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Moisture gain of biscuits in hermetically-sealed packages versus non-hermetically-sealed packages

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MOISTURE GAIN OF BISCUITS IN HERMETICALLY-SEALED PACKAGES VERSUS NON-HERMETICALLY-SEALED PACKAGES

By

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ABSTRACT

The objective of this study was to examine the affect of hermetic sealing on extending the shelf life of a biscuit product. Hermetically sealed packages were compared with non-hermetically-sealed packages received from the biscuit manufacturer. The package materials were the same so the only variable was the hermetic integrity of the package. A pressure test was conducted to determine the hermetic integrity of the package samples. The maximum moisture content that the biscuits gained before they were considered spoiled was then determined. Moisture gain of biscuit products kept in a 100% RH environment was monitored by recording the changes in biscuit weight over time. Data collected was analyzed in order to show a distinct and comparable trend of the hermetic samples and non-hermetic samples. A analysis of variance test was conducted to determine whether or not the means of the moisture gain of both samples was significantly different at a 0.05 significance level. Hermetically sealed packages for biscuits provide for longer shelf life of product than packages which are not hermetically sealed.

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INTRODUCTION

This study is based on a problem that a specialized biscuit company in Saudi Arabia is facing. The company is experiencing a considerable loss on a particular biscuit product that is marketed in the South Eastern Asian countries ; however this product shows no problem when marketed locally in Saudi Arabia in Ryadh City. Since markets in South Eastern Asian countries are more humid than its dry-desert counterparts like Ryadh, it is speculated that one of the major problems causing the reduction in shelf life of this biscuit product is the high humid environment. Packaging materials, sealing method, and formulation (recipe) of biscuits play an important role in moisture uptake of biscuits and so are certainly involved in this problem.

The methodology and experimental procedures were designed to help investigate the behavior of the biscuits currently packaged by the Company. It was found early in the investigation that the current package is not hermetically sealed. This piece of information drove the test to compare the moisture barrier of the current non-hermetic package with a sample hermetically sealed package. The company has provided enough biscuit products (packaged with non-hermetic sealing), and the packaging material, OPP, that is currently used for this product. The material obtained was used to make a hermetic sealed pouch for the biscuit products. The objective of this study is to provide a possible solution for solving the company's problem. This can be done by examining the extent to which hermetic sealing can extend shelf life of biscuit products. This would help them by moving them to a higher integrity biscuit package.

CHAPTER 1. LITERATURE REVIEW

1.1. BISCUITS AND CONVENIENCE FOODS

The snack food is considered to be the most widely consumed convenience food, and has a market that will continue to be promising. This market is attempting to move away from its "junk-food" image by emphasizing nutritional value. (Baker and Robins, 1988). The term "convenience food" is appropriately applied to snack foods which include salty snacks, cookies and crackers, microwaveable popcorn, candy, gum, nuts, and snack cakes and pies (Jenkins and Harrington, 1991).

There are several ways of classifying cookie and cracker types, but generally there are two major groups: hard and soft dough biscuits. The hard dough group falls into three subgroups of fermented doughs, puff doughs, and semi-sweet doughs. Hard dough include savory, unsweetened, or semi-sweet products such as crackers, puff doughs biscuits, and the semi-sweet varieties such as Marie, Rich Tea, and Petit Buerre. This proposal will study Marie biscuits. The soft dough group includes all the sweet biscuits, including plain biscuits, shells, and flow types such as gingernut. Such classification is favored because it is helpful in understanding many of the product properties and some of the formulation principles of cookie manufacture. (Matz, S. 1992).

There are three basic ingredients for snack food products: wheat flour, fat, and sugar. The ingredients are usually combined with salt and other additives, used in lesser quantities, to produce various products. The ingredients undergo a mixing process which achieves two purposes: intermingling of ingredients, and certain chemical and physical changes, depending on the type of expected properties for the targeted product. (Robertson, 1993).

1.2. BISCUITS PRODUCTION

Biscuits are normally manufactured by rather conventional production methods. First, the water content of the flour is checked and the information is passed to the mixer operators who adjust the water addition to obtain the correct dough consistency. Operators monitor and control dough temperature and the consistency or “feel” of doughs after mixing. The operators check weights of dough pieces and the amount of sugar or salt applied to the products prior to baking. Also, biscuit dimension and color should be closely controlled. (Anderson, 1979).

More importantly, the Quality Control Department in a biscuit company carries out regular examinations and checks on biscuit weight, moisture, oil weight, stack height, shape, color, flavor, and pH. Most of the main problems arise when attempts are made to maintain the weight, shape, and stack height of the product. (Anderson, 1979). Machinaries used in biscuit-making affect the general characteristics of the biscuits produced. For example, biscuits made on rotary cutters such as hard sweets and semi-hard sweets biscuits, tend to be hard and crunchy rather than crisp and flaky, and they are considerably denser than saltines. (Matz, 1992).

1.2.1. INGREDIENTS

The main structure-forming ingredient of biscuit doughs is flour. Other ingredients include sweeteners (sugar), texture-modifier (shortening), a leavener to expand the product during baking (thereby improving both texture and appearance), and various ingredients such as flavors, colors, nuts, and fruits. Snack products like saltines have very small amounts of sweeteners and are leavened with yeast. Sweet biscuits, such as cookies, contain moderate to large amounts of sugar and shortening, and are generally leavened with sodium bicarbonate or, less frequently, with ammonium bicarbonate. (Matz, 1992). Lecithin has been found to maintain a lower viscosity when traces of moisture are present, and thereby contributes to smoothness and uniformity (Matz, S. 1992).

Since the major ingredient in biscuits is flour, it is important to know differences among flour types so that knowledgeable selection of the suitable type for biscuit-making is possible. For instance, the pastry flour for biscuit making has been found to be stronger than the average cake flour, because it contains a slightly larger amount of gluten-forming protein. This property would contribute to the tenderness of the final product, and therefore it may also allow spreading and loss of shape. (Sultan, 1977).

1.3. MOISTURE EFFECT ON BISCUIT

In general, North American biscuits contain more moisture than their European counterparts which are in the range 2-2.5% moisture content (Smith, 1972). However, as little change in moisture content as 1-2% may noticeably alter the taste and texture of biscuits. Therefore all possible precautions are taken to produce biscuits at a controlled moisture content that can sufficiently complement their textural characteristics. (Jenkins and Harrington, 1991). But there is a critical upper and lower level of moisture which foods must maintain in order to assure their quality and safety for human consumption. It is therefore important to emphasize the fact that there are important differences in the responses of biscuits to moisture introduced in their processing, preparation, and formulation. (Brown, 1993).

Moreover, it is important that all ingredients should maintain their moisture content at the lowest possible level. During processing it is possible for a major difficulty to arise due to the effect of free water, where as little as 1% of which may result in agglomerating sugar particles (Matz, 1992).

1.3.1. WATER ACTIVITY

One of the most important factors affecting the rate of biscuit deterioration reaction is the relative humidity of the immediate environment which directly affects the biscuits moisture content and water activity a_w. Every food product, including biscuits, has its own characteristic water activity which describes the degree of binding of the water contained in the food, and its availability to act as a solvent and participate in chemical reactions. In addition, for every food product there is a critical level of a_w above which undesirable deterioration of food occurs, especially microbial growth or textural changes. Controlling a_w is the basis for dry and intermediate moisture foods (IMF) preservation. (Labouza and Taoukis, 1990).

Considering that the partial pressure of water in the food (p) and that the vapor pressure of pure water at the same temperature (p_o), then the ratio of (p/ p_o) is the water activity (a_w). Two common processes which decrease the water content of a food are concentration and dehydration. This simultaneously increases the concentration of solutes, and hence decreases perishability. The (a_w), unlike water content, is a more reliable tool to predict food stability, safety, and other properties. For instance, (a_w) can be correlated sufficiently well with rates of microbial growth and other degradative reactions which makes it a useful indicator for product stability and microbial safety. (Fennema, 1996).

However, there are mathematical models to predict the shelf life of moisture-sensitive foods. These predictions are used for packaged foods in conjunction with moisture transfer models that are developed according to properties of the food and the packaging materials. The a_w of packaged foods is a dynamic state of moisture exchange with the environment, which tends to equilibrate with the external relative humidity. The moisture transport models are useful because they allow the computation of the a_w which depends upon the ambient relative humidity and temperature, the barrier properties of the selected package, and the moisture isotherm of the food. (Labouza and Taoukis, 1990).

1.3.2. Moisture Sorption Isotherm

In addition, moisture sorption isotherm can be obtained as a plot of food water content (i.e. mass of water per unit mass of dry material) versus ($a_w = p/p_o$) at a constant temperature. The importance of the moisture sorption isotherm lies in its ability to lead to a better understanding of:

1) concentration and dehydration processes needed for a food product of interest.
2) formulation of a food mixture (as to account for moisture transfer among ingredients).
3) barrier properties of a packaging material.
4) moisture content required for a specific microorganism growth of importance for the product.
5) chemical and physical stability of food as a function of water content. (Fennema, 1996).

1.4. DETERIORATION

Generally, keeping properties of food are a function of its microenvironment. Important parameters that have direct effects on deterioration processes of foods include: gas composition (oxygen, carbon-dioxide, inert gases, ethylene, etc.), the relative humidity (RH), pressure or mechanical stresses, light, and temperature. Packaging and storage conditions determine the extent to which these parameters can effect a given food product. (Labouza and Taoukis, 1990). Although physical changes in food (e.g. sogginess in biscuits) may occur quickly, chemical and microbiological changes usually occur more slowly (Ihekoronye, and Ngoddy, 1985).

Physical spoilage is mostly not harmful. One of the forms of physical spoilage is moisture absorption. Once biscuits absorb moisture, they become soft. The foodstuff deterioration in quality can be easily detected by the senses. (Castberg, and Dommelen 1987).

1.4.1. Modes of Biscuit Deterioration

There are four modes of deterioration associated with biscuits: loss of crispness, development of rancidity, development of fat bloom, and breakage.

1- Loss of Crispness

Freshly baked biscuits have 1-5% moisture content, and a water activity (a_w) of about 0.1. Soon after being packaged with moisture barrier, the moisture content in the biscuit product reaches equilibrium with the moisture in the product head space. However, when packaged with higher moisture barrier, or when the sealing quality is not good enough, moisture will enter the package and, as a result, the biscuit will lose its crispness.

Studies have shown that moisture gain by semi-sweet (and short) biscuits can lead to the development of stale flavors without affecting the texture of the product. Other studies reveal that freshly-baked products with moisture content of 1.9-2.4% can have an extension of shelf life of up to 12 months on the other hand, those with 3.9-4.1% have a shelf life of only 6 months due to the onset of stale flavor. Samples with 5.2-5.8% moisture content became stale after 6 weeks.

2- Rancidity Development

Atmospheric oxygen as well as moisture penetrate into the package during the entire products shelf life. Rancidity reaction, resulting from oxidative reaction of lipids, is a direct result of oxygen presence within food products.

3- Fat Bloom Development

The development of gray discoloration on the surface of biscuits is referred to as fat bloom. Heating of the biscuits leads to the disappearance of the bloom. It is believed that the abusive temperatures during storage is responsible for the fat boom formation.

4- Breakage

Consumer acceptance is highly affected by the broken biscuits. Therefore the mechanical protection of the packaging materials plays an important role. This could be a challenging problem encountered with biscuits, as different formulation makes some biscuits more prone to mechanical damages and breakage than others. (Robertson, 1993).

1.5. TEXTURAL CHARACTERISTICS OF BISCUITS

Friability is one of the most important textural properties of biscuits and which characterizes the mechanical properties of the product. Mechanical properties of biscuits change as a function of hydration of the product. Water was found to act as a plasticizer that softens the rigid matrix of biscuits. It has been demonstrated that as the moisture content of biscuits increases, the modulus of elasticity decreases. Also it has been found that the higher moisture content, the higher the structure resistance to deformation caused by small stresses. Other experimental evidence shows that the failure mode of biscuits changes from brittle to ductile as a result of moisture gain. (Piazza, Bringiotti, and Masi, 1993).

Because physical properties of biscuits are important, there are elaborate methods that aim at measuring textural parameters of biscuits. Measurements of such important parameters as fibrousness, firmness, or hardness can be done with sophisticated equipment. For example, the FMBRA Biscuit Texture Meter is a rotating blade device used to measure biscuit hardness. (Kilcast and Eves, 1993). Compositional analysis using near infrared absorption spectroscopy and on-line NIR can also be used for measurements of biscuits moisture (Benson, 1993).

Biscuits combine hardness and crispness in texture, and they vary from soft to hard crispness. Experimental studies have shown that the texture of biscuits closely depends on water activity. Thus, controlling the moisture content insures good textural biscuit quality. (Bouvier, et al. 1989).

Biscuits can also become broken or cracked by a phenomenon called checking. Checking is a process which results in development of hair-like cracks in the biscuits after baking and/or packaging (not evident before packaging the biscuits). It is believed that loss or uptake of moisture in various parts of biscuits leads to expansion and contraction within the biscuit. This creates stress, which contributes to checking. Another speculative explanation suggests that heat (and thus chemical) changes within the biscuit structure may lead to stresses, and hence to checking. (Smith, 1972).

1.6. PACKAGING

One of the important considerations in any product development process is the packaging. More than ever before, food industry is producing processed foods and not commodities. This imposes a demand for an integrated and very well inter-related system that can link processing requirements and those of packaging to produce a given food product. For some food products, it suffices to say that the package costs more than the food, and often much more. (Baker, et al. 1988).

The current packaging used for biscuits include the following kinds. Small, nibble-sized products are packed in sealed bags, whereas larger biscuits are piled up in a column (stack pack) or in smaller piles side by side (pile pack). Now the most common wrapping material are flexible films with coatings on the surface of the film to improve moisture barrier properties and sealability (including metallized foil wrappings with tear strip openers). (Paine and Paine, 1992).

Because textural characteristics of biscuits are highly sensitive to moisture changes, sealing of the package must take place as soon as possible after baking biscuits. (Paine and Paine, 1992). Since biscuits contain moisture in the range of 2-8% (Paine and Pain, 1992), their packages must be designed to prevent escape as well as ingress of water vapor, depending if the biscuit is moist or dry. Therefore, a package with the ability to limit water ingress and egress is essential. A moisture vapor transmission rate (MVTR) in the range of 0.1 to 0.4 g/100 in 2.24 hr. is found to be desirable, according to work performed in several food laboratories. (Jenkins and Harrington, 1991; and Matz, 1992).

Additionally, biscuits contain fat, which is sensitive to odors. A packaging material with good oxygen- and grease-resistance properties is necessary to package biscuits. Also, biscuits are brittle and the packaging therefore must provide mechanical protection, which may be achieved by wrapping the biscuits together with the right degree of tightness to provide a mutual reinforcing effect. (Paine and Paine, 1992).The package is expected to protect biscuits against light, as the ultra-violet rays cause color fading and flavor deterioration (Smith, 1972).

In addition, packaging material and shape help to protect the product from damaging mechanical force, as from crushing, cracking, punctures, and vibrations, all of which can have disastrous effects on the product. Because a single homopolymer film may not provide all of the desired protective features, laminating together several different films may be necessary. For example, one layer may be used for its heat seal properties, another for its printing compatibility, a third as an oxygen barrier, a fourth for its low water vapor transmission rate, and a fifth for grease resistance. Although not common in biscuit products, as many as eight layers can be used as a package, though not all of them are different, as some are adhesive layers. Such materials become more expensive as the number of layers increase. (Matz, 1992).

