	1.285
Ave.		1.23725	1.26925	1.2625	1.28475	1.30075	1.303
	st.dev	0.0117	0.0202	0.0014	0.0138	0.0230	0.0255

wt. change

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no.	Time(hrs)	0	24	48	72	96	120
56-B		3.5927	3.5958	3.5987	3.5975	3.5956	3.6
56-B-1		3.9728	3.9752	3.9797	3.9776	3.9758	3.9791
Ave.		3.78275	3.7855	3.7892	3.78755	3.7857	3.78955
	st.dev	0.2688	0.2683	0.2694	0.2688	0.2688	0.2681

(Continued from table D9)

Length

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
S.no.	Time(hrs)	144	192	240	312	360	408
56-B		1.989	1.99	1.9855	1.966	1.9625	1.9665
56-B-1		2.006	2.0335	2.018	1.997	1.9955	2
Ave.		1.9975	2.01175	2.00175	1.9815	1.979	1.98325
	st.dev	0.0120	0.0308	0.0230	0.0219	0.0233	0.0237

Width

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	Time(hrs)	144	192	240	312	360	408
56-B		2.0815	2.0875	2.082	2.071	2.044	2.064
56-B-1		2.041	2.0565	2.056	2.034	1.999	2.0195
Ave.		2.06125	2.072	2.069	2.0525	2.0215	2.04175
	st.dev	0.0286	0.0219	0.0184	0.0262	0.0318	0.0315

Thickness

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	Time(hrs)	144	192	240	312	360	408
56-B		1.3175	1.3625	1.3515	1.321	1.3105	1.359
56-B-1		1.271	1.2745	1.2665	1.2645	1.2465	1.266
Ave.		1.29425	1.3185	1.309	1.29275	1.2785	1.3125
	st.dev	0.0329	0.0622	0.0601	0.0400	0.0453	0.0658

wt. change

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no.	Time(hrs)	144	192	240	312	360	408
56-B		3.5958	3.602	3.5987	3.5975	3.594	3.5923
56-B-1		3.9756	3.9833	3.9772	3.9748	3.9741	3.9735
Ave.		3.7857	3.79265	3.78795	3.78615	3.78405	3.7829
	st.dev	0.2686	0.2696	0.2676	0.2668	0.2688	0.2695

Table D10: Change in Length with respect to time

	Time	Length	st.dev	Net change
Date	(hrs)	(in)		Length
10/22/2003	0	1.9970	0.0467	0
10/23/2003	24	2.0070	0.0580	0.0100
10/24/2003	48	2.0078	0.0322	0.0108
25-Oct	72	1.9908	0.0251	-0.0062
10/27/2003	96	1.9775	0.0120	-0.0195
10/28/2003	120	2.0213	0.0265	0.0243
10/29/2003	144	1.9975	0.0120	0.0005
11/31/2003	192	2.0118	0.0308	0.0148
11/2/2003	240	2.0018	0.0230	0.0047
11/5/2003	312	1.9815	0.0219	-0.0155
11/7/2003	360	1.9790	0.0233	-0.0180
11/9/2003	408	1.9833	0.0237	-0.0138

Table D11. Change in Width with respect to time

	Time	Width		Net change
Date	(hrs)	(in)	st.dev	Width
10/22/2003	0	2.0518	0.0470	0
10/23/2003	24	2.0888	0.0310	0.0370
10/24/2003	48	2.0693	0.0293	0.0175
25-Oct	72	2.0700	0.0148	0.0182
10/27/2003	96	2.0785	0.0247	0.0267
10/28/2003	120	2.0945	0.0085	0.0427
10/29/2003	144	2.0613	0.0286	0.0094
11/31/2003	192	2.0720	0.0219	0.0202
11/2/2003	240	2.0690	0.0184	0.0172
11/5/2003	312	2.0525	0.0262	0.0007
11/7/2003	360	2.0215	0.0318	-0.0303
11/9/2003	408	2.0418	0.0315	-0.0101

Table D12. Change in Thickness with respect to time

	Time			Net change
Date	(hrs)	Thickness	st.dev	Thickness
10/22/2003	0	1.2373	0.0117	0
10/23/2003	24	1.2693	0.0202	0.0320
10/24/2003	48	1.2625	0.0014	0.0253
25-Oct	72	1.2848	0.0138	0.0475
10/27/2003	96	1.3008	0.0230	0.0635
10/28/2003	120	1.3030	0.0255	0.0658
10/29/2003	144	1.2943	0.0329	0.0570
11/31/2003	192	1.3185	0.0622	0.0813
11/2/2003	240	1.3090	0.0601	0.0718
11/5/2003	312	1.2928	0.0400	0.0555
11/7/2003	360	1.2785	0.0453	0.0413
11/9/2003	408	1.3125	0.0658	0.0753

Table D13. Moisture gain/loss change with respect to time

	Time	Weight change		Net wt.
Date	(hrs)	(g)	st.dev	change(g)
10/22/2003	0	3.7828	0.2688	0
10/23/2003	24	3.7855	0.2683	0.0027
10/24/2003	48	3.7892	0.2694	0.0064
25-Oct	72	3.7876	0.2688	0.0048
10/27/2003	96	3.7857	0.2688	0.0029
10/28/2003	120	3.7896	0.2681	0.0068
10/29/2003	144	3.7857	0.2686	0.0029
11/31/2003	192	3.7927	0.2696	0.0099
11/2/2003	240	3.7880	0.2676	0.0051
11/5/2003	312	3.7862	0.2668	0.0034
11/7/2003	360	3.7841	0.2688	0.0012
11/9/2003	408	3.7829	0.2695	0.0001

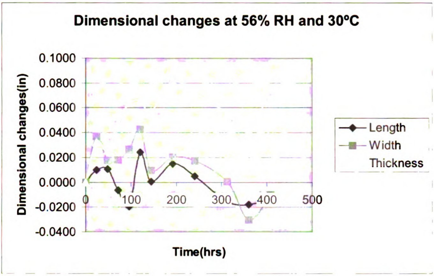

Figure D 4. Dimensional changes at 56% RH and 30°C.

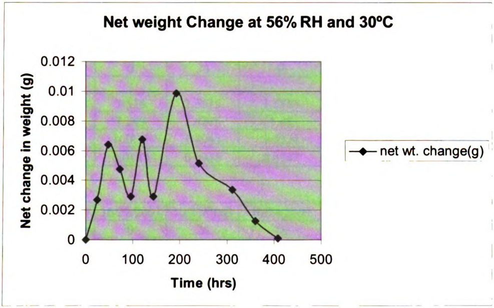

Figure D5. Moisture gain/loss at 56% RH and 30°C.

Dimensional Changes and Moisture gain/loss with respect to time at 75% RH and 30°C.

Table D14. Dimensional Changes data at 75% and 30°C.

Length

	Date	10/22/03	10/23/2003	10/24/2003	10/25/2003	10/27/2003	10/28/03
S.no.	hrs	0	24	48	72	96	120
75-B		1.968	1.975	1.998	1.966	1.998	1.983
75-B-1		2.043	2.023	2.0245	2.0245	2.028	2.0195
Ave.		2.0055	1.999	2.01125	1.99525	2.013	2.00125
St.dev.	St.dev.	0.0530	0.0339	0.0187	0.0414	0.0212	0.0258

Width

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
	hrs	0	24	48	72	96	120
s.no							
75-B		2.0795	2.11	2.1259	2.107	2.1235	2.115
75-B-1		2.048	2.12	2.1281	2.125	2.1395	2.108
Ave.		2.06375	2.11	2.127	2.116	2.1315	2.1115
	St.dev.	0.0223	0.0071	0.0016	0.0127	0.0113	0.0049

Thickness

		10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
	hrs	0	24	48	72	96	120
s.no							
75-B		1.318	1.5615	1.5856	1.6215	1.6585	1.6625
75-B-1		1.249	1.4275	1.48	1.482	1.515	1.5285
Ave.		1.2835	1.4945	1.5328	1.55175	1.58675	1.5955
	St.dev.	0.0488	0.0948	0.0747	0.0986	0.1015	0.0948

Weight change

		10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
wt. change	hrs	0	24	48	72	96	120
s.no.							
75-B		4.0916	4.2395	4.2406	4.2558	4.2714	4.2595
75-B-1		4.1859	4.3341	4.346	4.349	4.3638	4.3521
Ave.		4.13875	4.2868	4.2933	4.3024	4.3176	4.3058
	St. dev.	0.0667	0.0669	0.0745	0.0659	0.0653	0.0655

(Continued from table D14)

Length

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
S.no.	hrs	144	192	240	312	360	408
75-B		1.9715	1.971	1.963	1.964	1.96	1.9595
75-B-1		2.018	2.0105	2.0015	2.005	1.996	1.9965
Ave.		1.99475	1.99075	1.98225	1.9845	1.978	1.978
St.dev.	St.dev.	0.0329	0.0279	0.0272	0.0290	0.0255	0.0262

Width

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
	hrs	144	192	240	312	360	408
75-B		2.1125	2.1795	2.1115	2.103	2.1105	2.0895
75-B-1		2.08	2.142	2.109	2.0975	2.0775	2.0795
Ave.		2.09625	2.16075	2.11025	2.10025	2.094	2.0845
	St.dev.	0.0230	0.0265	0.0018	0.0039	0.0233	0.0071

Thickness

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
	hrs	144	192	240	312	360	408
75-B		1.6815	1.705	1.687	1.6985	1.6695	1.6725
75-B-1		1.531	1.535	1.5485	1.5845	1.505	1.5585
Ave.		1.60625	1.62	1.61775	1.6415	1.58725	1.6155
	St.dev.	0.1064	0.1202	0.0979	0.0806	0.1163	0.0806

Weight change

wt. change	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no.	hrs	144	192	240	312	360	408
75-B		4.2696	4.277	4.2716	4.2758	4.2686	4.268
75-B-1		4.3575	4.3717	4.3681	4.3702	4.3642	4.3644
Ave.		4.31355	4.32435	4.31985	4.323	4.3164	4.3162
	St.dev.	0.0622	0.0670	0.0682	0.0668	0.0676	0.0682

Table D15. Change in Length with respect to time

Time	Length (in)	St.dev.	Net change
hrs			Length (in)
0	2.0055	0.0530	0.0000
24	1.9990	0.0339	-0.0065
48	2.0113	0.0187	0.0057
72	1.9953	0.0414	-0.0103
96	2.0130	0.0212	0.0075
120	2.0013	0.0258	-0.0042
144	1.9948	0.0329	-0.0108
192	1.9908	0.0279	-0.0148
240	1.9823	0.0272	-0.0233
312	1.9845	0.0290	-0.0210
360	1.9780	0.0255	-0.0275
408	1.9780	0.0262	-0.0275

Table 16: Change in Width with respect to time

Time	Width	St.dev.	Net change
hrs			(Width)(in)
0	2.0638	0.0223	0.0000
24	2.1100	0.0071	0.0462
48	2.1270	0.0016	0.0632
72	2.1160	0.0127	0.0522
96	2.1315	0.0113	0.0677
120	2.1115	0.0049	0.0478
144	2.0963	0.0230	0.0325
192	2.1608	0.0265	0.0970
240	2.1103	0.0018	0.0465
312	2.1003	0.0039	0.0365
360	2.0940	0.0233	0.0303
408	2.0845	0.0071	0.0208

Table D17. Change in Thickness with respect to time

Time	Thickness	St.dev.	Net change
hrs	(in)	(in)	thickness(in)
0	1.2835	0.0488	0.0000
24	1.4945	0.0948	0.2110
48	1.5328	0.0747	0.2493
72	1.5518	0.0986	0.2683
96	1.5868	0.1015	0.3033
120	1.5955	0.0948	0.3120
144	1.6063	0.1064	0.3228
192	1.6200	0.1202	0.3365
240	1.6178	0.0979	0.3343
312	1.6415	0.0806	0.3580
360	1.5873	0.1163	0.3038
408	1.6155	0.0806	0.3320

Table D18. Moisture gain/loss with respect to time

Time	Wt.change	St.dev.	Net wt.change
hrs	(g)		(g)
0	4.1388	0.0667	0.0000
24	4.2868	0.0669	0.1481
48	4.2933	0.0745	0.1546
72	4.3024	0.0659	0.1637
96	4.3176	0.0653	0.1789
120	4.3058	0.0655	0.1671
144	4.3136	0.0622	0.1748
192	4.3244	0.0670	0.1856
240	4.3199	0.0682	0.1811
312	4.3230	0.0668	0.1843
360	4.3164	0.0676	0.1777
408	4.3162	0.0682	0.1775

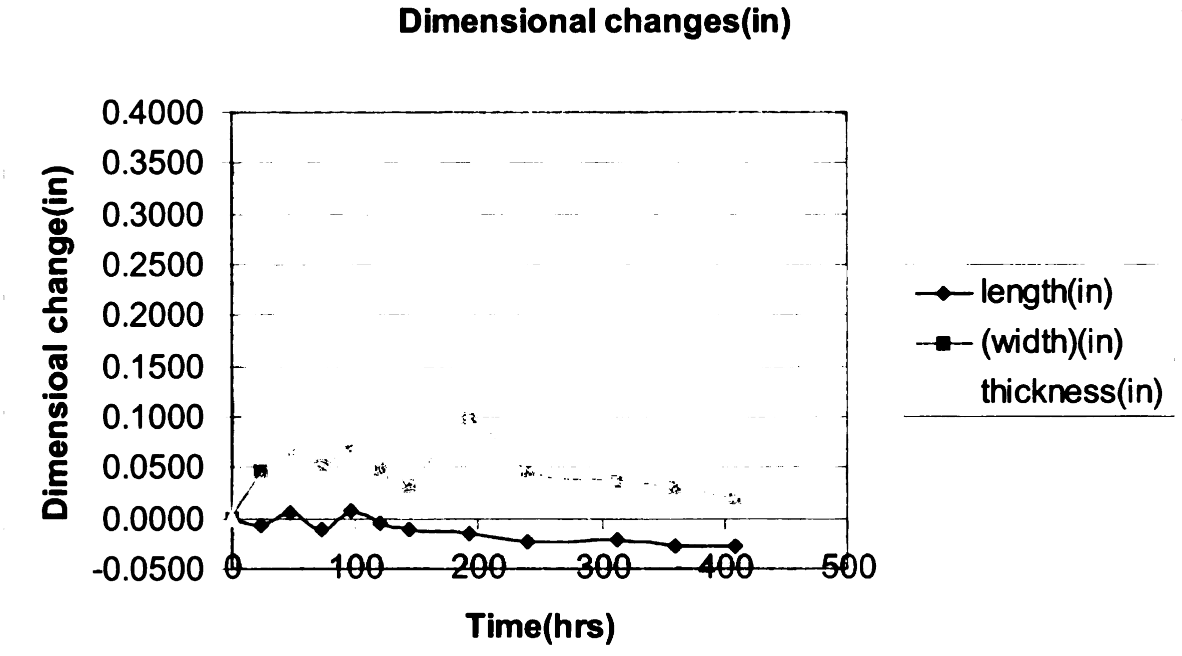

Figure D6. Dimensional changes at 75% RH and 30°C.

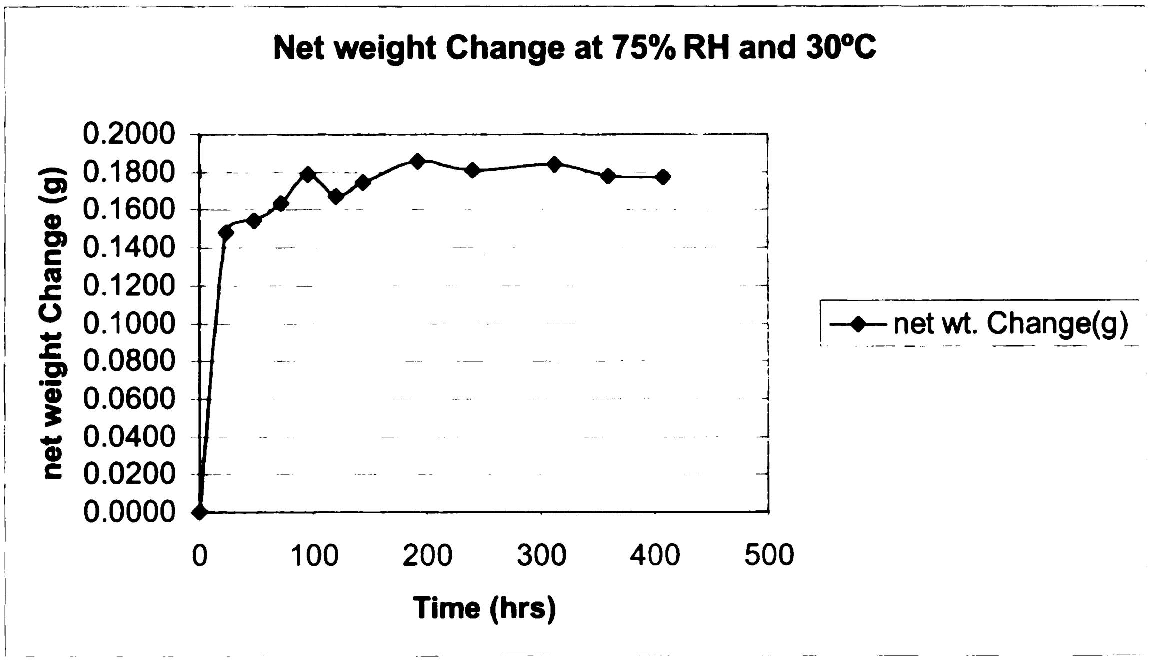

Figure D 7 Moisture gain/loss at 75% RH and 30°C.

Dimensional Changes and Moisture gain/loss with respect to time at 84% RH and 30°C.

Table D19. Dimensional Changes data and moisture gain/loss at 84% and 30°C.

Length

		10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
Time	hrs	0	24	48	72	96	120
84-B		2.0545	2.0315	2.004	1.9835	1.901	1.91
84-B-1		1.986	2.002	1.984	1.9835	1.876	1.8796
Ave.		2.027875	2.035	2.0225	2.009375	1.9495	1.950525
st.dev.	st.dev.	0.0279	0.0213	0.0345	0.0270	0.0629	0.0582

Width

	date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
Time	hrs	0	24	48	72	96	120
84-B		2.097	2.1125	2.078	2.0405	1.98	1.9987
84-B-1		2.062	2.103	2.0685	2.055	2.0275	2.071
Ave.		2.02025	2.062125	2.048625	2.039	2.007125	2.023675
	st.dev.	0.07752298	0.07469302	0.067005014	0.04793094	0.053381147	0.07143383

Thickness

Time	date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
	hrs	0	24	48	72	96	120
84-B		1.271	1.5305	1.5845	1.6165	1.66	1.6875
84-B-1		1.319	1.6175	1.6685	1.712	1.7765	1.7545
Ave.1"		1.295	1.574	1.6265	1.66425	1.71825	1.721
1"	st.dev.	0.0339	0.0615	0.0594	0.0675	0.0824	0.0474

wt. change

Time	date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
	hrs	0	24	48	72	96	120
84-B		3.7139	3.9096	3.9425	3.9574	3.9975	3.9886
84-B-1		4.0886	4.3005	4.3274	4.3452	4.3936	4.3837
ave.1" thick	ave.1" thick	3.90125	4.10505	4.13495	4.1513	4.19555	4.18615
	st.dev.	0.2650	0.2764	0.2722	0.2742	0.2801	0.2794

(Continued from Table D19)

Length

		10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
Time	hrs	144	192	240	312	360	408
84-B		1.8785	1.877	1.784	1.7625	1.724	1.7155
84-B-1		1.8335	1.8	1.7565	1.738	1.718	1.7065
Ave.		1.92625	1.920875	1.843125	1.825	1.8075	1.800375
st.dev.	st.dev.	0.0730	0.0902	0.0746	0.0770	0.0878	0.0897

Width

	date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
Time	hrs	144	192	240	312	360	408
84-B		2.097	2.1125	2.078	2.0405	1.98	1.9987
84-B-1		2.062	2.103	2.0685	2.055	2.0275	2.071
Ave.		2.0795	2.10775	2.07325	2.04775	2.00375	2.03485
	st.dev.	0.0175	0.00475	0.00475	0.00725	0.02375	0.03615

Thickness

Time	date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
84-B	hrs	144	192	240	312	360	408
84-B-1		1.271	1.5305	1.5845	1.6165	1.66	1.6875
Ave.1"		1.319	1.6175	1.6685	1.712	1.7765	1.7545
1"		1.295	1.574	1.6265	1.66425	1.71825	1.721
	st.dev.	0.0339	0.0615	0.0594	0.0675	0.0824	0.0474

wt. change

Time	date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
84-B	hrs	144	192	240	312	360	408
84-B-1		3.7139	3.9096	3.9425	3.9574	3.9975	3.9886
ave.1" thick		4.0886	4.3005	4.3274	4.3452	4.3936	4.3837
	ave.1" thick	3.90125	4.10505	4.13495	4.1513	4.19555	4.18615
	st.dev.	0.2650	0.2764	0.2722	0.2742	0.2801	0.2794

Table D 20. Change in Length with respect to time

	Time	Length		Net Change
Date	(hrs)	(in)	st.dev.	Length(in)
10/22/2003	0	2.0279	0.0279	0.0000
10/23/2003	24	2.0350	0.0213	0.0071
10/24/2003	48	2.0225	0.0345	-0.0054
25-Oct	72	2.0094	0.0270	-0.0185
10/27/2003	96	1.9495	0.0629	-0.0784
10/28/2003	120	1.9505	0.0582	-0.0773
10/29/2003	144	1.9263	0.0730	-0.1016
11/31/2003	192	1.9209	0.0902	-0.1070
11/2/2003	240	1.8431	0.0746	-0.1848
11/5/2003	312	1.8250	0.0770	-0.2029
11/7/2003	360	1.8075	0.0878	-0.2204
11/9/2003	408	1.8004	0.0897	-0.2275