1.6.1 PACKAGING EQUIPMENT

There are two general types of packaging schemes used for cookies and crackers. The first is dump packaging, in which the small pieces are allowed to fall into the pack in no particular order. The second is registered, or orderly, packaging, in which the pieces are kept in some predetermined relationship to each other throughout the packaging process and in the container itself. (Jenkin, and Harrington, 1991).

Packages for hot, humid summers not only require a good moisture barrier but also an enhanced oxygen barrier. Oxygen adversely affects taste, texture, and safety, causing rancidity in products. Gas-flushed packages are frequently used to further reduce oxidative degradation. In most cases, constructions that provide low enough MVTR will also provide a sufficient oxygen barrier, and so the package designer for these products concentrates mainly on the need for moisture protection, since the water related activity is a first-order reaction.

In addition to these barrier requirements, packages for these products must have rapid, high-integrity seal characteristics, a good light barrier, easy openability, and be able to resist transmission or absorption of flavors and odors. Replacement of waxed glassine by plastic films gives the producer a heat-sealable system that requires no adhesive and that is well on high-speed, form-fill-seal machines, producing reliable, high-integrity seals. This improves the moisture barrier and greatly increases the shelf life.

1.7. SHELF LIFE OF BISCUIT

Labouza and Taoukis (1990) defined the shelf life as the period food will retain an acceptable level of eating quality from a safety and organoleptic point of view. Four factors affect shelf life: formulation, processing, packaging, and storage conditions. For example, a perishable food (properly stored) has less than 14 days of shelf life, but with new aseptic technology and controlled/modified atmosphere packaging (CAP/MAP), such foods may last up to 90 days. Semi-perishable foods (cheeses and frozen desserts) have a shelf life up to 6 months, whereas shelf-stable non-perishable foods (canned foods) last over six months, and up to three years under proper storage conditions.

Shelf life of a product depends on the environmental conditions it is exposed to (distribution in the store and the consumer's home) and on how much of the product's initial quality is lost before its final quality will no longer be acceptable to the consumer. Generally, and as many other food products, biscuits shelf life depend on the following factors:

1) Microbial spoilage.
2) Chemical reactions.
3) Changes occurring during processing.
4) Protective barrier properties of the package.
5) Environmental conditions (distribution and storage).

(Graf and Saguy, 1991).

Unlike cookies that dry out quickly and lose chewiness, biscuits with substantial amounts of hygroscope ingredients will tend to become soft and chewy (Matz, 1992). The factors leading to a reduction of the shelf-life of biscuits, so far as palatability is concerned, are moisture and oxidative rancidity of the fat content, while light accelerates loss of crust color. (Smith, 1972). Therefore, shelf life of biscuits depends on the initial acceptance moisture content being achieved on correct sealing.

1.7.1 SHELF LIFE ESTIMATION

To determine shelf life of a given food product, an assessment should be conducted of the quality of the food stored in given packaging material for varying times under standard conditions. For instance, if a shelf life testing is needed for a product for which water vapor sorption is the determining factor in limiting the shelf life, the following information must be obtained:

1) Water vapor permeability of the packaging material (in g/m^2 d at 25°C and 75% RH or 37 °C and 90% RH).
2) Surface area of the whole package (A, cm^2).
3) Critical moisture content of the product (m*% on dry weight basis).
4) Equilibrium moisture content of the product (m) or the ERH (E) of the product when packaged.
5) The weight of product (M, in gm).

The arithmetic mean of the ERH of the original product and of the atmosphere provide an acceptable estimate of the shelf life of a packaged food. Thus, for example, if a product is stored at 25 °C and 75% RH, the shelf life (S) can be calculated as:

$$S = \frac{(m^*-m) \times M \times 1.5 \times 10{,}000;}{(P \times A \times 150) - (75 + E)}$$

(Ihekoronye and Ngoddy, 1985).

1.7.2. SHELF LIFE TESTING

According to Graf and Saugy (1991), normally, shelf life tests are carried out under accelerated or ambient conditions. Accelerated testing utilizes tropical conditions (37 oC and 90% RH) or temperature conditions (25 °C and 75% RH). Moisture and weight measurements are made and the product is tested after 1 month in tropical conditions or after 2 months in temperate conditions by a laboratory test pannel.

1.7.3. ACCELERATED SHELF-LIFE TESTING (ASLT)

In general, from the product development perspective, preliminary shelf life results are needed before the end of the actual shelf life, which in some cases may be as long as 10 to 24 months. Therefore, a rapid method is periodically used to evaluate the effects of formulation and processing variables on the shelf life stability of the product. To accomplish this task, various accelerated shelf life tests (ASLTs) have been devised. (Graf and Saugy, 1991).

ASLT is the methodology most often used in shelf life testing of food products. The objective of ASLT is to store the finished product/package combination under abusive conditions of RH and temperature, and test and evaluate the product periodically until the end of shelf-life with quality loss in principal properties. The obtained data is then used to project shelf-life under true distribution conditions. (Labouza and Taoukis, 1990).

In addition, simulated conditions affecting biscuits in transit can be conducted by subjecting cases of biscuit products to drop tests under laboratory conditions. Or biscuits can be shipped for breakage assessments through the distribution system and then returned to the laboratory for evaluation. (Graf and Saugy, 1991). Nonetheless, in such cases where moisture is critical in facilitating food deterioration, a moisture sorption isotherm of a packaged food is necessary for estimating its shelf life. Hence, knowledge about critical moisture contents and water vapor permeability of the packaging material is important in determining the shelf life. (Ihekoronye and Ngoddy, 1985). These tests are important for new products and usually done before marketing tests so that changes and adjustment of ingredients and packaging materials can be made. (Graf and Saugy, 1992).

1.8. FACTORS AFFECTING SEALING

Generally, heat-sealing applications involve relatively thin films or laminations. In order to ensure fast line speeds and a high-integrity, leak-proof seal, a profile of the following properties is needed: heat seal and hot tack. Thin materials, however, generally need heating from only one side. (Anonymous, 1991). Heat seal tests measure the force required to peel seals made within a range of temperatures and kept for 24 hours, whereas a hot tack is a measure of the force needed to peel a seal immediately after it is made while the seal is still hot. (Foster, 1995). In addition, seal-initiation temperature, minimum temperature at which fusion occurs, is an important parameter used to evaluate a sealing system (Blakistone, 1996).

There are important properties of the materials to be sealed that have an impact on the quality of sealing. For example, storage temperature has a linear relationship with crystallinity of polymeric films (e.g., polypropylene). Nicastro, et al (1993) have found that as storage temperature increases, the crystallinity of PP increases as well, which in turn decreases the sealability of the film. Consequently, the films examined show a reduced range of their heat-sealing temperature profile.

1.8.1. SEALING BISCUIT PRODUCTS

There are several methods to seal biscuit products. Vertical form-fill-seal machinery is widely used for dump packing small (or medium) sized biscuit products such as oyster crackers, round snack crackers, and small wafers. Operators of such machines wrap the plastic films around a metal tube open at both ends in such away that the two vertical edges of the plastic strip are overlapped and heat-sealed, making the web into a continuous cylinder. Then a heat seal is made across this cylinder below the forming tube. Then, a weighed amount of food pieces is allowed to drop down the forming tube into the closed-off area. Meanwhile the clamp that has made the seal draws the web downward and thus pulling more of the film along the forming tube. When a predetermined length is drawn down, the sealing jaw returns to its original position for another sealing cycle. Then the top seal of the bottom bag is cut off while the bottom seal of the next bag is being made. (Matz, 1992).

1.8.2. TYPES OF SEALING EQUIPMENT

1) Bar Sealing: A hinged jaw sealer with one or two heated bars. It is widely used for laminated pouches.
2) Rotary Sealing: A continuous rather than intermittent run of the machine.

Sometimes it does not maintain heat efficiently enough to make a good seal.

3) Band sealing: Two heated metal jaws that pass the heat to two bands which close to seal an open pouch.
4) Hot wire (hot knife) seal: Suitable for high-speed sealing operations. It does not provide hermetic sealing, but very economical for sealing and cutting polyethylene pouches.
5) Thermal impulse: The electric currents flow in a ribbon(s) for a fixed time while the jaw is kept closed till the sealed material is cooled. It can seal through wrinkles.
6) Hot air sealing: Can seal heavy packaging materials, with heat being supplied and removed and then removed from both surfaces to be sealed.
7) Heat induction seal: Heat is supplied to the foil by the resistance to the current from an alternating magnetic filed.
8) Electronic induction seals: Suitable to seal unsupported polyolefin materials. This method uses a gasket, made from the same material as the material to be sealed, which is placed between the sealing surface. An oscillating magnetic field generates heat, by rubbing the packaging materials at high frequency. The generated heat is enough to melt the gasket. (Anonymous, 1991).

CHAPTER 2. EXPERIMENTAL DESIGN AND METHODOLOGY

2.1. INTRODUCTION

The methodology of this study is designed to aid in determining the causes for the considerable reduction in shelf life of a particular biscuit product that, when marketed in humid countries (South Eastern Asian countries). Moisture gain in dry products like biscuits is a first order deteriorative reaction. This study focuses on the affect of hermetic sealing moisture gain and proposes it as a possible solution for the problem. There are some reasonable causes for biscuit spoilage but which were beyond the scope of this study and are not first order reactions. The company is using oriented polypropylene (OPP) as the packaging material, which is a constant between the two test groups. The food chemistry involved in the formulation of biscuits is also beyond the scope of this study and is a constant between the two sample groups. Therefore the sealing method and subsequent package integrity becomes a reasonable factor to investigate in this study and to which the short shelf life of the biscuit could reasonably be attributed.

To investigate the possible involvement of the sealing method in explaining the short shelf life of biscuits in a humid environment, a

To investigate the possible involvement of the sealing method in explaining the short shelf life of biscuits in a humid environment, a preliminary pressure test was conducted. The results show that the biscuit products straight from the manufacturer are non-hermetically sealed. Based on this result, this study has focused on comparing the effect of the hermetic seal versus the non-hermetic seal on extending the shelf life.

Three tests were then carried out in the following order. First, maximum moisture gain was determined for the un-packaged biscuits which can be used to estimate the shelf life of the biscuits. Secondly, a pressure test was run on both hermetically sealed and non-hermetically sealed biscuits. Thirdly, moisture gain for both hermetically sealed and non-hermetically sealed biscuits was investigated.

2.2. Null Hypothesis:

On a significant level of 0.05, there is no significant difference in moisture gain between hermetically sealed and non-hermetically sealed biscuits.

2.3. Alternate Hypothesis:

On a significant level of 0.05, there is a significant difference in moisture gain between hermetically sealed and non-hermetically sealed biscuits.

2.4. Equipment:

The following equipment was selected in such away so as to help reveal the effect of hermetic sealing on preventing moisture gain of biscuits. Therefore they are expected to complement the experimental design and would aid in measuring the differences in gaining moisture between hermetically sealed biscuits and non-hermetically sealed biscuits.

1- ARO Non-porous Package Tester- F099-1080.

2- Electrical Balance, according to 0.0001 gm.

3- Sealing equipment.

2.5. EXPERIMENTAL PROCEDURE

2.5.1. MAXIMUM MOISTURE GAIN OF BISCUITS

Thirty biscuits were emptied from their packages, weighed, and then put inside closed jars filled with 250 ml of water (to establish 100% RH).The weight of the thirty biscuits was taken every three hours till biscuits gained enough moisture to become soggy and unacceptable for consumption. Three hour intervals were found long enough for measurable difference in biscuit weight to be read by the electrical balance. The test was terminated when biscuits became obviously soggy, an indication of shelf life termination.

2.5.2. PRESSURE TEST OF SEALED BISCUITS

In order to ensure that the manufactured biscuits products are non-hermetically sealed and that samples sealed in this study are in fact hermetically sealed, the pressure test must be conducted. The two groups of biscuits were tested for their ability to stand the pressure test. One group was tested as received from the company. The other group was made by emptying thirty pieces of biscuits from as-received products, and then hermetically sealed. Then both groups of biscuit products were subjected to pressure test. Conditions for the pressure test were 12 inch Hg pressure and 2 minutes time.

2.5.2.1. SEALING PROCEDURE

The materials used for both hermetic sealing and non-hermetic sealing is the same (OPP). Biscuits were hermetically sealed with the same OPP material currently used by the manufacturer to package the biscuits. A sealing strength test was done to determine the best parameters for sealing variables using the OPP material. Results from the various tests showed the optimum sealing parameters, and 30 hermetic samples were sealed according to these parameters.

2.5.3. MOISTURE GAIN OF PACKAGED BISCUITS

For this step, biscuits were divided into two groups: hermetically sealed samples and non-hermetically sealed samples. Thirty samples of each group were exposed to a 100% moisture environment. The objective of this testing methodology is to investigate significant difference in moisture gaining between the two biscuits' samples. The shelf life testing procedure was done as follows:

1) 30 non-hermetically biscuit samples were obtained from the manufacturer and the initial weight of each was recorded.
2) Biscuits, from the same manufacturer were put in the same material (OPP) and hermetically sealed in a pouch. Initial weights of 30 such samples were recorded.
3) Each of the 60 samples was put in a jar with 250 ml of water. Each sample was raised inside the jar so that it did not contact the water.

Jars were tightly closed to insure 100% RH.

4) Weights of all the 60 samples were recorded every 24 hours for14 days.

5) Weight gain of every sample, i.e. moisture gain, was compared among all samples.

2.5.4. ANOVA TEST

However, significant differences in the moisture gain of both materials can not be established based solely on differences of the equations. Therefore an analysis of variance (ANOVA) test should be carried out to examine whether or not the means of moisture gain by the two samples were significantly different, which is needed to accept or reject the null hypothesis.