Table D 21. Change in Width with respect to time

	Time	**Width**		**Net change**
Date	**(hrs)**	**(in)**	**st.dev**	**Width(in)**
10/22/2003	0	2.0203	0.0775	0.0000
10/23/2003	24	2.0621	0.0747	0.0419
10/24/2003	48	2.0486	0.0670	0.0284
25-Oct	72	2.0390	0.0479	0.0187
10/27/2003	96	2.0071	0.0534	-0.0131
10/28/2003	120	2.0237	0.0714	0.0034
10/29/2003	144	2.0229	0.0608	0.0026
11/31/2003	192	1.9941	0.0666	-0.0261
11/2/2003	240	1.9411	0.0707	-0.0791
11/5/2003	312	1.9193	0.0767	-0.1010
11/7/2003	360	1.9036	0.0798	-0.1166
11/9/2003	408	1.8876	0.0825	-0.1326

Table D 22. Change in Thickness with respect to time

	Time	Thickness		Net change
Date	(hrs)	(in)	st.dev.	Thickness(in)
10/22/2003	0	1.2950	0.0339	0.0000
10/23/2003	24	1.5740	0.0615	0.2790
10/24/2003	48	1.6265	0.0594	0.3315
25-Oct	72	1.6643	0.0675	0.3693
10/27/2003	96	1.7183	0.0824	0.4233
10/28/2003	120	1.7210	0.0474	0.4260
10/29/2003	144	1.7255	0.0495	0.4305
11/31/2003	192	1.7450	0.0396	0.4500
11/2/2003	240	1.6688	0.0442	0.3738
11/5/2003	312	1.6610	0.0474	0.3660
11/7/2003	360	1.6560	0.0431	0.3610
11/9/2003	408	1.6788	0.0187	0.3838

Table 23: Moisture gain/loss with respect to time

	Time	Wt. Change	st.dev.	Net wt.change
Date	(hrs)	(g)		(g)
10/22/2003	0	3.9013	0.2650	0.0000
10/23/2003	24	4.1051	0.2764	0.2038
10/24/2003	48	4.1350	0.2722	0.2337
25-Oct	72	4.1513	0.2742	0.2501
10/27/2003	96	4.1956	0.2801	0.2943
10/28/2003	120	4.1862	0.2794	0.2849
10/29/2003	144	4.1909	0.2760	0.2896
11/31/2003	192	4.1987	0.2790	0.2975
11/2/2003	240	4.2188	0.2782	0.3175
11/5/2003	312	4.2149	0.2788	0.3136
11/7/2003	360	4.2108	0.2747	0.3095
11/9/2003	408	4.2133	0.2757	0.3120

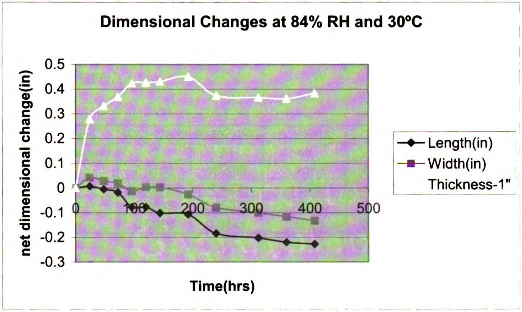

Figure D 8. Dimensional changes at 84% RH and 30°C.

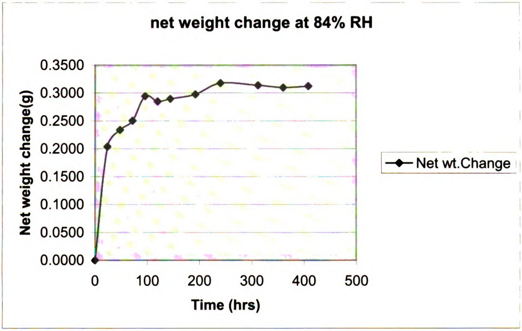

Figure D9. Moisture gain/loss 84% RH and 30°C.

Dimensional Changes and Moisture gain/loss with respect to time at 89% RH and 30°C.

Table D 24. Dimensional Changes data and moisture gain/loss at 89% and 30°C.

Length

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
S.no.	Time(hrs)	0	24	48	72	96	120
89-B		2.0105	1.3595	1.2665	1.2515	1.2483	1.231
89-B-1		2.1025	1.422	1.298	1.2835	1.2785	1.2545
Ave.		2.0565	1.39075	1.28225	1.2675	1.2634	1.24275
	st.dev.	0.0650	0.0441	0.0222	0.0226	0.0213	0.0166

Width

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no	Time(hrs)	0	24	48	72	96	120
89-B		1.9725	1.7795	1.715	1.694	1.685	1.6105
89-B-1		1.9805	1.3075	1.3012	1.2926	1.3875	1.385
Ave.		1.9765	1.5435	1.5081	1.4933	1.53625	1.49775
	st.dev.	0.005	0.33	0.29	0.28	0.210	0.1594

Thickness

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no	Time(hrs)	0	24	48	72	96	120
89-B		1.3195	1.3025	1.2375	1.2815	1.2365	1.2255
89-B-1		1.2896	1.2735	1.263	1.3205	1.316	1.273
Ave.		1.30455	1.288	1.25025	1.301	1.27625	1.24925
	st.dev.	0.02	0.02	0.018	0.027	0.056	0.033

wt. change

	Date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no.	Time(hrs)	0	24	48	72	96	120
89-B		3.9087	4.3288	4.364	4.3813	4.5213	4.518
89-B-1		4.0355	4.4966	4.5325	4.5514	4.6855	4.673
Ave.		3.9721	4.4127	4.44825	4.46635	4.6034	4.5955
	st.dev.	0.09	0.118	0.12	0.12	0.12	0.11

(continued from table D24)

Length

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
S.no.	Time(hrs)	144	192	240	312	360	408
89-B		1.221	1.2295	1.2165	1.211	1.205	1.209
89-B-1		1.222	1.245	1.2295	1.2156	1.2365	1.239
Ave.		1.2215	1.23725	1.223	1.2133	1.22075	1.224
	st.dev.	0.0007	0.0110	0.0092	0.0033	0.0223	0.0212

Width

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	Time(hrs)	144	192	240	312	360	408
89-B		1.5925	1.651	1.6075	1.5885	1.5465	1.5605
89-B-1		1.372	1.379	1.364	1.451	1.399	1.42
Ave.		1.48225	1.515	1.48575	1.51975	1.47275	1.49025
	st.dev.	0.1559	0.1923	0.1722	0.0972	0.1043	0.0993

Thickness

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	Time(hrs)	144	192	240	312	360	408
89-B		1.2315	1.256	1.2385	1.21	1.1654	1.2395
89-B-1		1.236	1.291	1.279	1.2085	1.198	1.2635
Ave.		1.23375	1.2735	1.25875	1.20925	1.1817	1.2515
	st.dev.	0.0032	0.0247	0.0286	0.0011	0.0231	0.0170

wt. change

	Date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no.	Time(hrs)	144	192	240	312	360	408
89-B		4.5572	4.5542	4.6219	4.6083	4.6038	4.613
89-B-1		4.7035	4.732	4.7888	4.7874	4.789	4.785
Ave.		4.63035	4.6431	4.70535	4.69785	4.6964	4.699
	st.dev.	0.1034	0.1257	0.1180	0.1266	0.1310	0.1216

Table D 25. Change in Length with respect to time

				Net change
Date	**Time(hrs)**	**Length**	**st.dev.**	**Length**
10/22/2003	0	2.0565	0.065054	0
10/23/2003	24	1.39075	0.044194	-0.6658
10/24/2003	48	1.28225	0.022274	-0.7743
25-Oct	72	1.2675	0.022627	-0.7890
10/27/2003	96	1.2634	0.021355	-0.7931
10/28/2003	120	1.24275	0.016617	-0.8138
10/29/2003	144	1.2215	0.000707	-0.8350
11/31/2003	192	1.23725	0.01096	-0.8193
11/2/2003	240	1.223	0.009192	-0.8335
11/5/2003	312	1.2133	0.003253	-0.8432
11/7/2003	360	1.22075	0.022274	-0.8358
11/9/2003	408	1.224	0.021213	-0.8325

Table D26. Change in Width with respect to time

				Net change
Date	Time(hrs)	Widt	st.dev.	Width
10/22/2003	0	1.9765	0.0057	0
10/23/2003	24	1.5435	0.3338	-0.433
10/24/2003	48	1.5081	0.2926	-0.4684
25-Oct	72	1.4933	0.2838	-0.4832
10/27/2003	96	1.53625	0.2104	-0.44025
10/28/2003	120	1.49775	0.1595	-0.47875
10/29/2003	144	1.48225	0.1559	-0.49425
11/31/2003	192	1.515	0.1923	-0.4615
11/2/2003	240	1.48575	0.1722	-0.49075
11/5/2003	312	1.51975	0.0972	-0.45675
11/7/2003	360	1.47275	0.1043	-0.50375
11/9/2003	408	1.49025	0.0993	-0.48625

Table D27. Change in Width with respect to time

	Time(hrs)	Width		Net change
Date	(hrs)	(in)	st.dev.	Width(in)
10/22/2003	0	1.9765	0.0057	0
10/23/2003	24	1.5435	0.3338	-0.4330
10/24/2003	48	1.5081	0.2926	-0.4684
25-Oct	72	1.4933	0.2838	-0.4832
10/27/2003	96	1.5363	0.2104	-0.4403
10/28/2003	120	1.4978	0.1595	-0.4788
10/29/2003	144	1.4823	0.1559	-0.4943
11/31/2003	192	1.5150	0.1923	-0.4615
11/2/2003	240	1.4858	0.1722	-0.4908
11/5/2003	312	1.5198	0.0972	-0.4568
11/7/2003	360	1.4728	0.1043	-0.5038
11/9/2003	408	1.4903	0.0993	-0.4863

Table D28. Moisture gain/loss with respect to time

	Time (hrs)	Thickness		Net change
Date	(hrs)	(in)	st.dev.	Thickness (in)
10/22/2003	0	1.3046	0.0211	0
10/23/2003	24	1.2880	0.0205	-0.0166
10/24/2003	48	1.2503	0.0180	-0.0543
25-Oct	72	1.3010	0.0276	-0.0035
10/27/2003	96	1.2763	0.0562	-0.0283
10/28/2003	120	1.2493	0.0336	-0.0553
10/29/2003	144	1.2338	0.0032	-0.0708
11/31/2003	192	1.2735	0.0247	-0.0311
11/2/2003	240	1.2588	0.0286	-0.0458
11/5/2003	312	1.2093	0.0011	-0.0953
11/7/2003	360	1.1817	0.0231	-0.1229
11/9/2003	408	1.2515	0.0170	-0.0531

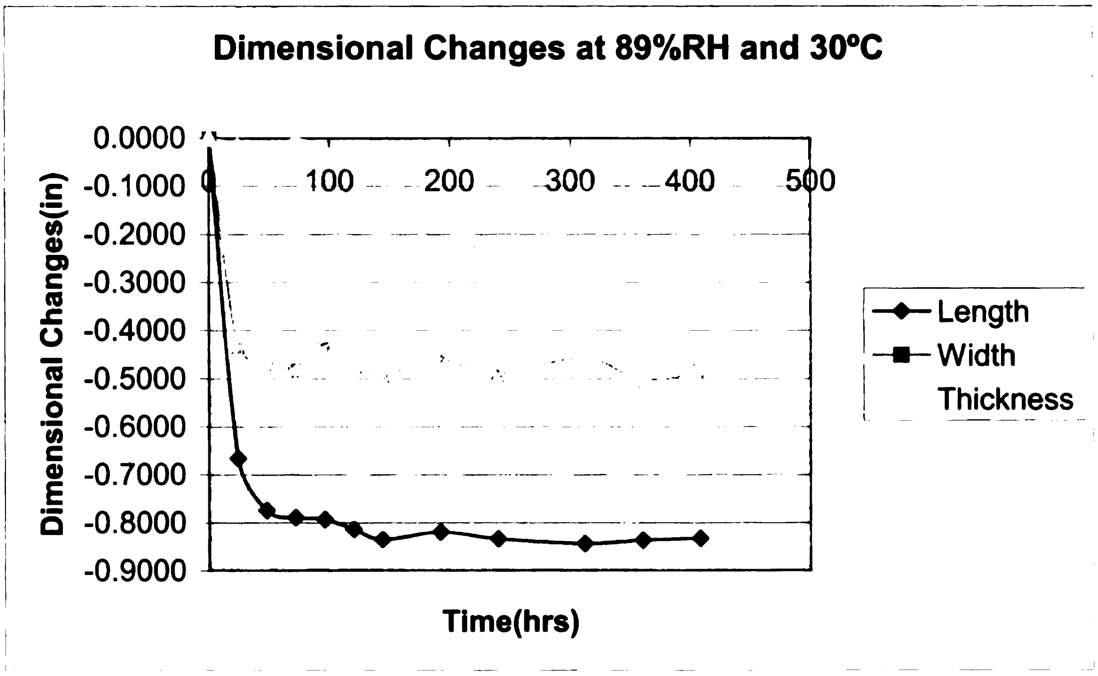

Figure D10. Dimensional changes at 89% RH and 30°C.

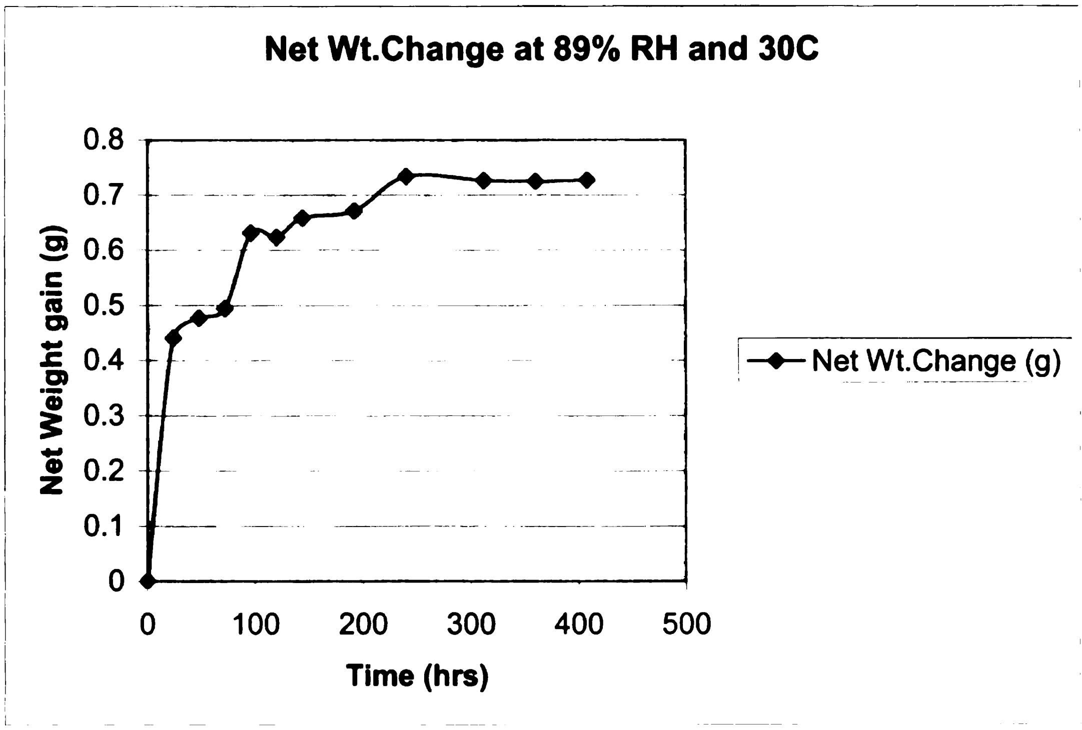

Figure D 11. Moisture gain/loss at 89% RH and 30°C.

Dimensional Changes and Moisture gain/loss with respect to time at 95% RH and 30°C.

Table D29. Dimensional Changes data and moisture gain/loss at 95% and 30°C.

Length

		10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
S.no.	Time(hrs)	0	24	48	72	96	120
95-B		2.017	1.298	1.2525	1.2155	1.1575	1.1495
95-B-1		2.0675	1.244	1.2225	1.189	1.1635	1.1205
Ave.	Length	2.04225	1.271	1.2375	1.20225	1.1605	1.135
	St Dev.	0.0357	0.0382	0.0212	0.0187	0.0042	0.0205

Width

	date	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no	hrs	0	24	48	72	96	120
95-B		2.114	1.521	1.443	1.415	1.393	1.3575
95-B-1		1.965	1.6395	1.6015	1.564	1.5615	1.548
Ave.	Width	2.0395	1.58025	1.52225	1.4895	1.47725	1.45275
	St Dev.	0.1054	0.0838	0.1121	0.1054	0.1191	0.1347

Thickness

	Days	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no							
95-B		1.293	1.3205	1.267	1.2255	1.2005	1.1985
95-B-1		1.2435	1.2995	1.223	1.2185	1.2035	1.2
Ave.	Thickness	1.26825	1.31	1.245	1.222	1.202	1.19925
	St Dev.	0.0350	0.0148	0.0311	0.0049	0.0021	0.0011

wt. change

	Days	10/22/2003	10/23/2003	10/24/2003	25-Oct	10/27/2003	10/28/2003
s.no.							
95-B		3.827	4.2351	4.2606	4.326	4.4378	4.4707
95-B-1		3.8273	4.2501	4.3056	4.345	4.4773	4.469
Ave.	Wt. Change	3.82715	4.2426	4.2831	4.3355	4.45755	4.46985
	St Dev.	0.0002	0.0106	0.0318	0.0134	0.0279	0.0012

(continued from Table D29)

Length

		10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
S.no.	Time(hrs)	144	192	240	312	360	408
95-B		1.146	1.1435	1.176	1.17	1.1685	1.167
95-B-1		1.112	1.1085	1.2445	1.217	1.204	1.1885
Ave.	Length	1.129	1.126	1.21025	1.1935	1.18625	1.17775
	St Dev.	0.0240	0.0247	0.0484	0.0332	0.0251	0.0152

Width

	date	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no	hrs	144	192	240	312	360	408
95-B		1.3555	1.3825	1.453	1.419	1.381	1.3885
95-B-1		1.53	1.537	1.5495	1.5245	1.4965	1.5365
Ave.	Width	1.44275	1.45975	1.50125	1.47175	1.43875	1.4625
	St Dev.	0.1234	0.1092	0.0682	0.0746	0.0817	0.1047

Thickness

	Days	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no		144	192	240	312	360	408
95-B		1.192	1.196	1.216	1.21	1.218	1.2165
95-B-1		1.186	1.178	1.1935	1.19	1.2075	1.209
Ave.	Thickness	1.189	1.187	1.20475	1.2	1.21275	1.21275
	St Dev.	0.0042	0.0127	0.0159	0.0141	0.0074	0.0053

wt. change

	Days	10/29/2003	11/31/2003	11/2/2003	11/5/2003	11/7/2003	11/9/2003
s.no.							
95-B		4.4739	4.4985	4.6515	4.6089	4.668	4.6593
95-B-1		4.4639	4.4721	4.6433	4.592	4.7501	4.6593
Ave.	Wt. Change	4.4689	4.4853	4.6474	4.60045	4.70905	4.6593
	St Dev.	0.0071	0.0187	0.0058	0.0120	0.0581	0.0000

Table D 30. Change in Length with respect to time

				Net change
Date	Time(hrs)	Length	St Dev.	(length)
10/22/2003	0	2.0423	0.0357	0
10/23/2003	24	1.2710	0.0382	-0.7713
10/24/2003	48	1.2375	0.0212	-0.8048
25-Oct	72	1.2023	0.0187	-0.8400
10/27/2003	96	1.1605	0.0042	-0.8818
10/28/2003	120	1.1350	0.0205	-0.9073
10/29/2003	144	1.1290	0.0240	-0.9133
11/31/2003	192	1.1260	0.0247	-0.9163
11/2/2003	240	1.2103	0.0484	-0.8320
11/5/2003	312	1.1935	0.0332	-0.8488
11/7/2003	360	1.1863	0.0251	-0.8560
11/9/2003	408	1.1778	0.0152	-0.8645

Table D 31: Change in Width with respect to time

	Time	Width		Net change
Date	(hrs)	(in)	St Dev.(width)	width (in)
10/22/2003	0	2.0395	0.1054	0
10/23/2003	24	1.5803	0.0838	-0.4593
10/24/2003	48	1.5223	0.1121	-0.5173
25-Oct	72	1.4895	0.1054	-0.5500
10/27/2003	96	1.4773	0.1191	-0.5623
10/28/2003	120	1.4528	0.1347	-0.5868
10/29/2003	144	1.4428	0.1234	-0.5968
11/31/2003	192	1.4598	0.1092	-0.5798
11/2/2003	240	1.5013	0.0682	-0.5383
11/5/2003	312	1.4718	0.0746	-0.5678
11/7/2003	360	1.4388	0.0817	-0.6008
11/9/2003	408	1.4625	0.1047	-0.5770