CHAPTER 3. RESULTS AND DISCUSSION

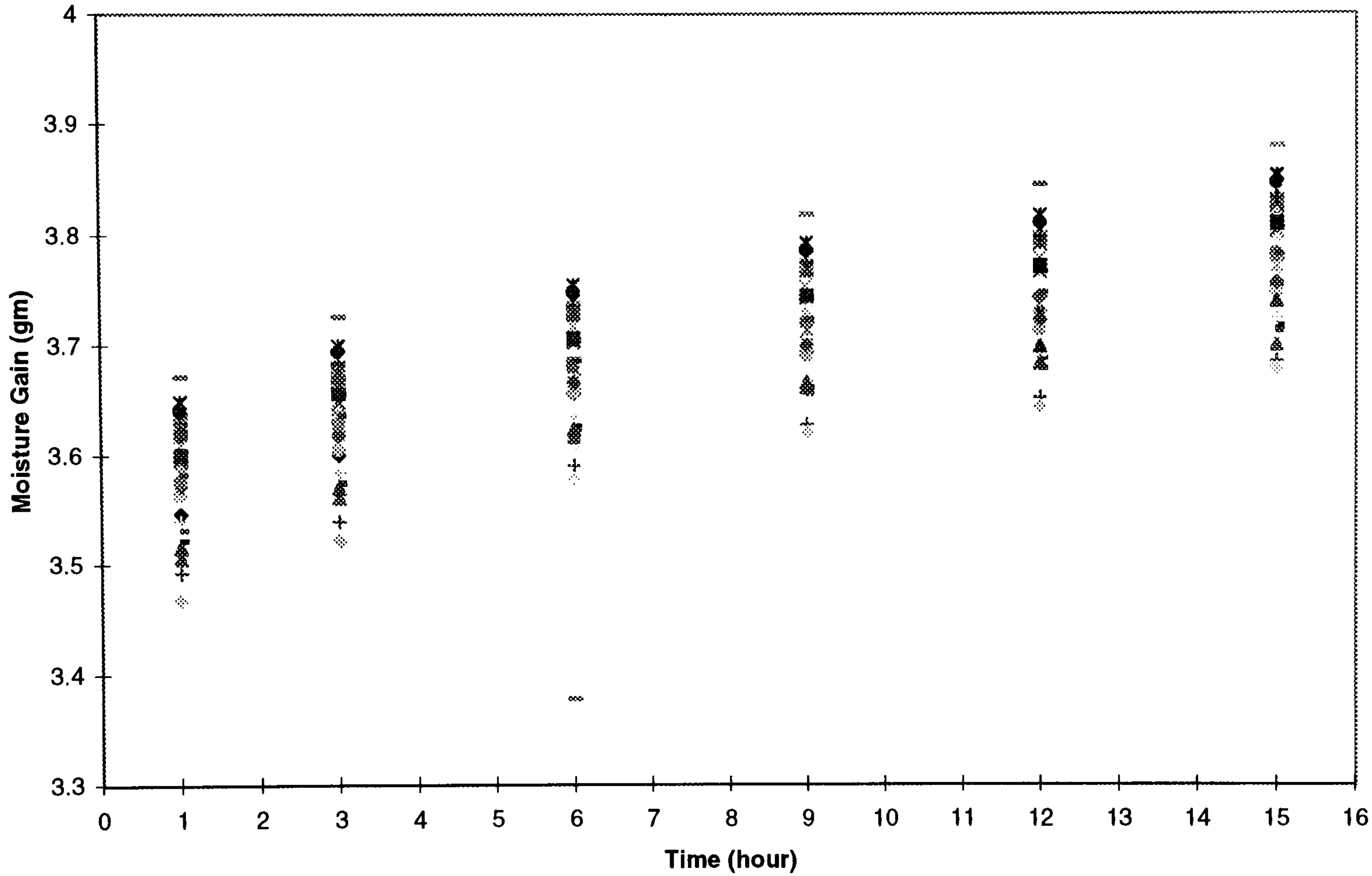
3.1. DETERMINATION OF MAXIMUM MOISTURE GAIN OF BISCUITS

Table 1 and graph 1 show the raw data collected for moisture gain (in grams) of the 30 unpackaged biscuits. The trend of percent increase in moisture of these biscuits is shown by graph 2. This test shows that unpackaged biscuits have become very soggy after 15 hours. At this time the biscuits have reached maximum capacity of moisture uptake to have an average moisture increase of about 5.56% form initial weights. This moisture increase amounts to 0.1999 gm of moisture on average (refer to Appendix A). Therefore, the maximum moisture gain which terminated the biscuits shelf life is assumed to be 5.6%. This step is essential for establishing the upper limit of moisture-uptake in order for the biscuit to be considered spoiled. In other words, both hermetically sealed and non-hermetically sealed biscuits will be assumed spoiled when their moisture content increases by 5.6%.

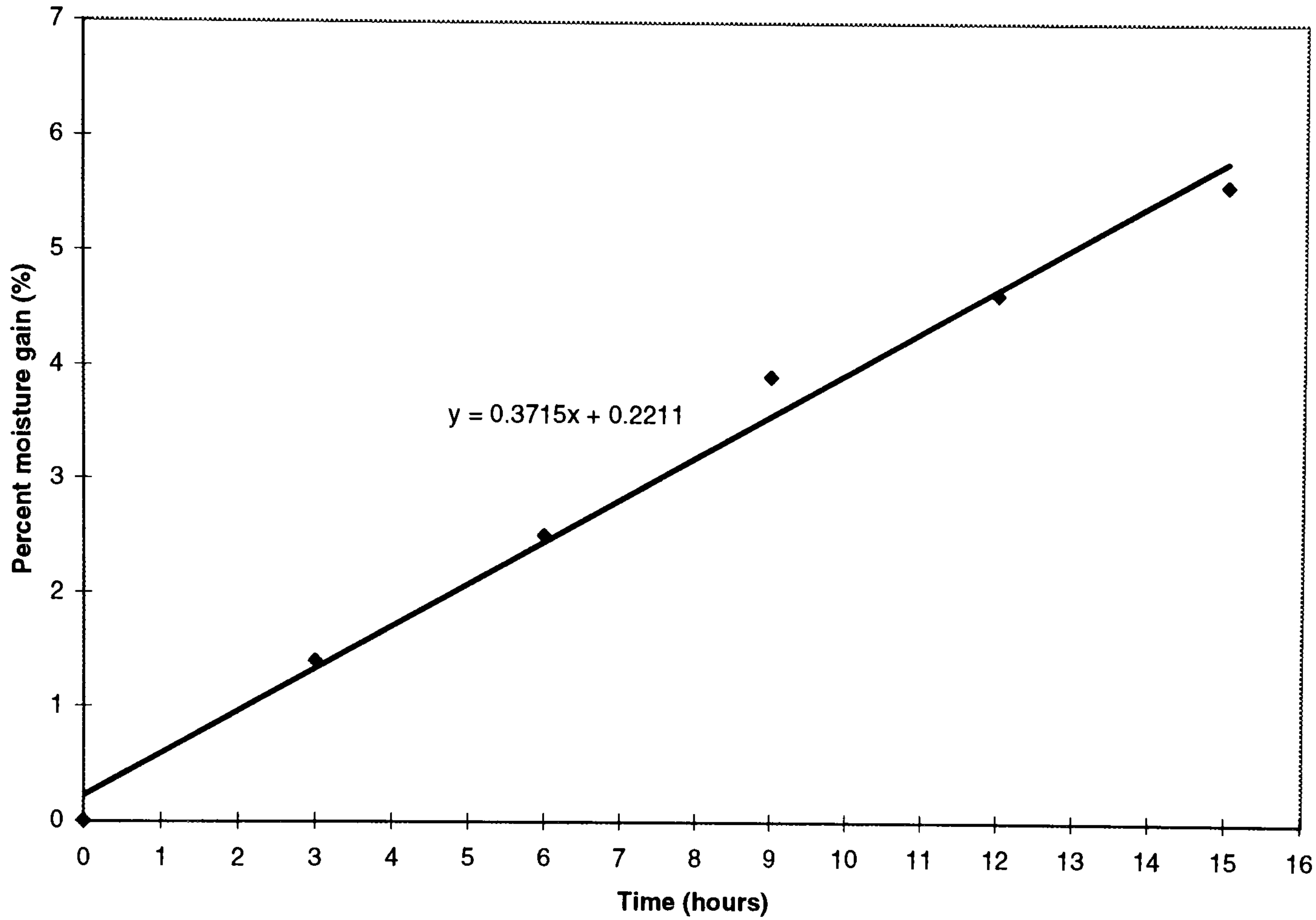
Table 1. Moisture Gain of Unpackaged Biscuits (Total Weight in Grams)

Sample Number	1 Hour	3 Hours	6 Hours	9 Hours	12 Hours	15 Hours
1	3.5467	3.6008	3.6567	3.6947	3.73	3.7533
2	3.6186	3.6698	3.728	3.768	3.7967	3.8245
3	3.5942	3.6445	3.7019	3.7298	3.7666	3.8
4	3.6087	3.6589	3.7163	3.754	3.7798	3.8218
5	3.6491	3.6999	3.7551	3.7929	3.8178	3.8531
6	3.6414	3.694	3.7485	3.7858	3.811	3.8455
7	3.493	3.5397	3.5912	3.628	3.6524	3.6852
8	3.5225	3.5749	3.627	3.6618	3.6883	3.7172
9	3.672	3.7266	3.3781	3.819	3.846	3.88
10	3.4686	3.5221	3.5784	3.6203	3.6438	3.6786
11	3.5966	3.6464	3.7028	3.7415	3.7693	3.8062
12	3.5146	3.5577	3.6114	3.6462	3.6706	3.707
13	3.5685	3.6114	3.666	3.7006	3.725	3.76
14	3.5849	3.6275	3.6793	3.7137	3.7376	3.7717
15	3.5629	3.6056	3.6563	3.6904	3.7135	3.7474
16	3.5402	3.5845	3.6349	3.667	3.69	3.7235
17	3.5317	3.5759	3.6234	3.656	3.6789	3.7124
18	3.5936	3.6393	3.6877	3.7197	3.743	3.7765
19	3.5723	3.6184	3.6668	3.6999	3.7233	3.7557
20	3.6332	3.6806	3.7342	3.7723	3.7971	3.8304
21	3.5058	3.5613	3.6177	3.6618	3.6833	3.6999
22	3.5958	3.6481	3.703	3.7437	3.7666	3.8031
23	3.6235	3.6757	3.7289	3.7699	3.7923	3.8296
24	3.5765	3.6284	3.6799	3.7197	3.7429	3.7823
25	3.6302	3.6841	3.7365	3.7751	3.7986	3.8334
26	3.5832	3.6365	3.6862	3.7237	3.7479	3.7826
27	3.604	3.6566	3.7048	3.7425	3.7672	3.8056
28	3.6396	3.6963	3.7462	3.7852	3.81	3.8487
29	3.6004	3.6572	3.7063	3.745	3.7718	3.8101
30	3.5162	3.5706	3.6238	3.666	3.6991	3.7395

Graph1. Changes in Total Weight of Unpackaged Biscuits
(Moisture Gain in gm)



Graph2.Percent Moisture Gain of Unpackaged Biscuits



3.2. PRESSURE TEST OF SEALED BISCUITS

The pressure test shows that all of the non-hermetically sealed biscuits failed the test when just submerged before the machine began pulling a vacuum; and that all of the hermetically sealed biscuits passed the test even when the pressure reached 15 inch Hg. The result of this step ensures that the hermetic sealing in the only difference between the two sample groups which is expected to affect the moisture gain of the biscuit products.

3.3. MOISTURE GAIN FOR PACKAGED BISCUITS

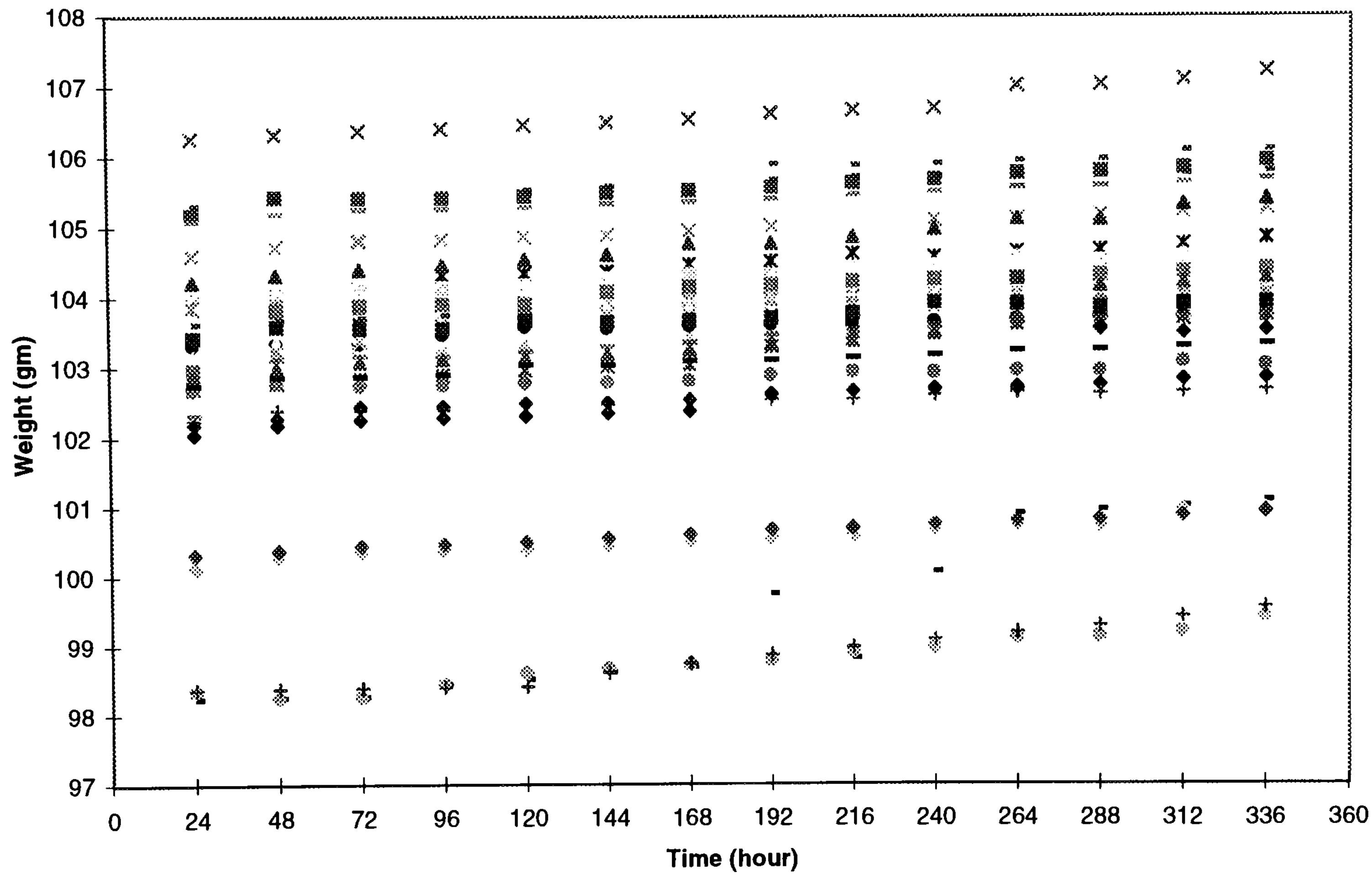
The data collected shows two different trends for both hermetically and non-hermetically sealed biscuits. Table 2 contains the raw data collected representing the change in total weights due to moisture gain, which is also shown by graph 3. However, when an average was taken for the total weight of all the 30 samples (non-hermetically sealed) moisture gain seems to increase with a trend that is shown in graph 4. This graph shows a rate in increasing the total weight of the biscuit with a straight line equation of $Y=0.003x+102.76$. This means that the moisture gain occurs with a rate that is equivalent to 0.003gm/hour.

Also, when only moisture gain content is considered, by subtracting the weight of a sample on a given day from its weight on a previous day, an

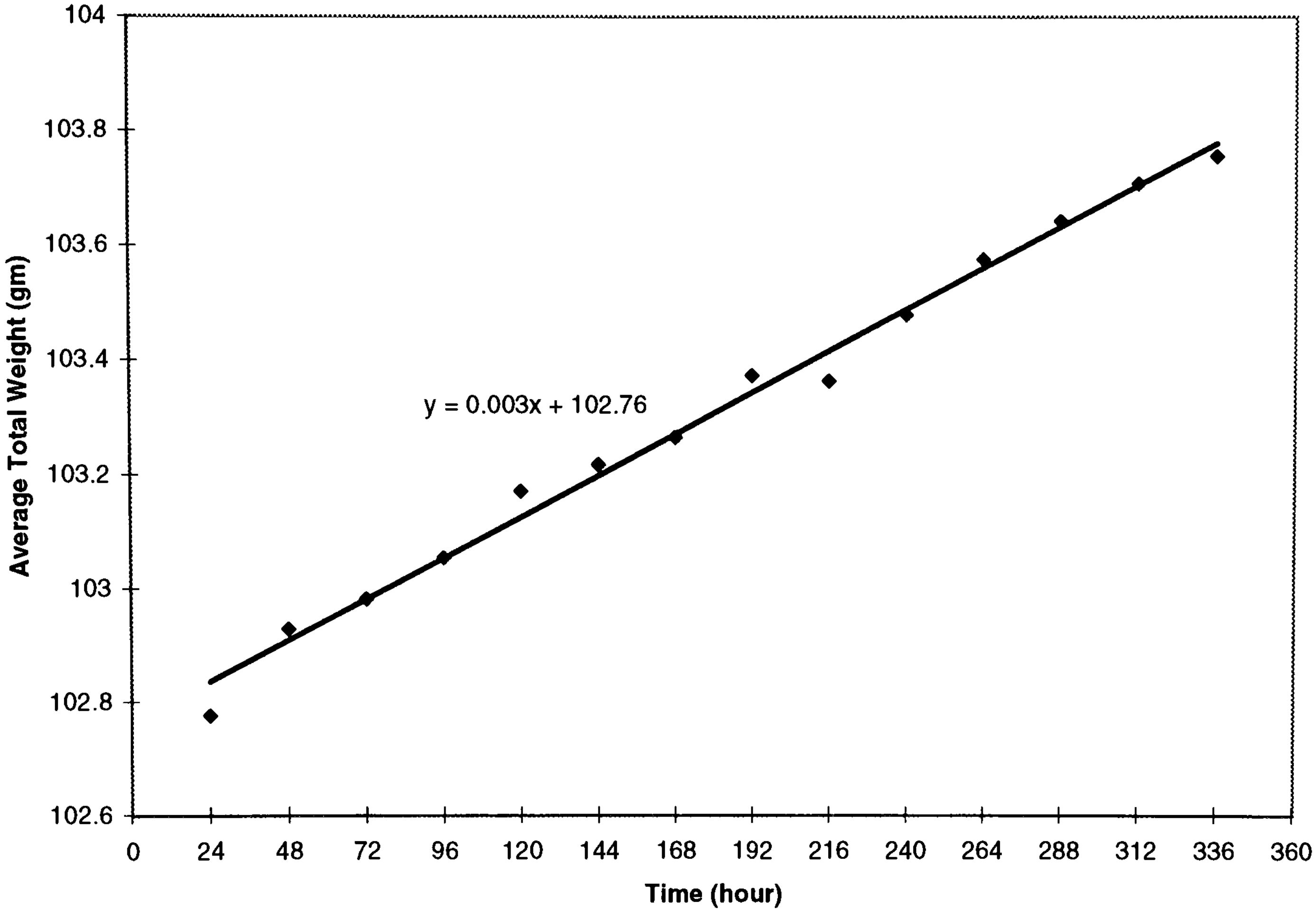
Table 2. Changes in Total Weight of Non-Hermetically Sealed biscuits

Sample	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
1	102.05	102.18	102.26	102.29	102.31	102.35	102.38	102.63	102.66	102.69	102.72	102.75	102.83	102.85
2	105.18	105.44	105.42	105.43	105.45	105.51	105.54	105.58	105.64	105.69	105.77	105.8	105.84	105.95
3	103.12	103.23	103.3	103.29	103.34	103.37	103.42	103.45	103.48	103.51	103.6	103.71	103.71	103.74
4	104.6	104.74	104.81	104.82	104.87	104.91	104.96	105.02	104.06	105.1	105.12	105.17	105.23	105.26
5	103.42	103.58	103.63	104.33	104.36	104.38	104.48	104.52	104.63	104.58	104.65	104.68	104.76	104.84
6	103.31	103.33	103.34	103.48	103.58	103.56	103.59	103.61	103.62	103.64	103.68	103.7	103.71	103.72
7	102.25	102.4	102.39	102.41	102.49	102.48	102.56	102.54	102.55	102.6	102.64	102.63	102.66	102.68
8	98.245	98.261	98.277	98.459	98.522	98.621	98.696	99.759	98.822	100.08	100.92	100.97	101.02	101.09
9	102.32	103.12	103.18	103.17	103.25	103.31	103.37	103.47	103.5	103.56	103.65	103.7	103.72	103.72
10	100.12	100.27	100.36	100.38	100.4	100.45	100.5	100.56	100.59	100.69	100.73	100.73	100.97	100.98
11	103.99	104.05	104.14	104.15	104.18	104.28	104.34	104.33	104.41	104.46	104.57	104.53	104.57	104.63
12	103.16	103.36	103.45	103.77	103.93	103.97	104.04	104.09	104.17	104.23	104.36	104.42	104.6	104.57
13	102.88	103.23	103.38	103.61	103.73	103.74	103.73	103.75	103.91	103.87	103.89	103.92	103.98	104.02
14	103.85	103.88	103.9	103.9	103.93	103.94	103.96	103.97	104	104.02	104.02	104.03	104.04	104.06
15	98.338	98.247	98.263	98.439	98.607	98.666	98.721	98.783	98.896	98.956	99.105	99.124	99.191	99.401
16	103.62	103.73	103.86	103.84	103.86	103.92	103.92	104	104.03	104.05	104.12	104.14	104.19	104.22
17	105.32	105.45	105.5	105.48	105.51	105.55	105.58	105.91	105.89	105.91	105.95	105.97	106.09	106.1
18	105.1	105.2	105.26	105.27	105.3	105.35	105.37	105.41	105.47	105.52	105.57	105.59	105.64	105.69
19	100.32	100.38	100.43	100.47	100.51	100.55	100.61	100.68	100.71	100.75	100.8	100.83	100.88	100.93
20	102.97	103.82	103.87	103.91	103.9	104.09	104.15	104.18	104.24	104.25	104.26	104.31	104.36	104.4
21	102.9	102.99	103.08	103.13	103.15	103.2	103.26	103.34	103.39	103.49	103.7	104.17	104.21	104.28
22	106.27	106.33	106.38	106.41	106.46	106.51	106.56	106.64	106.67	106.7	107.02	107.03	107.09	107.22
23	102.71	102.78	102.85	102.9	102.98	103.02	103.05	103.3	103.49	103.54	103.61	103.64	103.68	103.73
24	102.68	102.77	102.74	102.76	102.78	102.79	102.81	102.89	102.93	102.92	102.94	102.95	103.08	103.02
25	98.377	98.383	98.397	98.409	98.42	98.614	98.75	98.876	98.985	99.092	99.194	99.287	99.422	99.557
26	103.62	103.68	103.72	103.75	105.55	105.6	105.56	105.69	105.73	105.73	105.74	105.75	105.76	105.79
27	102.75	102.87	102.88	102.91	103.05	103.05	103.11	103.11	103.15	103.17	103.24	103.25	103.3	103.34
28	102.19	*102.27*	102.45	102.46	102.5	102.5	102.55	102.61	102.66	102.68	102.7	103.54	103.49	103.52
29	103.43	103.59	103.56	103.57	103.68	103.66	103.68	103.71	103.77	103.93	103.91	103.87	103.91	103.93
30	104.22	104.33	104.4	104.47	104.55	104.62	104.78	104.78	104.87	104.97	105.12	105.1	105.32	105.4

Graph 3. Changes in Total Weight of Non-Hermetically Sealed Biscuits



Graph 4. Average Total weight of Non-hermetically Sealed Biscuits

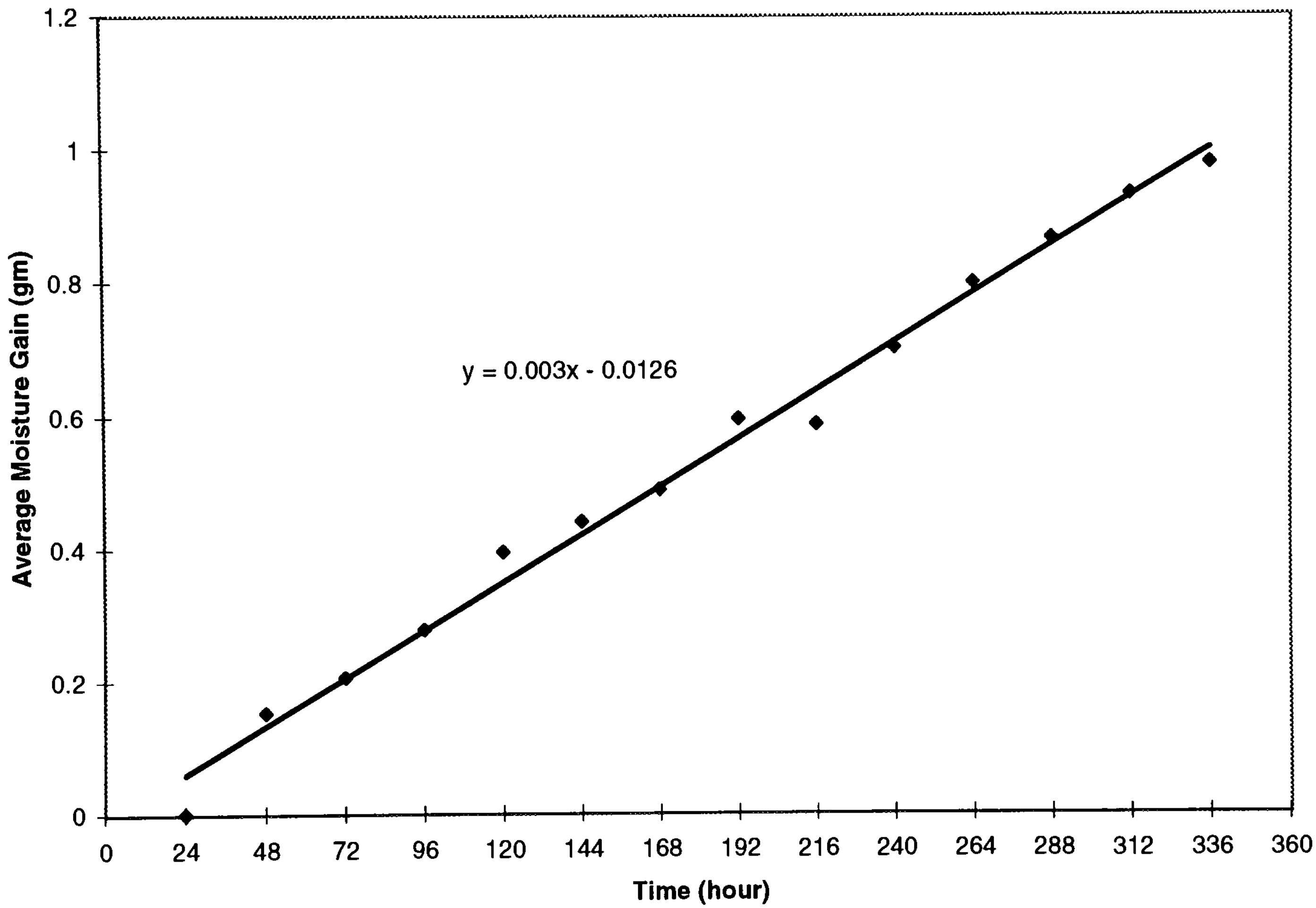


increasing trend in moisture gain is obtained as shown in graph 5. In addition, the percent increase in moisture gain is also obtained and shown in graph 6. The percentages are obtained by taking the average of all the 30 samples in terms of their percent increase of moisture gain on a given day. Biscuits packaged in these non-hermetic pouches gain measurable amounts moisture every 24 hours. Their moisture percent increases with a rate that corresponds to the straight line equation: Y=0.003x-0.0141 (Refer to Appendix B for more detailed analysis of the data collected for the non-hermetically sealed biscuits).

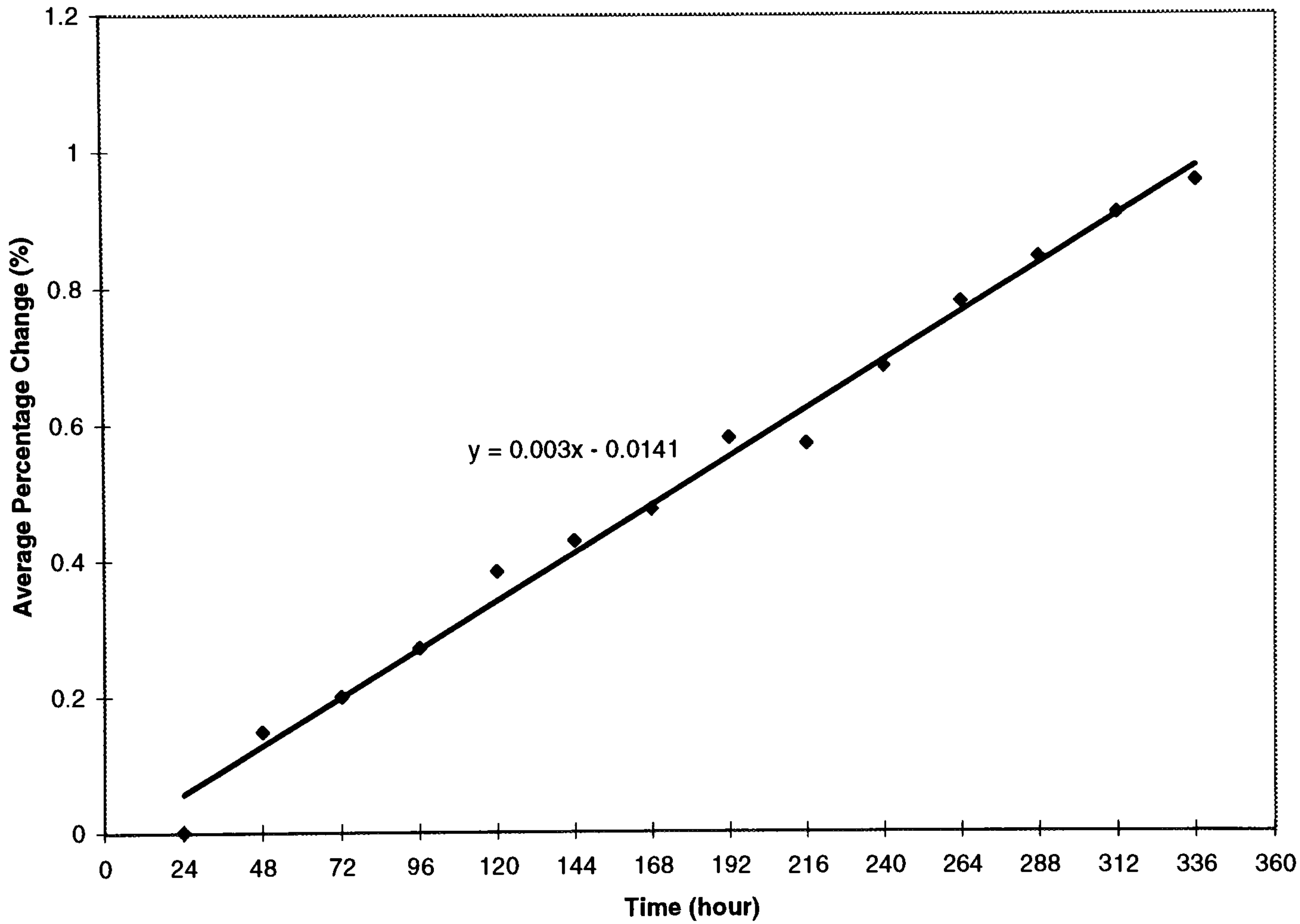
More importantly, and according to the trend of moisture gain of the non-hermetically sealed biscuits, a projected time frame can be estimated at which the biscuits are expected to gain about 5.6% moisture and thus become spoiled. Graph 7 shows that non hermrtically biscuits will be spoiled (when they gain the maximum upper limit of moisture content of 5.6% moisture) after approximately 76.67 days (1840 hours).