Table D32. Change in Thickness with respect to time

Date	Time (hrs)	Thickness (in)	St Dev.	Net change thickness(in)
10/22/2003	0	1.2683	0.0350	0
10/23/2003	24	1.3100	0.0148	0.0417
10/24/2003	48	1.2450	0.0311	-0.0233
25-Oct	72	1.2220	0.0049	-0.0463
10/27/2003	96	1.2020	0.0021	-0.0663
10/28/2003	120	1.1993	0.0011	-0.0691
10/29/2003	144	1.1890	0.0042	-0.0793
11/31/2003	192	1.1870	0.0127	-0.0813
11/2/2003	240	1.2048	0.0159	-0.0636
11/5/2003	312	1.2000	0.0141	-0.0683
11/7/2003	360	1.2128	0.0074	-0.0556
11/9/2003	408	1.2128	0.0053	-0.0556

Table 33: Moisture gain/loss with respect to time

Date	Time (hrs)	Wt. Change (g)	St Dev.	Net wt. change (g)
10/22/2003	0	3.8272	0.0002	0
10/23/2003	24	4.2426	0.0106	0.4154
10/24/2003	48	4.2831	0.0318	0.4560
25-Oct	72	4.3355	0.0134	0.5084
10/27/2003	96	4.4576	0.0279	0.6304
10/28/2003	120	4.4699	0.0012	0.6427
10/29/2003	144	4.4689	0.0071	0.6418
11/31/2003	192	4.4853	0.0187	0.6582
11/2/2003	240	4.6474	0.0058	0.8203
11/5/2003	312	4.6005	0.0120	0.7733
11/7/2003	360	4.7091	0.0581	0.8819
11/9/2003	408	4.6593	0.0000	0.8322

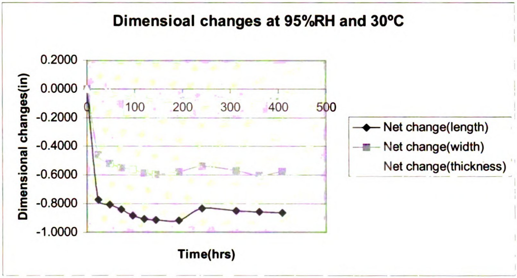

Figure D 12. Dimensional changes at 95% RH and 30°C.

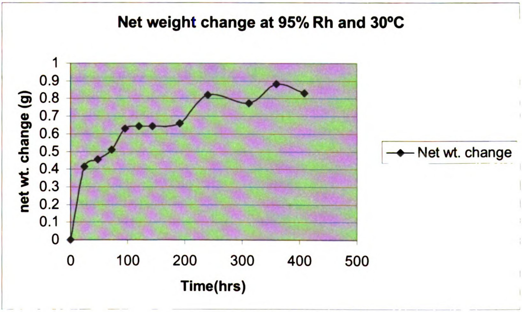

Figure D13. Moisture loss/gain at 95% RH and 30°C.

APPENDIX C

MOISTURE SENSITIVITY OG GREEN CELL® FOAM

Initial Moisture Content "Mi" calculations

Table M . Initial moisture Content Calculations of Green Cell® foam

Sample No.	Dish Wt (g)	Wt.of product+ dish before heating	Wt. of product before heating (g)	after heating	Wt. of product dish after heating (g)	Wt. of product after heating(g)	Mi (g)
ss1	1.2711	2.0412	0.7701	4.6269	1.9274	0.6563	0.1734
ss2	1.2745	2.0023	0.7278	4.8564	1.9028	0.6283	0.1584
ss3	1.2717	2.0148	0.7431		1.9173	0.6456	0.1510
ss4	1.2821	1.9012	0.6191		1.8485	0.5664	0.0930
ss5	1.2755	1.9086	0.6331		1.8556	0.5801	0.0914
ss6	1.2734	1.9092	0.6358	4.7730	1.8563	0.5829	0.0908
	Sum	11.7773	4.1290	14.2563	11.3079	3.6596	0.7579
	Ave.	1.9629	0.6882	Avg	1.8847	0.6099	0.1263
						Ave.	0.1263

Mi	0.1263

Experimental Moisture Content “Me” Calculations at 20°C and different humidity conditions.

Table M 1. Experimental Moisture Content “Me” Calculations at 20°C and different humidity conditions.

Date :					11/12/2003	11/13/2003	11/14/2003
SNO.	%RH	PAN	Salt	PAN Wt	Pan + Prod	Pan+ prod	
		No.	Name	gm	gm (R1)		
1	11	Licl-sa1	Lithium Chloride	1.2788	1.7795	1.7595	1.7602
2		sa2		1.2686	1.7936	1.7687	1.769
3		sa3		1.2782	1.7716	1.7541	1.7563
4	21	KC2H3O2-sa1	Potassium	1.2744	1.7697	1.7582	1.7586
5		sa2	Acetate	1.2656	1.75	1.7395	1.7394
6		sa3		1.2743	1.7855	1.7745	1.7749
7	34	MgCl2-sa1	magnesium	1.2695	1.7348	1.7274	1.727
8		sa2	Chloride	1.2704	1.7497	1.7494	1.7437
9		sa3		1.272	1.7564	1.7434	1.7494
10	55	Mg(NO3)2-sa1	magnesium	1.2698	1.7636	1.7662	1.7661
11		sa2	Nitrate	1.2856	1.7888	1.7914	1.7916
12		sa3		1.2743	1.764	1.7662	1.7663
13	63	NaNO3-sa1	Sodium Nitrate	1.2643	1.7562	1.7634	1.7645
14		sa-2		1.282	1.758	1.765	1.7658
15		sa-3		1.2757	1.7608	1.7673	1.7685
16	7200 %	NaCl-sa1	Sodium	1.2637	1.7507	1.7782	1.7808
17		sa2	Chloride	1.2742	1.7777	1.8062	1.8093
18		sa3		1.2699	1.7807	1.8103	1.8113
19	83	KCl-sa1	Potassium	1.2763	1.7955	1.8431	1.8438
20		sa2	Chloride	1.2764	1.7563	1.7989	1.7992
21		sa3		1.2756	1.7873	1.8328	1.8335
22	96	K2SO4- sa1	Potassium	1.2689	1.772	1.913	1.9074
23		kclsa2	Sulphate	1.268	1.7625	1.9149	1.8944
24		kclsa3		1.2805	1.7752	1.9016	1.9008

(continued from Table M1)

Date :				11/15/2003	11/16/2003
SNO.	%RH	PAN	Salt		
		No.	Name		
1	11	Licl-sa1	Lithium Chloride	1.7618	1.7624
2		sa2		1.7695	1.77
3		sa3		1.7575	1.758
4	21	KC2H3O2-sa1	Potassium		
5		sa2	Acetate		
6		sa3			
7	34	MgCl2-sa1	magnesium		
8		sa2	Chloride		
9		sa3			
10	55	Mg(NO3)2-sa1	magnesium		
11		sa2	Nitrate		
12		sa3			
13	63	NaNO3-sa1	Sodium Nitrate		
14		sa-2			
15		sa-3			
16	7200%	NaCl-sa1	Sodium		
17		sa2	Chloride		
18		sa3			
19	83	KCl-sa1	Potassium		
20		sa2	Chloride		
21		sa3			
22	96	K2SO4- sa1	Potassium		
23		kclsa2	Sulphate		
24		kclsa3			

(continued from table M1)

Date :				11/17/03	11/19/03	11/21/03	11/24/03
SNO.	%RH	PAN	Salt				
		No.	Name				
1	11	Licl-sa1	Lithium Chloride	1.7637	1.7643	1.7627	1.7632
2		sa2		1.7702	1.7712	1.7703	1.7715
3		sa3		1.7583	1.7587	1.758	1.7588
4	21	KC2H3O2-sa1	Potassium	1.7592	1.7592	1.7599	1.758
5		sa2	Acetate	1.7403	1.7405	1.7393	1.7383
6		sa3		1.7764	1.7764	1.7757	1.7743
7	34	MgCl2-sa1	Magnesium	1.7271	1.7278	1.7278	1.727
8		sa2	Chloride	1.7434	1.7435	1.7428	1.7427
9		sa3		1.7492	1.75	1.7492	1.7493
10	55	Mg(NO3)2-sa1	Magnesium	1.7664	1.7664	1.7664	1.7663
11		sa2	Nitrate	1.7917	1.7918	1.792	1.792
12		sa3		1.7666	1.7668	1.7668	1.7667
13	63	NaNO3-sa1	Sodium Nitrate	1.7657	1.7662	1.7659	1.7661
14		sa-2		1.7666	1.7689	1.7675	1.7676
15		sa-3		1.7701	1.7705	1.7703	1.7705
16	7200%	NaCl-sa1	Sodium	1.781	1.7825	1.7815	1.7823
17		sa2	Chloride	1.8094	1.81	1.8098	1.8106
18		sa3		1.8114	1.8116	1.811	1.8127
19	83	KCl-sa1	Potassium	1.842	1.8412	1.8411	1.841
20		sa2	Chloride	1.7985	1.7981	1.7985	1.7986
21		sa3		1.8327	1.8321	1.832	1.8321
22	96	K2SO4- sa1	Potassium	1.9256	1.917	1.9216	1.8805
23		kclsa2	Sulphate	1.9133	1.903	1.9076	1.8681
24		kclsa3		1.9242	1.9142	1.9188	1.8786

(continued from table M1)

Date :				11/27/2003	11/30/2003	12/4/2003
SNO.	%RH	PAN	Salt			
		No.	Name			
1	11	Licl-sa1	Lithium Chloride	1.765	1.7682	1.7677
2		sa2		1.7753	1.7784	1.7759
3		sa3		1.7645	1.7671	1.7639
4	21	KC2H3O2-sa1	Potassium	1.7589	1.7585	1.7576
5		sa2	Acetate	1.7401	1.7396	1.739
6		sa3		1.7784	1.7758	1.7749
7	34	MgCl2-sa1	magnesium	1.7273	1.7288	1.7277
8		sa2	Chloride	1.7434	1.7438	1.7421
9		sa3		1.7499	1.7503	1.7494
10	55	Mg(NO3)2-sa1	magnesium	1.7666	1.7666	1.7665
11		sa2	Nitrate	1.7922	1.7923	1.7916
12		sa3		1.7668	1.7678	1.7666
13	63	NaNO3-sa1	Sodium Nitrate	1.7662	1.7667	1.7671
14		sa-2		1.7677	1.7685	1.7689
15		sa-3		1.7708	1.772	1.7725
16	7200%	NaCl-sa1	Sodium	1.7834	1.7839	1.7828
17		sa2	Chloride	1.8109	1.8115	1.8097
18		sa3		1.8135	1.8151	1.8132
19	83	KCl-sa1	Potassium	1.8431	1.843	1.844
20		sa2	Chloride	1.8007	1.801	1.8022
21		sa3		1.8333	1.8335	1.8377
22	96	K2SO4- sa1	Potassium	1.9028	1.9017	1.8562
23		kclsa2	Sulphate	1.8895	1.8887	1.8876
24		kclsa3		1.9036	1.9025	1.8612

(Continued from table M1)