Biscuits that are packaged in hermetically sealed pouches show a considerably limited moisture gain. Table 3 shows the raw data of the total weight of biscuits with extremely slow moisture uptake. Graph 8 shows the trend of the average total weigt change of all the 30 hermetiaclly sealed biscuits. More specifically, the average moisture gain of the 30 samples

Graph 5. Average Gain in Moisture by Non-hermetically Sealed Biscuits



Graph 6. Average Percent Change in Moisture Gain by Non-hermetically Sealed Biscuits



Graph 7. Projected Time Till 5.6% Increase in Moisture Gain of Non-hermetically Sealed Biscuits

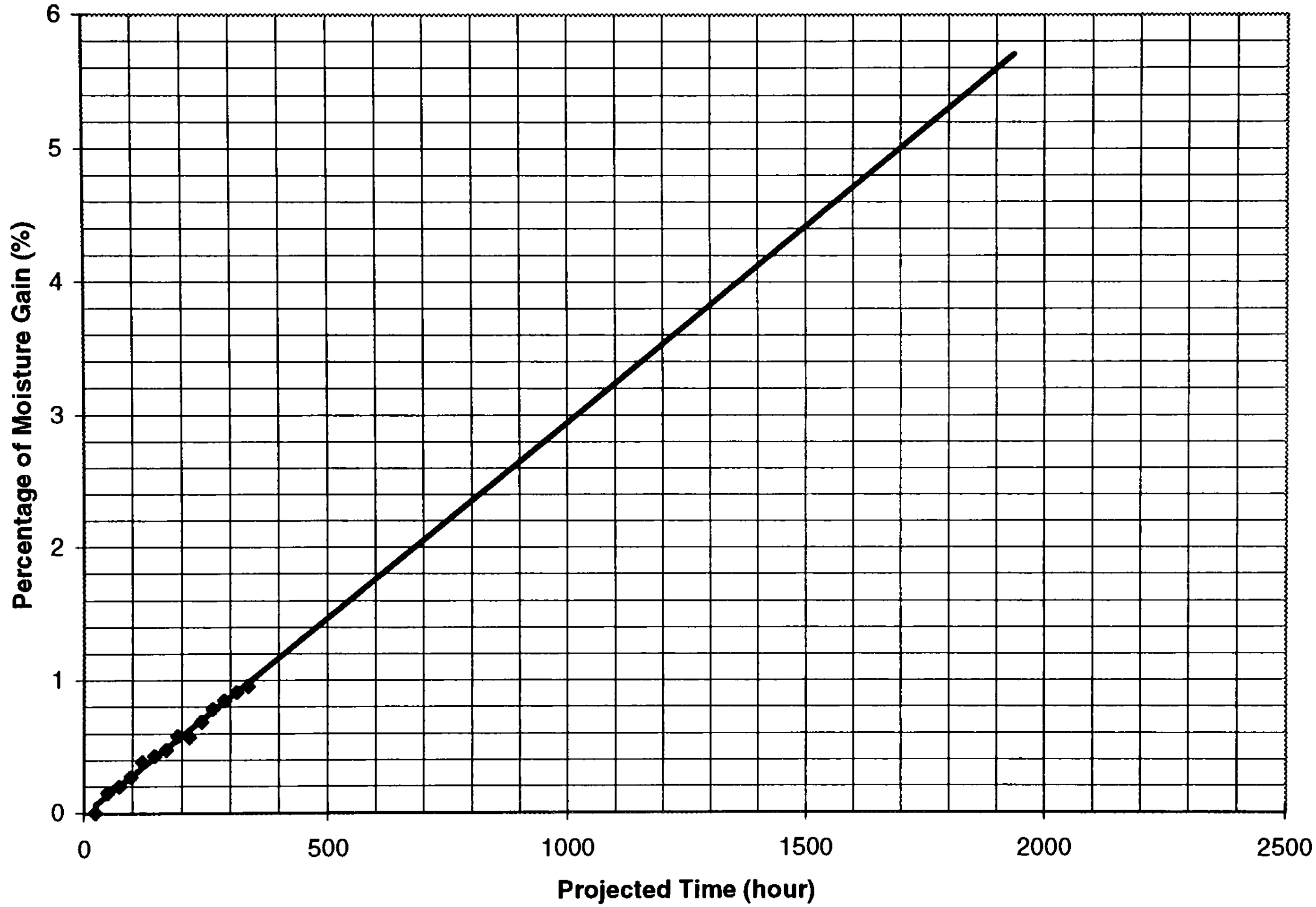
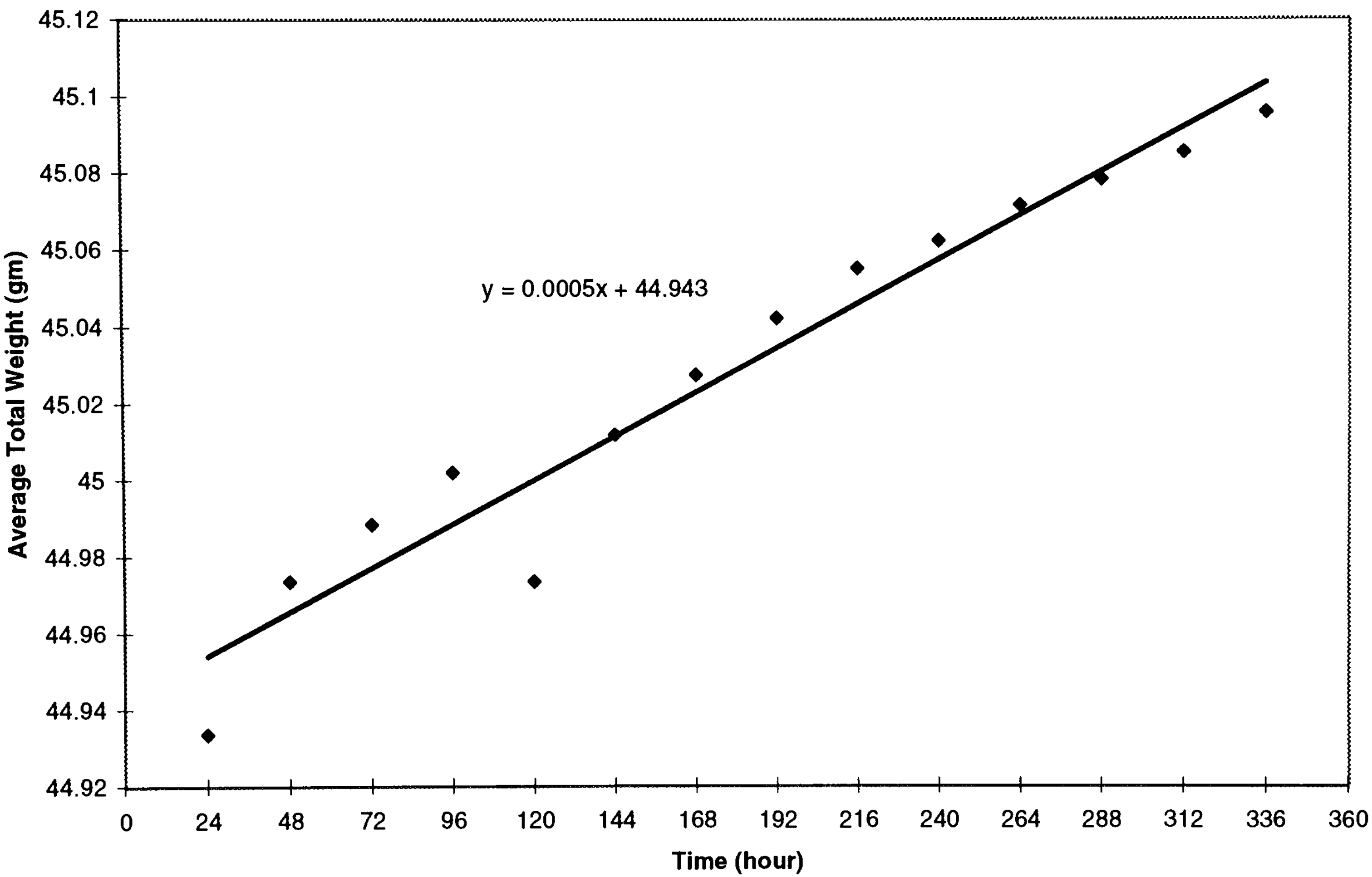


Table 3. Changes in Total Weight of Hermetically sealed biscuits

Sample	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14
1	45.543	45.612	45.565	45.584	45.59	45.593	45.61	45.625	45.633	45.642	45.641	45.65	45.677	45.682
2	44.898	44.973	44.943	44.95	44.946	44.961	44.983	44.983	44.996	45.007	45.017	45.015	45.032	45.07
3	44.779	44.824	44.808	44.819	44.829	44.835	44.838	44.858	44.891	44.899	44.964	44.941	44.947	44.928
4	36.82	36.871	36.873	36.851	36.869	36.877	36.88	36.981	36.897	36.922	36.963	36.949	36.923	36.941
5	44.952	44.976	45.091	45.056	45.053	45.036	45.029	45.059	45.072	45.074	45.09	45.094	45.099	45.124
6	41.658	41.677	41.677	41.704	41.72	41.714	41.772	41.791	41.749	41.78	41.757	41.761	41.768	41.797
7	44.966	45.015	44.986	45.031	45.051	45.023	45.019	45.05	45.06	45.128	45.123	45.102	45.087	45.089
8	49.035	49.068	49.094	49.079	49.113	49.119	49.122	49.158	49.158	49.206	49.208	49.212	49.229	49.218
9	44.992	45.063	45.106	45.106	45.011	45.05	45.1	45.073	45.089	45.07	45.094	45.08	45.094	45.079
10	44.998	45.032	45.02	45.044	45.071	45.084	45.108	45.117	45.167	45.166	45.159	45.143	45.178	45.168
11	44.491	44.526	44.531	44.535	44.542	44.565	44.589	44.589	44.61	44.617	44.628	44.68	44.646	44.665
12	45.498	45.561	45.558	45.557	45.583	45.582	45.583	45.594	45.611	45.625	45.628	45.662	45.636	45.663
13	45.801	45.873	45.843	45.875	45.885	45.882	45.905	45.924	45.92	45.946	45.968	45.988	45.97	45.982
14	45.538	45.568	45.572	45.696	45.634	45.645	45.643	45.684	45.673	45.669	45.709	45.706	45.728	45.745
15	44.849	44.88	44.884	44.891	44.916	44.932	44.973	44.963	44.977	44.999	45.004	44.994	45.037	45.03
16	44.495	44.545	44.543	44.558	44.57	44.576	44.583	44.584	44.648	44.601	44.601	44.622	44.649	44.666
17	45.374	45.399	45.397	45.553	45.439	45.427	45.449	45.462	45.475	45.515	45.52	45.499	45.534	45.566
18	45.281	45.308	45.331	45.356	45.394	45.406	45.405	45.386	45.413	45.417	45.418	45.431	45.451	45.46
19	45.149	45.18	45.191	45.201	45.348	45.274	45.267	45.257	45.314	45.268	45.275	45.294	45.301	45.33
20	45.523	45.513	45.536	45.548	45.558	45.572	45.57	45.602	45.62	45.598	45.629	45.63	45.644	45.656
21	45.361	45.391	45.407	45.4	45.424	45.438	45.438	45.464	45.509	45.49	45.497	45.549	45.533	45.529
22	45.375	45.368	45.678	45.574	45.517	45.466	45.445	45.431	45.467	45.468	45.485	45.478	45.505	45.508
23	45.498	45.51	45.519	45.596	45.548	45.601	45.605	45.615	45.676	45.632	45.628	45.616	45.616	45.623
24	45.802	45.844	45.858	45.873	45.874	45.877	45.889	45.912	45.923	46.051	45.958	45.944	45.99	45.996
25	45.258	45.282	45.291	45.316	45.335	45.353	45.367	45.361	45.384	45.36	45.383	45.389	45.408	45.422
26	45.489	45.518	45.538	45.534	45.564	45.573	45.601	45.62	45.648	45.627	45.64	45.646	45.671	45.68
27	44.934	44.985	45	44.987	44.026	45.042	45.177	45.066	45.058	45.097	45.096	45.081	45.122	45.119
28	45.607	45.68	45.665	45.661	45.661	45.681	45.693	45.723	45.76	45.723	45.735	45.82	45.77	45.764
29	44.656	44.714	44.718	44.699	44.711	44.721	44.73	44.757	44.763	44.761	44.792	44.781	44.813	44.816
30	45.387	45.449	45.43	45.425	45.425	45.452	45.457	45.577	45.497	45.517	45.538	45.595	45.505	45.557

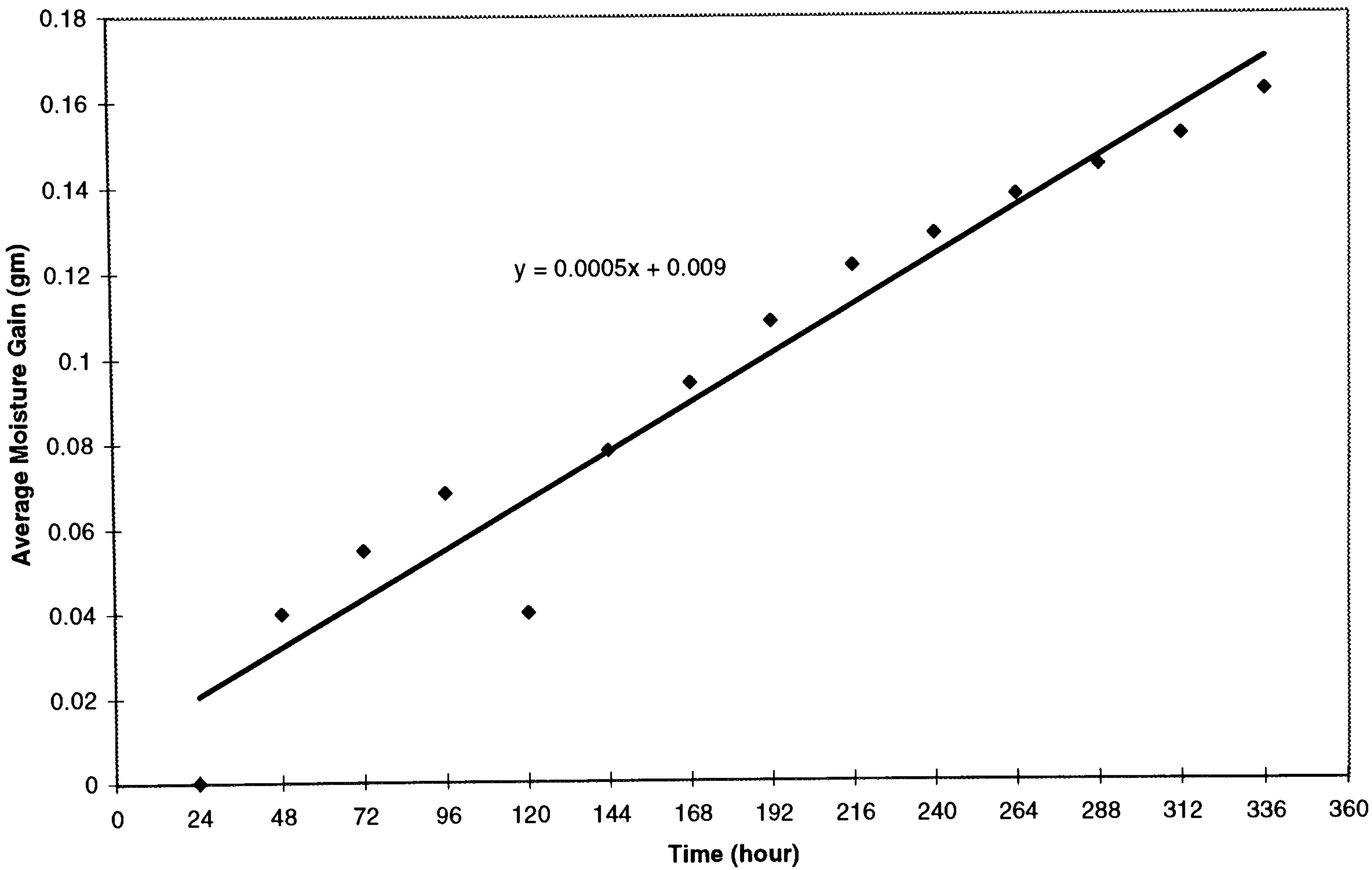
Graph 8. Average Total Weight of Hermetically Sealed Biscuits