Date :				12/8/2003	12/15/2003
SNO.	%RH	PAN	Salt		
		No.	Name		
1	11	Licl-sa1	Lithium Chloride	1.736	1.7659
2		sa2		1.7737	1.7794
3		sa3		1.7612	1.7672
4	21	KC2H3O2-sa1	Potassium	1.758	1.7573
5		sa2	Acetate	1.7392	1.738
6		sa3		1.7749	1.7738
7	34	MgCl2-sa1	magnesium	1.7273	1.7276
8		sa2	Chloride	1.7422	1.7425
9		sa3		1.7494	1.749
10	55	Mg(NO3)2-sa1	magnesium	1.7669	1.7673
11		sa2	Nitrate	1.7916	1.7922
12		sa3		1.7665	1.7671
13	63	NaNO3-sa1	Sodium Nitrate	1.7665	1.7663
14		sa-2		1.768	1.7682
15		sa-3		1.7715	1.7713
16	7200%	NaCl-sa1	Sodium	1.7819	1.7821
17		sa2	Chloride	1.809	1.811
18		sa3		1.8126	1.8124
19	83	KCl-sa1	Potassium	1.8421	1.8464
20		sa2	Chloride	1.8009	1.8054
21		sa3		1.835	1.8403
22	96	K2SO4- sa1	Potassium	1.9643	2.0065
23		kclsa2	Sulphate	1.9597	1.9954
24		kclsa3		1.9075	1.989
				Fungus	Fungus

(continued from Table M1)

%RH	PAN	Salt							
	No.	Name	Avg We	Wi	Avg Wi	%RH	Me	Aw	Aw/Me
11	Licl-sa1	Lithium Chloride		0.5007		0	0	0	0
	sa2			0.525					
	sa3		0.4943	0.4934	0.5064	11	0.0995	0.1100	1.1051
21	KC2H3O2-sa1	Potassium		0.4953					
	sa2	Acetate		0.4844					
	sa3		0.4849	0.5112	0.4970	21	0.0990	0.2100	2.1206
34	MgCl2-sa1	magnesium		0.4653					
	sa2	Chloride		0.4793					
	sa3		0.4691	0.4844	0.4763	34	0.1091	0.3400	3.1159
55	Mg(NO3)2-sa1	magnesium		0.4938					
	sa2	Nitrate		0.5032					
	sa3		0.4990	0.4897	0.4956	55	0.1340	0.5500	4.1036
63	NaNO3-sa1	Sodium Nitrate		0.4919					
	sa-2			0.476					
	sa-3		0.4946	0.4851	0.4843	63	0.1502	0.6300	4.1951
7200 %	NaCl-sa1	Sodium		0.487					
	sa2	Chloride		0.5035					
	sa3		0.5326	0.5108	0.5004	0.72	0.1986	0.7200	3.6250
83	KCl-sa1	Potassium		0.5192					
	sa2	Chloride		0.4799					
	sa3		0.5546	0.5117	0.5036	83	0.2404	0.8300	3.4531
96	K2SO4- sa1	Potassium		0.5031					
	kcl-sa2	Sulphate		0.4945					
	kcl-sa3		0.5959	0.4947	0.4974	96	0.3492	0.9600	2.7493

GAB model constants and T ,C Wm and K Values:

α = -11.089

β = 13.525

γ = -0.1353

T = -117.92
C = 0.9917,-118.9143
W_m = -0.0752, 0.0752
K = 99.1363

RMS calculations.

Table M 2. RMS calculation for GAB model at 20°C and different %RH conditions

Aw	CkAw	(1-kAw)..	M (Gab)	M (Exp)		
0	0		0	0		
0.11	10.8141	-9.0042	0.0903	0.0995	0.0925	0.0086
0.21	20.6450	-16.3779	0.0948	0.0990	0.0427	0.0018
0.34	33.4253	-23.5130	0.1069	0.1091	0.0206	0.0004
0.55	54.0703	-29.1872	0.1393	0.1340	-0.0392	0.0015
0.63	61.9350	-29.4473	0.1581	0.1502	-0.0530	0.0028
0.72	70.7829	-28.4860	0.1868	0.1986	0.0595	0.0035
0.83	81.5970	-25.5080	0.2405	0.2404	-0.0006	0.0000
0.96	94.3772	-19.4315	0.3651	0.3490	-0.0463	0.0021
						0.0026
					RMS	5.1025

Experimental Moisture Content "Me" Calculations at 25°C and different humidity conditions.

Table M 3. Experimental Moisture Content "Me" Calculations at 25°C and different humidity conditions.

Date :					7/7/2003	7/7/2003	7/8/2003
SNO.	%RH	PAN	Salt	PAN Wt	Pan + Prod	Pan+ prod	
		No.	Name	gm	gm (R1)		
1	15	Licl-sa1	Lithium	1.2748	2.0449	1.9968	1.995
2		sa2	Chloride	1.2737	2.0261	1.9825	1.9786
3		sa3		1.2726	2.0386	1.9906	1.9883
4	23	K(C2H3O2)-sa1	Potassium	1.2708	2.0291	1.9971	1.9966
5		sa2	Accetate	1.2684	2.0295	1.993	1.991
6		sa3		1.2748	2.1493	2.1104	2.1076
7	35	MgCl-sa1	Magnesium	1.2732	2.02	1.9889	1.9885
8		sa2	Chroride	1.2739	2.026	1.9931	1.9922
9		sa3		1.275	2.0126	1.9829	1.982
10	51	Mg(NO3)2-sa1	Magnesium	1.2666	2.0123	2.0069	2.0057
11		sa2	Chloride	1.2785	2.004	1.9979	1.9968
12		sa3		1.2834	2.0199	2.0124	2.0115
13	63	NaNo2-sa1	Sodium	1.2719	2.0168	2.0166	2.0161
14		sa2	Nitride	1.2753	2.0207	2.02	2.0193
15		sa3		1.2725	2.0313	2.0308	2.0305
16	73	Naclsa1	Sodium	1.2732	2.0371	2.0728	2.0744
17		Naclsa2	Chroride	1.2746	2.0016	2.0295	2.0309
18		NaClsa3		1.2737	2.016	2.0455	2.0469
19	84	kcl -sa1	Potassium	1.2755	2.0182	2.0928	2.0912
20		kcl-sa2	Chloride	1.2717	2.0024	2.0769	2.081
21		kcl-sa3		1.2797	2.0114	2.0886	2.0902

(continued from table M3)

Date :				7/9/2003	7/10/2003	7/11/2003
SNO.	%RH	PAN	Salt			
		No.	Name			
1	15	Licl-sa1	Lithium	1.9944	1.9946	1.9946
2		sa2	Chloride	1.9782	1.9784	1.9773
3		sa3		1.9888	1.9891	1.9873
4	23	K(C2H3O2)-sa1	Potassium	1.9949	1.9975	1.9931
5		sa2	Accetate	1.9906	1.992	1.9896
6		sa3		2.1073	2.1114	2.1057
7	35	MgCl-sa1	Magnesium	1.9875	1.9877	1.9863
8		sa2	Chroride	1.9904	1.9907	1.9802
9		sa3		1.9812	1.9816	1.9801
10	51	Mg(NO3)2-sa1	Magnesium	2.0047	2.0049	2.0032
11		sa2	Chloride	1.9966	1.9966	1.9949
12		sa3		2.011	2.011	2.0094
13	63	NaNo2-sa1	Sodium	2.015	2.0152	2.0146
14		sa2	Nitride	2.0186	2.0184	2.0178
15		sa3		2.0297	2.0073	2.007
16	73	Naclsa1	Sodium	2.073	2.0733	2.0705
17		Naclsa2	Chroride	2.0306	2.0297	2.0282
18		NaClsa3		2.0462	2.047	2.0453
19	84	kcl -sa1	Potassium	2.088	2.0802	2.0802
20		kcl-sa2	Chloride	2.0762	2.0656	2.066
21		kcl-sa3		2.0822	2.0754	2.0721

(continued from Table M3)

				7/12/03/	7/13/03/	7/12/03/	7/14/03/
SNO.	%RH	PAN	Salt	Pan + Prod	Pan + Prod	Pan + Prod	Pan + Prod
		No.	Name	gm (R2)	gm (R2)	gm (R2)	gm (R2)
1	15	Licl-sa1	Lithium	1.9929	0.7181	1.993	0.7182
2		sa2	Chloride	1.9761	0.7024	1.9765	0.7028
3		sa3		1.9863	0.7137	1.9871	0.7145
4	23	K(C2H3O2)-sa1	Potassium	1.9927	0.7219	1.9929	0.7221
5		sa2	Accetate	1.9887	0.7203	1.9898	0.7214
6		sa3		2.1047	0.8299	2.105	0.8302
7	35	MgCl-sa1	Magnesium	1.9869	0.7137	1.9886	0.7154
8		sa2	Chroride	1.9898	0.7159	1.9906	0.7167
9		sa3		1.9805	0.7055	1.9819	0.7069
10	51	Mg(NO3)2-sa1	Magnesium	2.004	0.7372	2.0038	2.0038
11		sa2	Chloride	1.9959	0.717	1.9955	1.9956
12		sa3		2.0105	0.7266	2.01	2.0101
13	63%	NaNo2-sa1	Sodium	2.0156	0.7437	2.0161	0.7442
14		sa2	Nitride	2.0189	0.7436	2.0185	0.7432
15		sa3		2.0079	0.7354	2.0083	0.7358
16	73	Naclsa1	Sodium	2.0725	0.7993	2.0726	0.7994
17		Naclsa2	Chroride	2.0298	0.7552	2.0298	0.7552
18		NaClsa3		2.0726	0.7989	2.0472	0.7735
19	84	kcl -sa1	Potassium	2.0882	0.8127	2.0854	2.0902
20		kcl-sa2	Chloride	2.0694	0.7977	2.075	2.0759
21		kcl-sa3		2.078	0.7983	2.0792	2.0804

(continued from table M3)

				7/15/2003	7/17/2003
SNO.	%RH	PAN	Salt	Pan + Prod	
		No.	Name		
1	15	Licl-sa1	Lithium	1.9923	1.9929
2		sa2	Chloride	1.766	1.9756
3		sa3		1.986	1.986
4	23	K(C2H3O2)-sa1	Potassium	1.9932	1.9932
5		sa2	Accetate	1.9892	1.9892
6		sa3		2.105	2.1047
7	35	MgCl-sa1	Magnesium	1.967	1.9866
8		sa2	Chroride	1.991	1.9898
9		sa3		1.9811	1.9806
10	51	Mg(NO3)2-sa1	Magnesium	2.004	2.004
11		sa2	Chloride	1.9957	1.9956
12		sa3		2.01	2.0104
13	63%	NaNo2-sa1	Sodium	2.0153	2.0152
14		sa2	Nitride	2.0184	2.0182
15		sa3		2.0081	2.0079
16	73	Naclsa1	Sodium	2.0723	2.0722
17		Naclsa2	Chroride	2.0292	2.029
18		NaClsa3		2.046	2.0461
19	84	kcl -sa1	Potassium	2.0876	2.1044
20		kcl-sa2	Chloride	2.0771	2.077
21		kcl-sa3		2.0826	2.0825