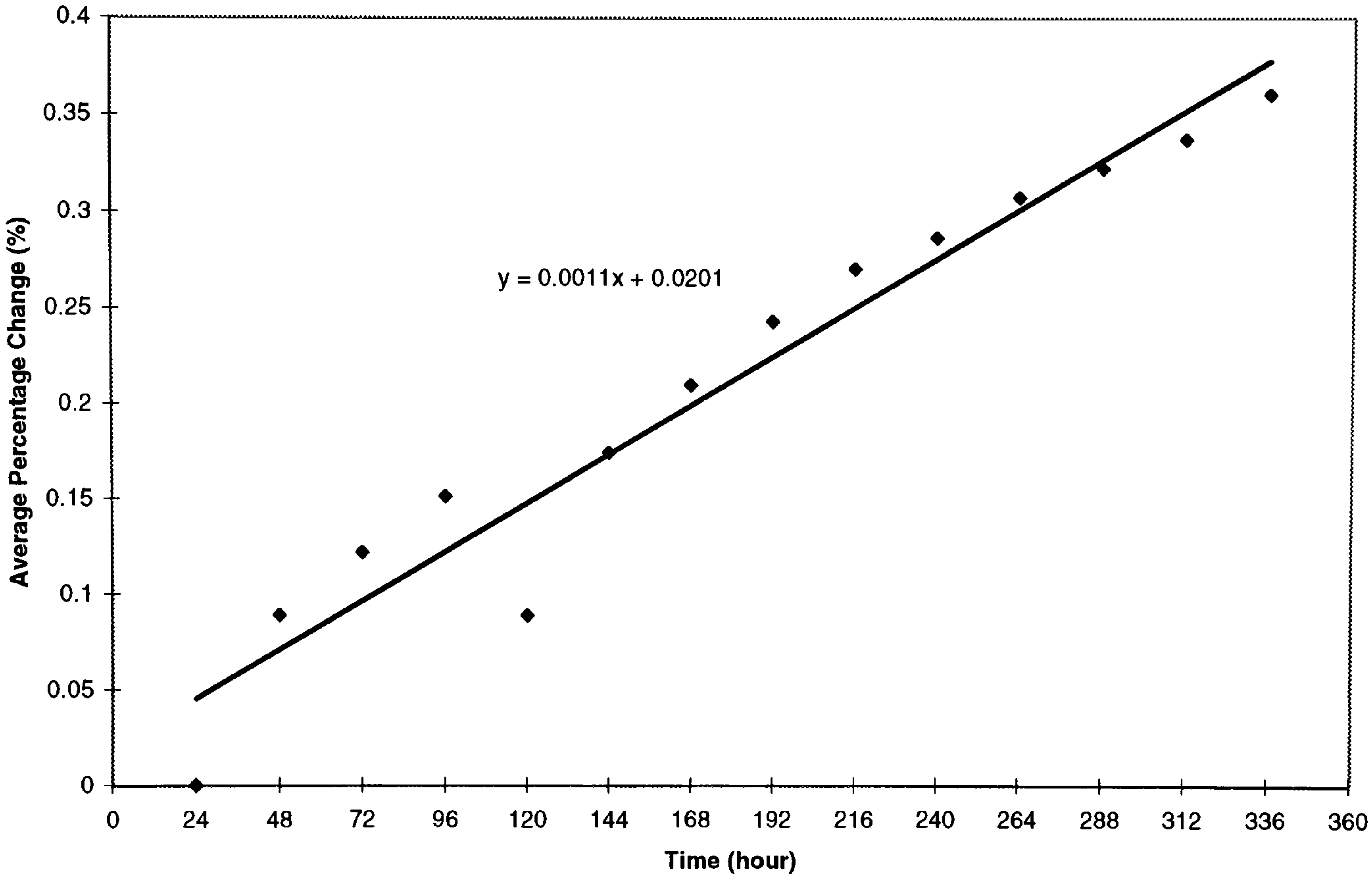
increases every day at a very slow rate according to its corresponding straight line: Y=0.0005x+0.009. This means that non hermetically sealed samples gained 0.003gm moisture /hour, where as hermetically sealed sample gained 0.0005gm moisture /hour (refer to graph 9).Moveover, the percent change in moisture gain provides a more direct indication of the biscuit moisture uptake behavior. As depicted in graph 10, when the average of percent moisture gain of the 30 samples is plotted as a function of time, a straight-line equation of Y=0.0011x + 0.0201 is obtained. The percent increase rate in moisture gain is very small (0.0011% moisture / hour) compared to the rate obtained for the non-hermetically sealed biscuits (0.003% moisture / hour). Graph 11 depicts this comparison.

Graph 12 shows projected shelf life of the biscuits sealed hermetically. The biscuits are expected to reach the moisture upper limit after about 216.67 days (approximately 5200 hours) when the moisture content of the biscuits are expected to be 5.6%. Since non-hermetically sealed biscuits are expected to reach 5.6% moisture content by 76.67 days (1840 hours), they gain moisture with a rate that is 3 times faster than the hermetically sealed biscuits. Therefore hermetically sealed biscuits are expected to have a shelf life that is about 3 times longer than non-hermetically sealed biscuits.

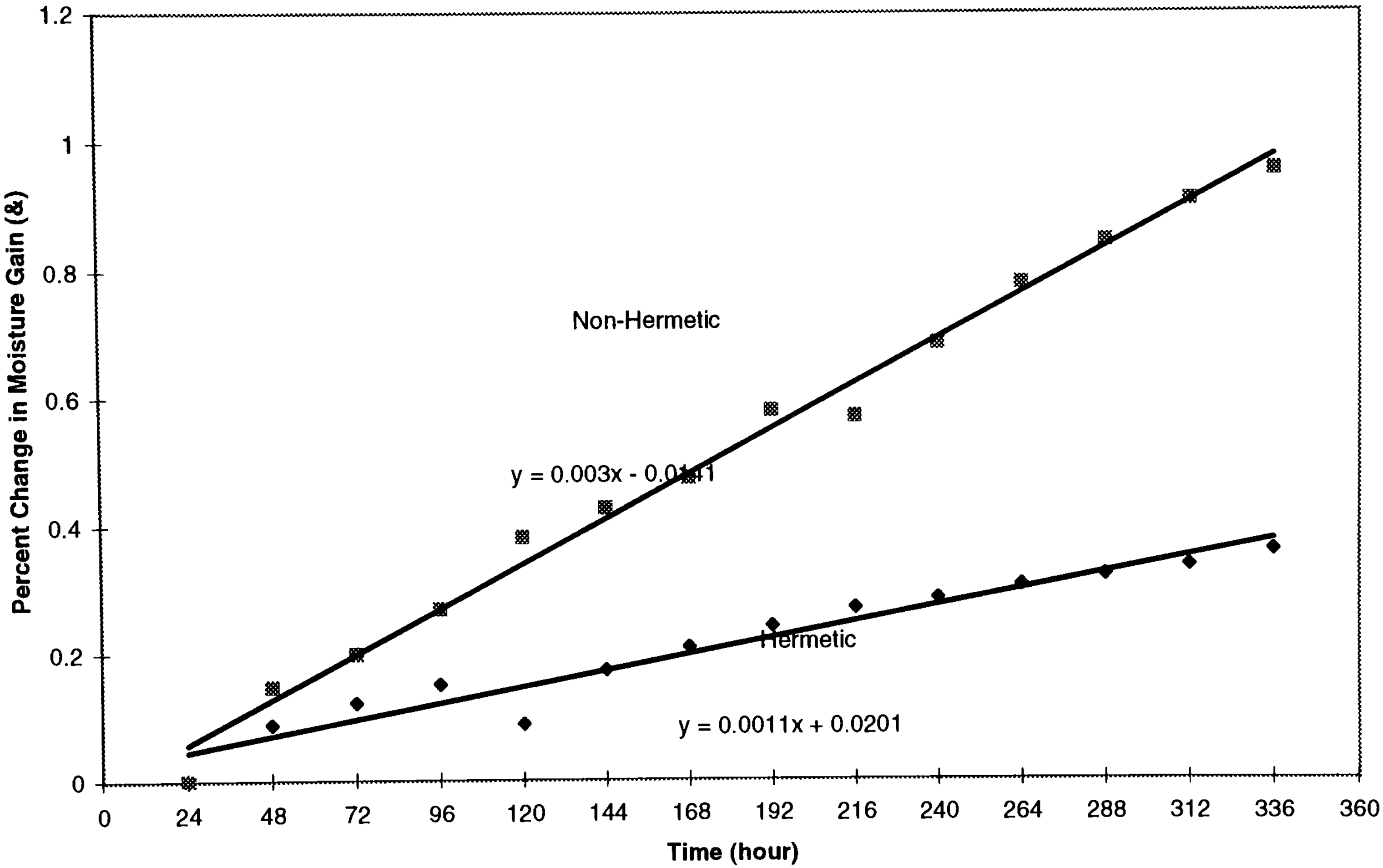
Graph 9. Average Gain in Moisture by Hermetically Sealed Biscuits



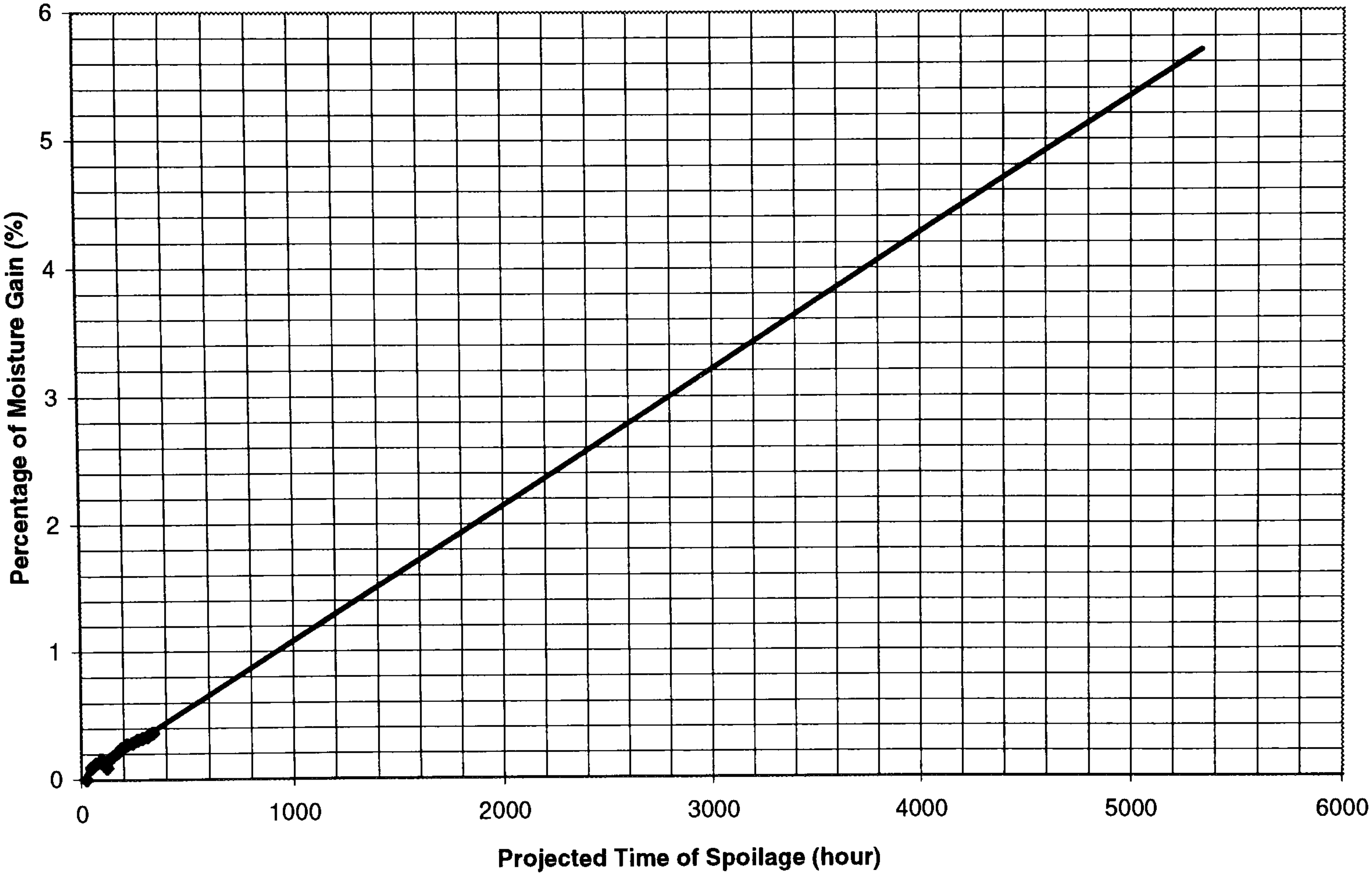
Graph 10. Average Percent Change in Moisture Gain by Hermetically Sealed Biscuits



Graph 11. Comparison in Percent Increase Rate in Moisture Gain Between Hermetically and Non-Hermetically Sealed Samples



Graph 12. Projected Tim Till 5.6% Increase in Moisture Gain of Hermetically Sealed Biscuits



3.4. ANOVA TEST

With the ANOVA test, the moisture gain data (Tables 2 and 3) for both samples was statistically compared to examine whether or not their means are significantly different at the significance level of 0.05. The result of the ANOVA test (Appendix D) shows a p-value of 0.0009 which is smaller than the significance level of 0.05 upon which the null hypothesis was based. Therefore, the null hypothesis must be rejected and the alternative hypothesis must be accepted. Hence it can be concluded that the moisture gain of hermetically sealed and non-hermetically sealed biscuits are significantly different.

3.5. CONCLUSION

This case study is directed at determining a possible cause for the quality deterioration of a particular biscuit product that is marketed in humid markets (South Eastern Asian countries). Analysis and testing of the biscuit product lead to the conclusion that the sealing method can be involved in promoting moisture gain of the biscuit product, and hence contribute to the product's textural deterioration.

There is a drastic difference in moisture gain between hermetically-sealed and non-hermetically sealed biscuits. The ANOVA test of this study does not support the null hypothesis but it supports the alternative hypothesis. Therefore, at a significance level of 0.05, there is a significant difference in moisture gain between hermetically sealed and non-hermetically sealed biscuits. Also, the moisture gain data of the samples show that hermetically sealed biscuits have a significantly lower moisture gain than the non-hermetically sealed biscuits. As a result, hermetic sealing is considered to extend the shelf life of this particular biscuit product by about three times that of non-hermetic sealing.

There are many factors that may have direct influence on moisture uptake of these biscuit products. One of such factors is the formulating recipe of the biscuits. Although this is beyond the scope of this study, further research in its effect and role in moisture gain is needed. In addition, the material used in this product, OPP, is considered as a good moisture barrier; however, its integrity is compromised when non-hermetic sealing is used with this material, particularly for this biscuit product. This is a waste of economic resources that can be saved. Therefore a search for another, cheaper material than OPP to be used in hermetically sealing these biscuits can optimize the economic feasibility for producing this product. Another issue that should be taken into consideration is the cost of the establishing hermetic sealing equipment along with the biscuits' production line. The cost can be economically unfeasible for this particular case.

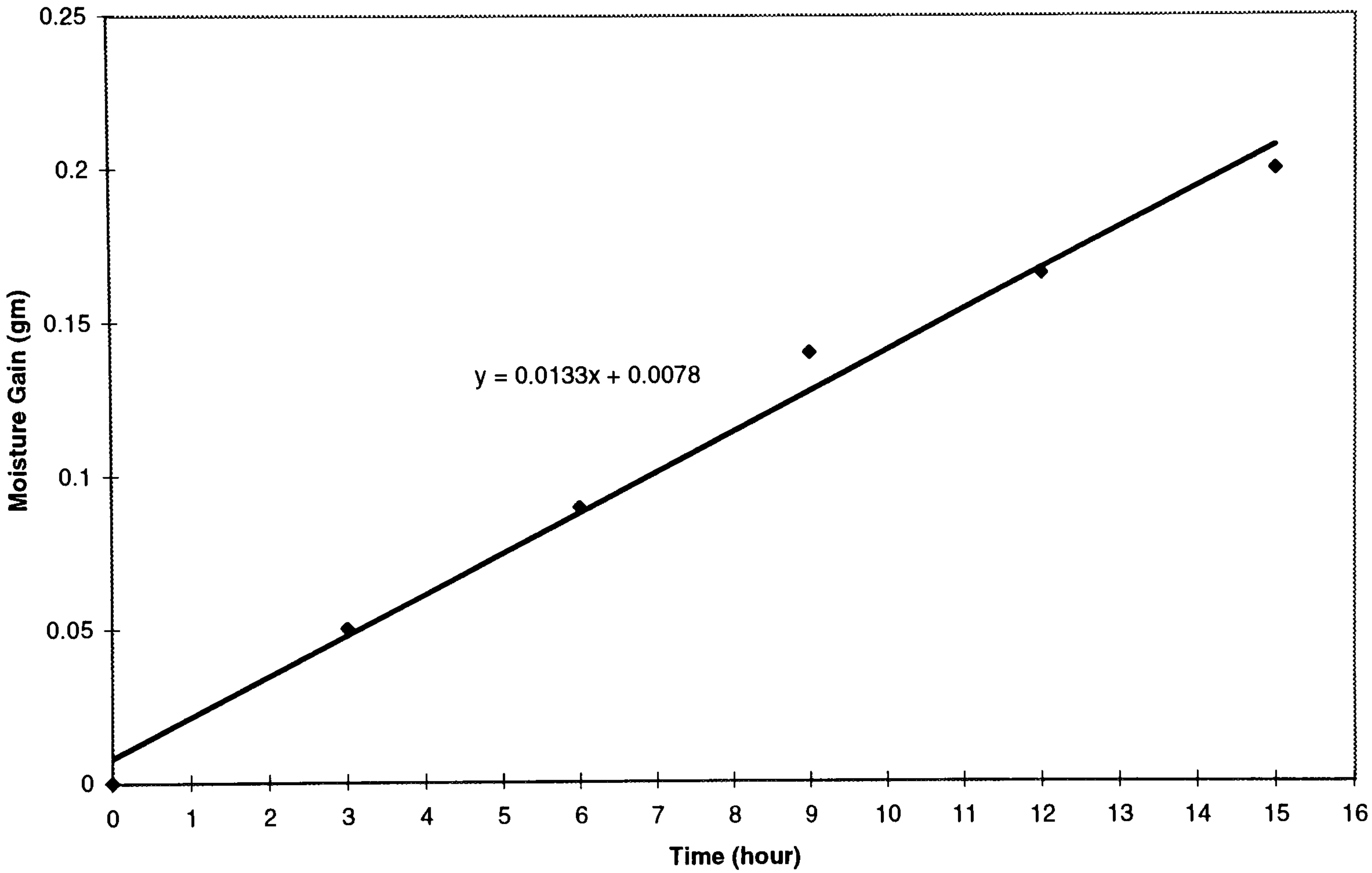
Appendices

Appendix A: Unpackaged Biscuits

A- Table of Moisture Gain (gm)

Sample Number	3 Hours	6 Hours	9 Hours	12 Hours	15 Hours
1	0.0541	0.11	0.148	0.1833	0.2066
2	0.0512	0.1094	0.1494	0.1781	0.2059
3	0.0503	0.1077	0.1356	0.1724	0.2058
4	0.0502	0.1076	0.1453	0.1711	0.2131
5	0.0508	0.106	0.1438	0.1687	0.204
6	0.0526	0.1071	0.1444	0.1696	0.2041
7	0.0467	0.0982	0.135	0.1594	0.1922
8	0.0524	0.1045	0.1393	0.1658	0.1947
9	0.0546	-0.2939	0.147	0.174	0.208
10	0.0535	0.1098	0.1517	0.1752	0.21
11	0.0498	0.1062	0.1449	0.1727	0.2096
12	0.0431	0.0968	0.1316	0.156	0.1924
13	0.0429	0.0975	0.1321	0.1565	0.1915
14	0.0426	0.0944	0.1288	0.1527	0.1868
15	0.0427	0.0934	0.1275	0.1506	0.1845
16	0.0443	0.0947	0.1268	0.1498	0.1833
17	0.0442	0.0917	0.1243	0.1472	0.1807
18	0.0457	0.0941	0.1261	0.1494	0.1829
19	0.0461	0.0945	0.1276	0.151	0.1834
20	0.0474	0.101	0.1391	0.1639	0.1972
21	0.0555	0.1119	0.156	0.1775	0.1941
22	0.0523	0.1072	0.1479	0.1708	0.2073
23	0.0522	0.1054	0.1464	0.1688	0.2061
24	0.0519	0.1034	0.1432	0.1664	0.2058
25	0.0539	0.1063	0.1449	0.1684	0.2032
26	0.0533	0.103	0.1405	0.1647	0.1994
27	0.0526	0.1008	0.1385	0.1632	0.2016
28	0.0567	0.1066	0.1456	0.1704	0.2091
29	0.0568	0.1059	0.1446	0.1714	0.2097
30	0.0544	0.1076	0.1498	0.1829	0.2233

B- Average Gain in Moisture



C- Table of Percent Moisture Gain

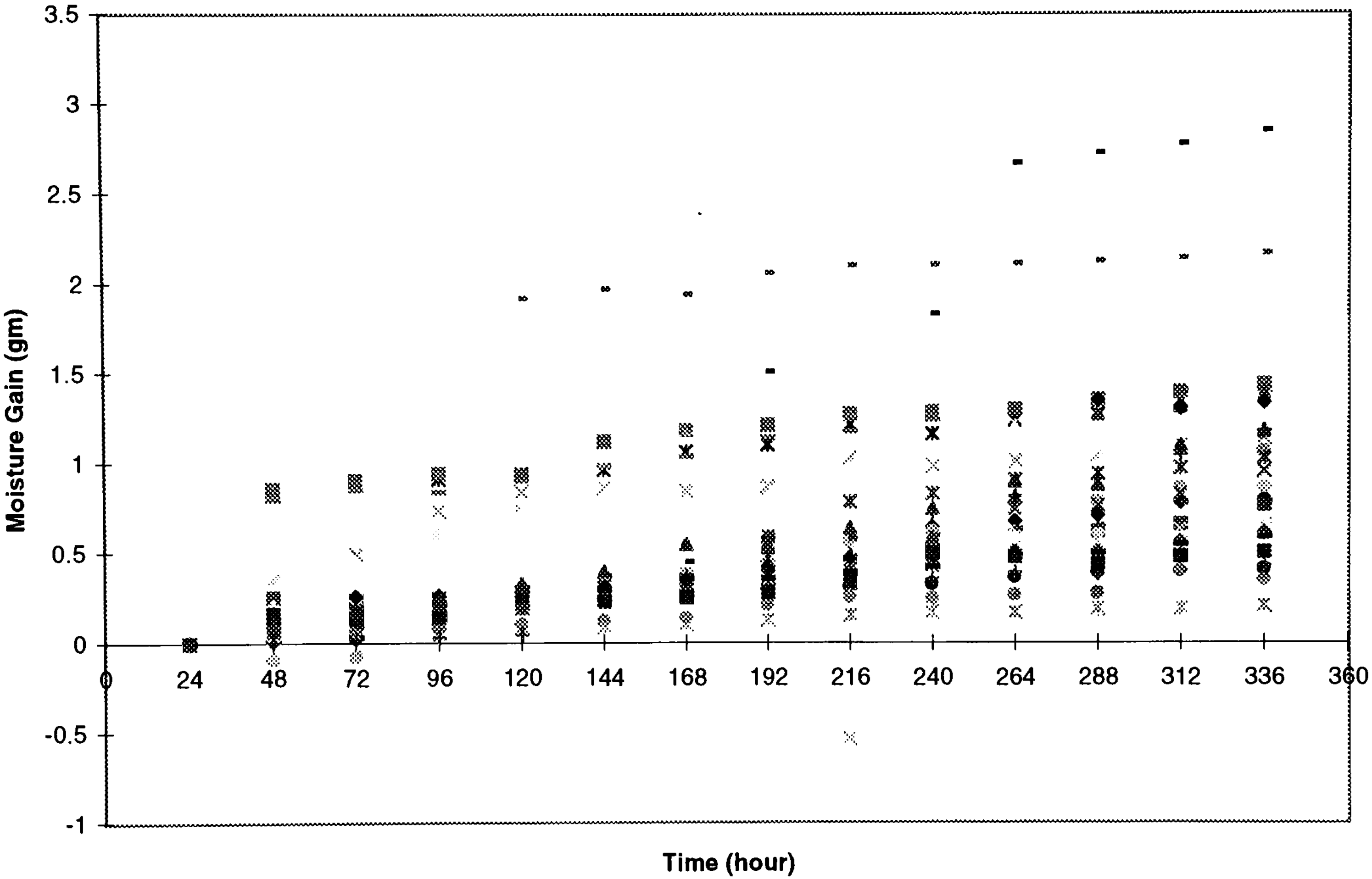
Sample Number	3 Hours	6 Hours	9 Hours	12 Hours	15 Hours
1	1.525362	3.101475	4.172893	5.168185	5.825133
2	1.414912	3.023269	4.128669	4.921793	5.690046
3	1.399477	2.996494	3.772745	4.796617	5.725892
4	1.391083	2.981683	4.026381	4.74132	5.905174
5	1.392124	2.904826	3.940698	4.623058	5.59042
6	1.444499	2.941176	3.965508	4.657549	5.604987
7	1.33696	2.811337	3.864873	4.563413	5.502433
8	1.48758	2.966643	3.954578	4.706884	5.527324
9	1.486928	-8.00381	4.003268	4.738562	5.664488
10	1.542409	3.165542	4.373522	5.051029	6.054316
11	1.384641	2.952789	4.028805	4.801757	5.827726
12	1.226313	2.754225	3.744381	4.438627	5.474307
13	1.202186	2.73224	3.701836	4.385596	5.3664
14	1.188318	2.633267	3.592848	4.259533	5.210745
15	1.198462	2.62146	3.578546	4.226894	5.178366
16	1.251342	2.67499	3.581719	4.231399	5.177674
17	1.251522	2.596483	3.519551	4.167964	5.116516
18	1.271705	2.618544	3.509016	4.157391	5.089604
19	1.290485	2.645355	3.571928	4.226969	5.133947
20	1.304635	2.779919	3.828581	4.511175	5.427722
21	1.583091	3.191853	4.449769	5.063038	5.536539
22	1.454475	2.981256	4.113132	4.749986	5.765059
23	1.440596	2.90879	4.040293	4.658479	5.687871
24	1.451139	2.891095	4.003914	4.652593	5.754229
25	1.484767	2.928213	3.991516	4.638863	5.597488
26	1.487497	2.874526	3.921076	4.59645	5.564858
27	1.459489	2.796892	3.842952	4.528302	5.593785
28	1.557864	2.928893	4.00044	4.681833	5.745137
29	1.577602	2.94134	4.01622	4.760582	5.824353
30	1.547125	3.060122	4.260281	5.201638	6.350606

Appendix B: Non-hermetically-Sealed Packages

A- Table of Moisture Gain (gm)