(continued from M3)

%										
RH	PAN	Salt			S.D	S.D	Ave.		Ave.	S.D
	No.	Name	We	We	(We)	(We)	Wi	Wi	Wi	(wi)
15	Licl-sa1	Lithium	0.718					0.770		
	sa2	Chloride	0.701					0.752		
	sa3		0.713	0.711	0.0083	0.0083	0.762	0.766	0.7628	0.0093
23	K(C2H3O2)-sa1	Potassium	0.722					0.758		
	sa2	Accetate	0.720					0.761		
	sa3		0.829	0.757	0.0625	0.0625	0.797	0.874	0.7980	0.0663
35	MgCl-sa1	Magnesium	0.713					0.746		
	sa2	Chroride	0.715					0.752		
	sa3		0.705	0.711	0.005	0.0054	0.745	0.737	0.7455	0.0073
51	Mg(NO3)2	Magnesium	0.737					0.746		
	sa2	Chloride	0.717					0.725		
	sa3		0.727	0.727	0.010	0.0102	0.745	0.736	0.7450	0.0103
63	NaNo2-sa1	Sodium	0.743					0.744		
	sa2	Nitride	0.742					0.745		
	sa3		0.735	0.740	0.004	0.0045	0.749	0.758	0.7497	0.0079
73	Naclsa1	Sodium	0.79					0.763		
	Naclsa2	Chroride	0.754					0.727		
	NaClsa3		0.772	0.775	0.022	0.0224	0.744	0.742	0.7444	0.0185
84	kcl -sa1	Potassium	0.828					0.742		
	kcl-sa2	Chloride	0.805					0.730		
	kcl-sa3		0.802	0.812	0.014	0.0144	0.735	0.731	0.7350	0.0067

(continued from M3)

%RH	Me (separate)	Me	Aw	Aw/Me
0	0.0502	0	0	0
	0.0507			
15	0.0490	0.0499665	0.15	3.00200912
	0.0730			
	0.0667			
23	0.0689	0.0694651	0.23	3.31101463
	0.0759			
	0.0721			
35	0.0774	0.0751343	0.35	4.65832494
	0.1129			
	0.1128			
51	0.1115	0.0993394	0.51	5.13391716
	0.1239			
	0.1225			
63	0.0916	0.1125286	0.63	5.59857659
	0.1781			
	0.1687			
73	0.1720	0.1730022	0.73	4.21959923
	0.2570			
	0.2413			
84	0.2357	0.2447477	0.84	3.43210614

GAB model constants and T ,C Wm and K Values:

α = -18.971
β = 19.935
γ = 0.0619

T = 342.417
C = 341.4136 , 1.0029
$\mathbf{W_m}$ = 0.0499, -0.0499
K = 0.9488

RMS Calculations

Table M 4. RMS calculation for GAB model at 25°C and different %RH conditions

Aw	CkAw	(1-kAw)..	M (Gab)	M (Exp)		
0	0		0			
0.15	48.5924	42.4120	0.0571	0.0501	-0.1401	0.0196
0.23	74.5084	58.8592	0.0631	0.0695	0.0917	0.0084
0.35	113.3823	76.1745	0.0742	0.0760	0.0233	0.0005
0.51	165.2142	85.5314	0.0963	0.0993	0.0299	0.0009
0.63	204.0881	82.2514	0.1237	0.1125	-0.0999	0.0100
0.73	236.4831	72.7755	0.1620	0.1730	0.0633	0.0040
0.84	272.1175	55.2724	0.2455	0.2447	-0.0033	0.0000
						0.0062
					RMS	7.8810

Experimental Moisture Content "Me" Calculations at 30°C and different humidity conditions.

Table M 5. Experimental Moisture Content "Me" Calculations at 30°C and different humidity conditions.

Date :					10/22/2003	10/23/2003	10/24/2003
SNO.	%RH	PAN	Chemical	PAN Wt	Pan + Prod	Pan+ prod	Pan+ prod
		No.	Name	g	g	(g)	(g)
1	11	Licl-sa1	Lithium	1.2742	1.7724	1.7587	1.7576
2		sa2	Chloride	1.2823	1.7839	1.7696	1.769
3		sa3		1.2746	1.8024	1.7882	1.7865
4	45	K2co3-sa1	Potassium	1.271	1.7585	1.7559	1.7552
5		sa2	Carbonate	1.2761	1.7894	1.7863	1.786
6		sa3		1.2691	1.7469	1.7441	1.7443
7	56	Mg2No3-sa1	Magnesium	1.2743	1.7207	1.7231	1.7238
8		sa2	Nitrate	1.2813	1.7587	1.761	1.7621
9		sa3		1.2633	1.7577	1.7608	1.7619
10	77	Nacl-sa1	Sodium	1.2639	1.7227	1.7395	1.74
11		sa2	Chloride	1.2664	1.7683	1.7882	1.7897
12		sa3		1.2756	1.7563	1.7746	1.7763
13	8400%	Kcl-sa1	Potassium	1.2692	1.7522	1.7822	1.7856
14		sa2	Chroride	1.273	1.7482	1.7773	1.7833
15		sa3		1.2827	1.7695	1.798	1.8024
16	90	K2No3-sa1	Potassium	1.2799	1.7678	1.8237	1.8279
17		sa2	Nitrate	1.2754	1.7563	1.8109	1.8147
18		sa3		1.2728	1.777	1.8321	1.8382
19	96	K2so4- sa1	Potassium	1.277	1.7766	1.8346	1.853
		kclsa2	Sulphate	1.2755	1.7724	1.8273	1.8516
		kclsa3		1.2809	1.7942	1.8546	1.8744

(continued from table M5)

Date :				10/25/2003	10/27/2003	10/28/2003	10/29/2003
SNO.	%RH	PAN	Chemical				
		No.	Name				
1	11	Licl-sa1	Lithium	1.7577	mfd		
2		sa2	Chloride	1.7678	1.7595	1.7558	1.7564
3		sa3		1.7864	1.7857	1.7809	1.7823
4	45	K2CO3-sa1	Potassium	1.755	1.7551	1.7539	1.7547
5		sa2	Carbonate	1.785	1.7853	1.7849	1.7852
6		sa3		1.7437	1.7438	1.7433	1.7432
7	56	Mg2NO3-sa1	Magnesium	1.723	1.7225	1.724	1.723
8		sa2	Nitrate	1.7613	1.7628	1.7613	1.7608
9		sa3		1.7605	1.7625	1.7619	1.7606
10	77	NaCl-sa1	Sodium	1.7404	1.742	1.7423	1.7419
11		sa2	Chloride	1.7892	1.791	1.7909	1.7906
12		sa3		1.7772	1.7778	1.7773	1.7769
13	8400	KCl-sa1	Potassium	1.7864	1.7902	1.7904	1.7924
14		sa2	Chroride	1.7845	1.7875	1.785	1.788
15		sa3		1.8037	1.8056	1.806	1.808
16	90	K2No3-sa1	Potassium	1.8314	1.852	1.844	1.8494
17		sa2	Nitrate	1.8189	1.8393	1.8306	1.8361
18		sa3		1.8416	1.8573	1.8535	1.8561
19	96	K2SO4- sa1	Potassium	1.8564	1.8643	1.8576	1.8623
		KClsa2	Sulphate	1.855	1.8624	1.8597	1.8593
		KClsa3		1.8812	1.8832	1.8806	1.8839

(continued from table M5)

Date :				10/30/2003	11/2/2003	11/3/2003	11/5/2003
SNO.	%RH	PAN	Chemical				
		No.	Name				
1	11	Licl-sa1	Lithium				
2		sa2	Chloride	1.7604	1.7915	1.7627	1.7532
3		sa3		1.787	1.7972	1.788	1.788
4	45	K2co3-sa1	Potassium	1.7554	1.7547	1.7538	1.7536
5		sa2	Carbonate	1.7858	1.7854	1.7852	1.7845
6		sa3		1.7439	1.7438	1.7436	1.7436
7	56	Mg2No3-sa1	Magnesium	1.7233	1.7224	1.728	1.726
8		sa2	Nitrate	1.7623	1.7609	1.7613	1.761
9		sa3		1.7614	1.7605	1.7598	1.7603
10	77	Nacl-sa1	Sodium	1.7438	1.743	1.7428	1.7424
11		sa2	Chloride	1.7918	1.7921	1.7921	1.7923
12		sa3		1.7798	1.7784	1.7782	1.7782
13	8400%	Kcl-sa1	Potassium	1.7915	1.7932	1.7958	1.7972
14		sa2	Chroride	1.788	1.7888	1.7891	1.7978
15		sa3		1.808	1.81	1.811	1.8099
16	90	K2No3-sa1	Potassium	1.8506	1.8615	1.8661	1.86
17		sa2	Nitrate	1.8391	1.8473	1.8535	1.8474
18		sa3		1.8607	1.8669	1.8754	1.8669
19	96	K2so4- sa1	Potassium	1.864	1.8869	1.8848	1.8836
		kclsa2	Sulphate	1.8629	1.8776	1.8772	1.8764
		kclsa3		1.8853	1.9043	1.9035	1.9014

(continued from table M5)

Date :				11/7/2003	11/9/2003	11/17/2003
SNO.	%RH	PAN	Chemical			
		No.	Name			
1	11	Licl-sa1	Lithium			
2		sa2	Chloride	1.753	1.75	1.75
3		sa3		1.7874	1.7871	1.7871
4	45	K2co3-sa1	Potassium	1.7536	1.736	1.735
5		sa2	Carbonate	1.785	1.7851	1.7851
6		sa3		1.7442	1.7441	1.744
7	56	Mg2No3-sa1	Magnesium	1.7221	1.722	1.7222
8		sa2	Nitrate	1.7602	1.7602	1.7603
9		sa3		1.7602	1.7602	1.7604
10	77	Nacl-sa1	Sodium	1.7426	1.7425	1.743
11		sa2	Chloride	1.792	1.7922	1.7923
12		sa3		1.7782	1.7782	1.7792
13	8400%	Kcl-sa1	Potassium	1.7935	1.7936	1.794
14		sa2	Chroride	md		
15		sa3		1.8088	1.8091	1.81
16	90	K2No3-sa1	Potassium	1.8606	1.8595	1.8661
17		sa2	Nitrate	1.8472	1.8465	1.8535
18		sa3		1.8683	1.8683	1.8754
19	96	K2so4- sa1	Potassium	1.8816	1.8837	1.9094
		kclsa2	Sulphate	1.8774	1.8809	1.9039
		kclsa3		1.903	1.9075	1.9333

(continued from table M5)

SNO.	%RH	PAN	Chemical				
		No.	Name	We	Avg We	Wi	Avg Wi
1	11	Licl-sa1	Lithium			0.4982	
2		sa2	Chloride	0.4677		0.5016	
3		sa3		0.5125	0.4901	0.5278	0.5092
4	45	K2co3-sa1	Potassium	0.4640		0.4875	
5		sa2	Carbonate	0.5090		0.5133	
6		sa3		0.4749	0.4826	0.4778	0.4929
7	56	Mg2No3-sa1	Magnesium	0.4479		0.4464	
8		sa2	Nitrate	0.4790		0.4774	
9		sa3		0.4971	0.4747	0.4944	0.4727
10	77	Nacl-sa1	Sodium	0.4791		0.4588	
11		sa2	Chloride	0.5259		0.5019	
12		sa3		0.5036	0.5029	0.4807	0.4805
13	8400%	Kcl-sa1	Potassium	0.5248		0.483	
14		sa2	Chroride			0.4752	
15		sa3		0.5273	0.5261	0.4868	0.4817
16	90	K2No3-sa1	Potassium	0.5862		0.4879	
17		sa2	Nitrate	0.5781		0.4809	
18		sa3		0.6026	0.5890	0.5042	0.4910
19	96	K2so4- sa1	Potassium	0.6324		0.4996	
		kclsa2	Sulphate	0.6284		0.4969	
		kclsa3		0.6524	0.6377	0.5133	0.5033

(continued from table M5)

SNO.	%RH	PAN	Chemical				
		No.	Name	%RH	Me	Aw	Aw/Me
1	11	Licl-sa1	Lithium	0	0	0	0
2		sa2	Chloride				
3		sa3		11.0000	0.0841	0.11	1.3087
4	45	K2co3-sa1	Potassium				
5		sa2	Carbonate				
6		sa3		43.0000	0.1029	0.43	4.1782
7	56	Mg2No3-sa1	Magnesium				
8		sa2	Nitrate				
9		sa3		53.0000	0.1309	0.53	4.0487
10	77	Nacl-sa1	Sodium				
11		sa2	Chloride				
12		sa3		75.0000	0.1788	0.75	4.1944
13	8400%	Kcl-sa1	Potassium				
14		sa2	Chroride				
15		sa3		83.0000	0.2301	0.83	3.6074
16	90	K2No3-sa1	Potassium				
17		sa2	Nitrate				
18		sa3		90.0000	0.3510	0.9	2.5639
19	96	K2so4- sa1	Potassium				
		kclsa2	Sulphate				
		kclsa3		96.0000	0.4272	0.96	2.2470

GAB model constants and T ,C Wm and K Values for GAB model at 30C:

α = -13.726

β = 15.643

γ = -0.1123

T = -154.7509
C = 0.9936
W_m = -0.0647
K = 138.4135

RMS Calculations:

Table M 6. RMS calucaltions at 30°C and different %RH conditions

Aw	CkAw	(1-kAw)..	M (Gab)	M (Exp)		
0	0		0			
0.11	15.1283	-12.8437	0.0763	0.0841	0.0932	0.0087
0.45	61.8887	-36.9326	0.1085	0.1029	-0.0544	0.0030
0.56	77.0170	-38.6759	0.1289	0.1309	0.0151	0.0002
0.77	105.8984	-33.7904	0.2029	0.1765	-0.1499	0.0225
0.84	115.5256	-29.7663	0.2513	0.2301	-0.0922	0.0085
0.9	123.7774	-25.3637	0.3160	0.3510	0.0999	0.0100
0.96	132.0292	-20.0810	0.4257	0.4272	0.0036	0.0000
						0.0075
					RMS	8.6861

APPENDIX D

THERMAL INSULATION PROPERTIES CALCULATIONS OF GREEN CELL® FOAM.

Table T 1. (R-Value) calculation of GCF and EPS coolers at 50%RH and 25°C

Condition = 50%RH and 25°C

Preconditioning time = 145 minutes=2.416 hrs

Inside temperature=T1=32°F
Outside temperature=T2=77°F
Temperature difference= 45° F

Latent heat of ice= 1lb of ice at 32F absorb 144btu(36.3Kcal)

Area of cooler EPS=2(LD+WD=LW)=4.421ft2

Length	Width	Height					
L	W	D	2LD	2WD	2LW	Area	Area
in	in	in				in^2	ft^2
11.875	10	9.125	216.71875	182.5	237.5	636.719	4.4217

Area of cooler Green Cell cooler=2(LD+WD=LW)=4.37ft^2

Length	Width	Height					
L	W	D	2LD	2WD	2LW	Area	Area
in	in	in				in^2	ft^2
11.687	10	9.125	213.28775	182.5	233.74	629.528	4.3717

EPS Coolers

Trial	wt of bucket	wt. Of water	wt. Of water	wt. Of water	Time	Melt Rate	R- value
No.	and ice	collected					
	lbs	ml	kg	lbs	hr	lbs/hr	hr.ft2.F/Btu
1	7	2350	2.35	5.17	48	0.1077	12.8250
2	7	1061	1.061	2.3342	24	0.0973	14.2019

Green Cell cooler

trial no.	wt of bucket	wt. Of water	wt. Of water	wt. Of water	Time	Melt Rate	R- value
	and ice	collected					
	lbs	ml	kg	lbs	hr	lbs/hr	hr.ft2.F/Btu
1	7	2500	2.5	5.5	48	0.1146	11.9182
2	7	1125	1.125	2.475	24	0.1031	13.2424

Table T 2. (R-Value) calculation of GCF and EPS coolers at 80%RH and 30°C

Condition = 80%RH and 30°C(86F)

Preconditioning time = 145 minutes=2.416 hrs

Inside temperature=T1=32°F

Outside temperature=T2=86°F

Temperature difference= 54 °F

Latent heat of ice= 1lb of ice at 32°F absorb 144btu(36.3Kcal)

Area of cooler EPS=2(LD+WD=LW)=4.421ft2

Length	Width	Height					
L	W	D	2LD	2WD	2LW	Area	Area
in	in	in				in^2	ft^2
11.875	10	9.125	216.71875	182.5	237.5	636.719	4.4217

Area of cooler Green Cell cooler=2(LD+WD=LW)=4.37ft2

Length	Width	Height					
L	W	D	2LD	2WD	2LW	Area	Area
in	in	in				in^2	ft^2
11.687	10	9.125	213.2878	182.5	233.74	629.528	4.3717

EPS Coolers

trial no.	wt of bucket	wt. Of water	wt. Of water	wt. Of water	Time	Melt Rate	R value
	and ice	collected					
	lbs	ml	kg	lbs	hr	lbs/hr	hr.ft2.F/Btu
1	7	1950	1.95	4.29	26	0.165	10.0455

Green Cell cooler

Trial no.	wt of bucket	wt. Of water	wt. Of water	wt. Of water	Time	Melt Rate	R value
	and ice	collected					
	lbs	ml	kg	lbs	hr	lbs/hr	hr.ft2.F/Btu
1	7	2400	2.4	5.28	26	0.2031	7.8036

Density Calculations:

Table T 3. Density calculation of 1-inchand 2-inch Green Cell® foam

1 " thickness Green Cell Foam

s.no	Weight	Weight	Volume	Density
	(g)	(lb)	W* L * D	(lb/ft^3)
			(in^3)	
1	20.78	0.04577	25.2123	3.1368
2	30.98	0.06823	37.6068	3.1349
3	15.39	0.03389	19.9149	2.9405
			Ave.	3.07073

2 " thickness Green Cell Foam

	Weight	Weight	Volume	Density
	(g)	(lb)	W* L * D	(lb/ft^3)
			in3	
1	123.78	0.2726	141.504	3.3288
2	135.15	0.2976	149.216	3.4463
3	135.32	0.298	156.224	3.2961
			Ave.	3.3571

Average value of 2-inch thick foam = 3.35lb/ft^3

Average value of 1-inch thick foam = 3.07lb/ft^3

Average value of 1-inch thick and 2- inch thick foam = 3.21lb/ft^3

APPENDIX E

PREPARATION OF SALT SOLUTION ASTM STD. E 104

Salt Solutions.

Materials

- Biodegradable Starch based foam (Green Cell®)
- 80 Aluminum dishes
- 3 sets of HDPE buckets, every set contains 8 HDPE buckets, maintained at different relative humidity (%RH) conditions and three different temperatures (20°C, 25°Cand 30°C).
- 8 aqueous salt solutions to create different (% RH) condition in HDPE buckets.
- **Reagents**

Total ten chemicals were used to create different relative humidity conditions like Lithium Chloride, Potassium Acetate, Magnesium Chloride, Potassium Carbonate, Magnesium Nitrate, Sodium Nitrite, Sodium Chloride, Potassium Chloride, Barium Chloride, Potassium Sulfate.

Reagents grade chemicals were used to prepare all standard salt solutions according to ASTM standard E104 [2].

Saturated salt solutions were prepared by using hydrated reagents. Hydrated reagents are often preferred to amorphous forms for their solvating characteristics. Equilibrium Relative humidity values (standards and actual) for selected saturated

Additional reagents and Equipments

- Demilitarized water:
- Analytical Balance (sensitivity is ±0.0001 grams)

- Vacuum Oven (80-75°C and 22-25 inches Hg)
- Hygrometer
- 24 Pyrex container
- Hot Plate
- Magnetic stirrer.

Preparation Method

2.1.3-a Preparation of salt solution:

A quantity of the selected salt was weighed into the Pyrex container and water was added in about 2-ml increments. Each container was heated on the hot plate to maintain a constant temperature; one magnetic stirrer was inserted into the container to provide mixing, until equilibrium was reached. [2]

A saturated salt solution occurs when any excess quantity of undisclosed solute is present. After preparing the salt solution, the containers were placed inside the HDPE buckets and tightly closed with a lid .One hour was given to maintain the temperature stabilization before checking the first reading of humidity by Hygrometer.

The stability of the humidity conditions was checked periodically over a three weeks period.

Table S-1 shows the Equilibrium Relative humidity values (standards and actual) for selected saturated solutions.

The stability of the humidity conditions was checked periodically over a three weeks period.

Table S-1 represents the equilibrium Relative humidity values (standards and actual) for selected saturated solutions.

Salt Name	Formula	Temperature (°C)					
		20°C		25°C		30°C	
		E 104	Actual	E 104	Actual	E 104	Actual
Lithium Chloride	LiCl	11.3	11	11.3	15	11.3	11
Potassium Acetate	$KC_2H_3O_2$	23.1	21	22.5	23	21.6	
Magnesium Chloride	$MgCl_2$	33.1	34	32.8	35	32.4	
Potassium Carbonate	K_2CO_3	43.2		43.2		43.2	45
Magnesium Nitrate	$Mg(No_3)_2$	54.4	55	52.9	51	51.4	56
Sodium Nitrite			63		63		
Sodium Chloride	NaCl	75.5	72	75.3	73	75.1	77
Potassium Chloride	KCl	85.1	83	84.3	84	84.3	84
Barium Chloride	$BaCl_2$	91		90		89	90
Potassium Sulphate	K_2SO_4	97.3	96	97.3		97.0	96

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