Sample	Time (hour)													
Number	24	48	72	96	120	144	168	192	216	240	264	288	312	336
1	0	0.13	0.21	0.241	0.264	0.306	0.333	0.582	0.614	0.645	0.676	0.707	0.781	0.801
2	0	0.254	0.237	0.247	0.273	0.324	0.357	0.398	0.457	0.509	0.59	0.617	0.66	0.767
3	0	0.114	0.181	0.175	0.219	0.256	0.303	0.335	0.365	0.397	0.481	0.588	0.594	0.627
4	0	0.139	0.215	0.225	0.274	0.312	0.364	0.424	-0.536	0.497	0.525	0.575	0.627	0.658
5	0	0.165	0.215	0.912	0.941	0.965	1.064	1.104	1.213	1.162	1.238	1.265	1.342	1.427
6	0	0.013	0.026	0.162	0.264	0.243	0.277	0.295	0.306	0.323	0.363	0.388	0.397	0.408
7	0	0.145	0.142	0.155	0.243	0.229	0.304	0.293	0.296	0.353	0.391	0.379	0.405	0.429
8	0	0.016	0.032	0.214	0.277	0.376	0.451	1.514	0.577	1.831	2.671	2.726	2.777	2.848
9	0	0.798	0.855	0.843	0.922	0.982	1.042	1.146	1.179	1.24	1.322	1.377	1.394	1.398
10	0	0.149	0.238	0.262	0.283	0.327	0.378	0.441	0.473	0.573	0.614	0.611	0.854	0.863
11	0	0.056	0.147	0.153	0.19	0.283	0.341	0.332	0.418	0.461	0.571	0.532	0.577	0.64
12	0	0.207	0.292	0.617	0.774	0.815	0.881	0.93	1.014	1.077	1.201	1.265	1.441	1.413
13	0	0.349	0.495	0.731	0.844	0.86	0.846	0.869	1.027	0.984	1.009	1.036	1.096	1.135
14	0	0.029	0.047	0.05	0.08	0.086	0.103	0.122	0.152	0.166	0.166	0.182	0.191	0.203
15	0	-0.091	-0.075	0.101	0.269	0.328	0.383	0.445	0.558	0.618	0.767	0.786	0.853	1.063
16	0	0.119	0.241	0.222	0.249	0.302	0.308	0.383	0.413	0.439	0.501	0.521	0.575	0.605
17	0	0.135	0.181	0.162	0.196	0.233	0.262	0.594	0.578	0.597	0.633	0.653	0.777	0.787
18	0	0.098	0.165	0.174	0.203	0.249	0.273	0.316	0.376	0.418	0.47	0.487	0.542	0.589
19	0	0.064	0.114	0.156	0.19	0.234	0.289	0.363	0.39	0.436	0.486	0.509	0.563	0.613
20	0	0.857	0.907	0.944	0.932	1.128	1.184	1.215	1.273	1.284	1.297	1.346	1.392	1.435
21	0	0.095	0.187	0.229	0.251	0.302	0.362	0.447	0.489	0.589	0.803	1.268	1.313	1.379
22	0	0.065	0.113	0.144	0.194	0.24	0.288	0.367	0.403	0.431	0.746	0.764	0.824	0.952
23	0	0.076	0.142	0.193	0.269	0.312	0.348	0.593	0.787	0.831	0.905	0.938	0.972	1.027
24	0	0.091	0.062	0.08	0.099	0.117	0.131	0.21	0.251	0.243	0.266	0.271	0.399	0.346
25	0	0.006	0.02	0.032	0.043	0.237	0.373	0.499	0.608	0.715	0.817	0.91	1.045	1.18
26	0	0.056	0.094	0.128	1.922	1.973	1.94	2.063	2.103	2.105	2.114	2.125	2.14	2.167
27	0	0.116	0.129	0.162	0.305	0.296	0.356	0.357	0.396	0.424	0.489	0.501	0.549	0.587
28	0	0.08	0.258	0.264	0.305	0.312	0.353	0.417	0.469	0.487	0.504	1.348	1.3	1.33
29	0	0.163	0.138	0.144	0.258	0.23	0.25	0.281	0.346	0.502	0.48	0.44	0.483	0.505
30	0	0.103	0.178	0.243	0.328	0.396	0.551	0.551	0.642	0.749	0.899	0.88	1.098	1.174

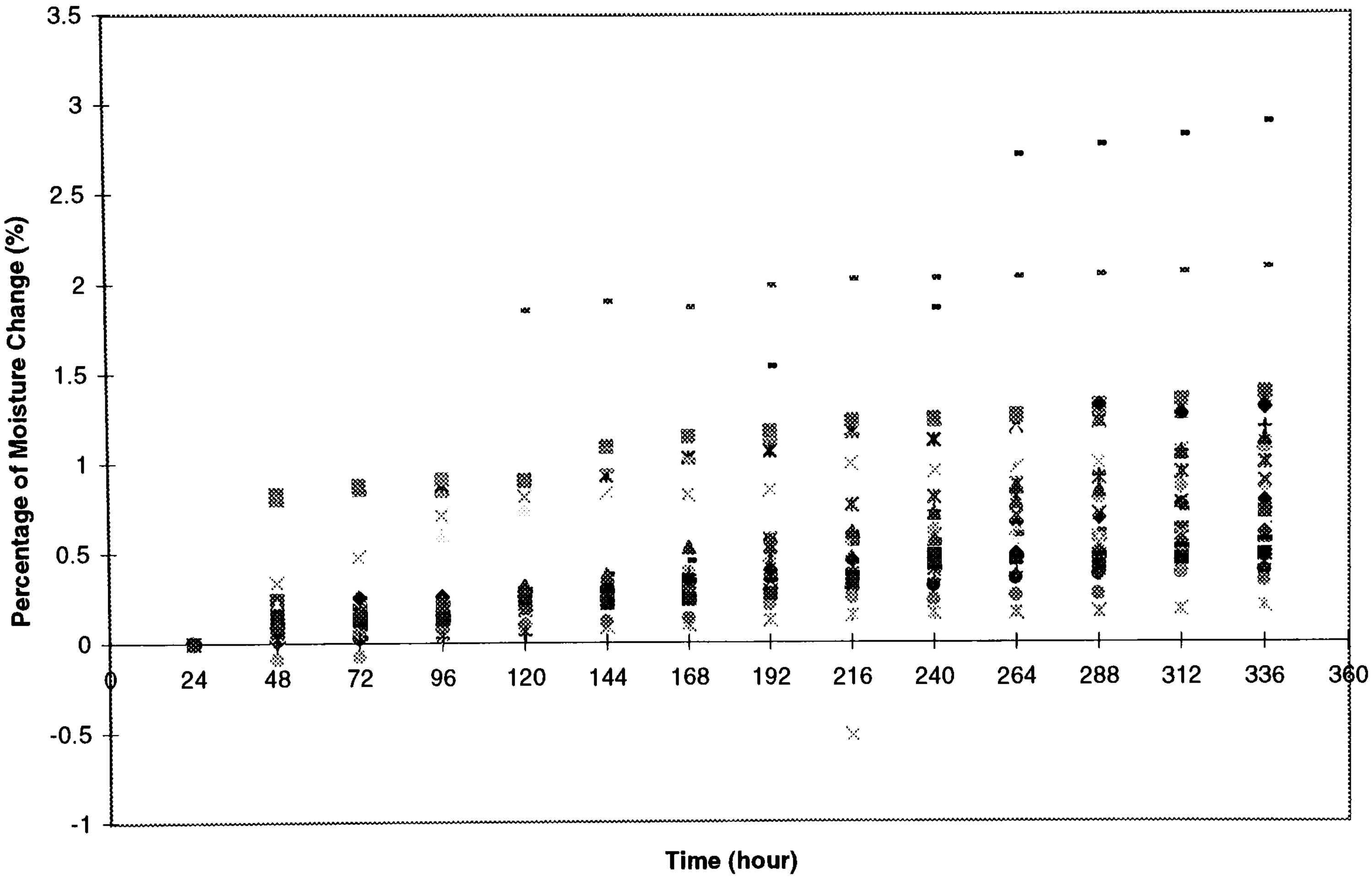
B- Graph of Moisture Gain



C- Table of Pecent Moisture Gain

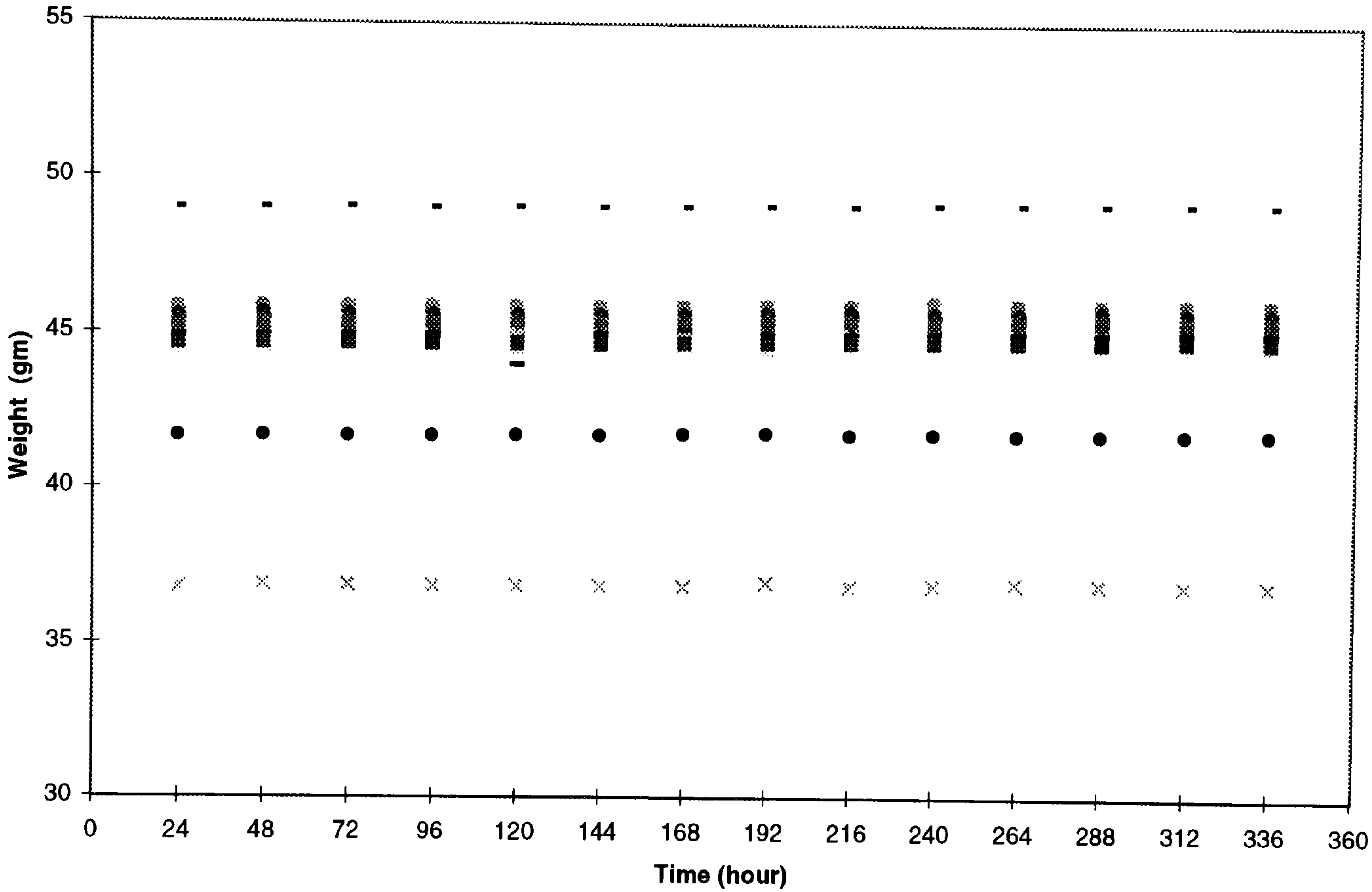
Sample	Time (hour)													
Number	24	48	72	96	120	144	168	192	216	240	264	288	312	336
1	0	0.1274	0.2058	0.2362	0.2587	0.2999	0.3263	0.5703	0.6017	0.6321	0.6624	0.6928	0.7653	0.7849
2	0	0.2415	0.2253	0.2348	0.2596	0.308	0.3394	0.3784	0.4345	0.4839	0.5609	0.5866	0.6275	0.7292
3	0	0.1106	0.1755	0.1697	0.2124	0.2483	0.2938	0.3249	0.354	0.385	0.4665	0.5702	0.576	0.608
4	0	0.1329	0.2055	0.2151	0.262	0.2983	0.348	0.4054	-0.5124	0.4751	0.5019	0.5497	0.5994	0.6291
5	0	0.1596	0.2079	0.8819	0.9099	0.9331	1.0289	1.0675	1.1729	1.1236	1.1971	1.2232	1.2977	1.3799
6	0	0.0126	0.0252	0.1568	0.2555	0.2352	0.2681	0.2855	0.2962	0.3126	0.3514	0.3756	0.3843	0.3949
7	0	0.1418	0.1389	0.1516	0.2377	0.224	0.2973	0.2865	0.2895	0.3452	0.3824	0.3707	0.3961	0.4196
8	0	0.0163	0.0326	0.2178	0.2819	0.3827	0.4591	1.541	0.5873	1.8637	2.7187	2.7747	2.8266	2.8989
9	0	0.7799	0.8356	0.8239	0.9011	0.9597	1.0183	1.12	1.1522	1.2118	1.292	1.3457	1.3623	1.3662
10	0	0.1488	0.2377	0.2617	0.2827	0.3266	0.3776	0.4405	0.4724	0.5723	0.6133	0.6103	0.853	0.862
11	0	0.0538	0.1414	0.1471	0.1827	0.2721	0.3279	0.3192	0.4019	0.4433	0.5491	0.5116	0.5548	0.6154
12	0	0.2007	0.2831	0.5981	0.7503	0.7901	0.854	0.9015	0.983	1.044	1.1642	1.2263	1.3969	1.3698
13	0	0.3392	0.4811	0.7105	0.8204	0.8359	0.8223	0.8447	0.9982	0.9564	0.9807	1.007	1.0653	1.1032
14	0	0.0279	0.0453	0.0481	0.077	0.0828	0.0992	0.1175	0.1464	0.1598	0.1598	0.1752	0.1839	0.1955
15	0	-0.0925	-0.0763	0.1027	0.2735	0.3335	0.3895	0.4525	0.5674	0.6284	0.78	0.7993	0.8674	1.081
16	0	0.1148	0.2326	0.2143	0.2403	0.2915	0.2973	0.3696	0.3986	0.4237	0.4835	0.5028	0.5549	0.5839
17	0	0.1282	0.1719	0.1538	0.1861	0.2212	0.2488	0.564	0.5488	0.5669	0.601	0.62	0.7378	0.7473
18	0	0.0932	0.157	0.1656	0.1932	0.2369	0.2598	0.3007	0.3578	0.3977	0.4472	0.4634	0.5157	0.5604
19	0	0.0638	0.1136	0.1555	0.1894	0.2333	0.2881	0.3618	0.3888	0.4346	0.4845	0.5074	0.5612	0.6111
20	0	0.8323	0.8809	0.9168	0.9052	1.0955	1.1499	1.18	1.2363	1.247	1.2596	1.3072	1.3519	1.3937
21	0	0.0923	0.1817	0.2226	0.2439	0.2935	0.3518	0.4344	0.4752	0.5724	0.7804	1.2323	1.276	1.3402
22	0	0.0612	0.1063	0.1355	0.1826	0.2258	0.271	0.3454	0.3792	0.4056	0.702	0.7189	0.7754	0.8958
23	0	0.074	0.1383	0.1879	0.2619	0.3038	0.3388	0.5774	0.7663	0.8091	0.8812	0.9133	0.9464	0.9999
24	0	0.0886	0.0604	0.0779	0.0964	0.114	0.1276	0.2045	0.2445	0.2367	0.2591	0.2639	0.3886	0.337
25	0	0.0061	0.0203	0.0325	0.0437	0.2409	0.3792	0.5072	0.618	0.7268	0.8305	0.925	1.0622	1.1995
26	0	0.054	0.0907	0.1235	1.8548	1.904	1.8722	1.9909	2.0295	2.0314	2.0401	2.0507	2.0652	2.0912
27	0	0.1129	0.1255	0.1577	0.2968	0.2881	0.3465	0.3474	0.3854	0.4127	0.4759	0.4876	0.5343	0.5713
28	0	0.0783	0.2525	0.2583	0.2985	0.3053	0.3454	0.4081	0.4589	0.4766	0.4932	1.3191	1.2721	1.3015
29	0	0.1576	0.1334	0.1392	0.2495	0.2224	0.2417	0.2717	0.3345	0.4854	0.4641	0.4254	0.467	0.4883
30	0	0.0988	0.1708	0.2332	0.3147	0.38	0.5287	0.5287	0.616	0.7186	0.8626	0.8443	1.0535	1.1264

D- Graph of Percent Moisture Gain



Appendix C: Hermetically-Sealed Packages

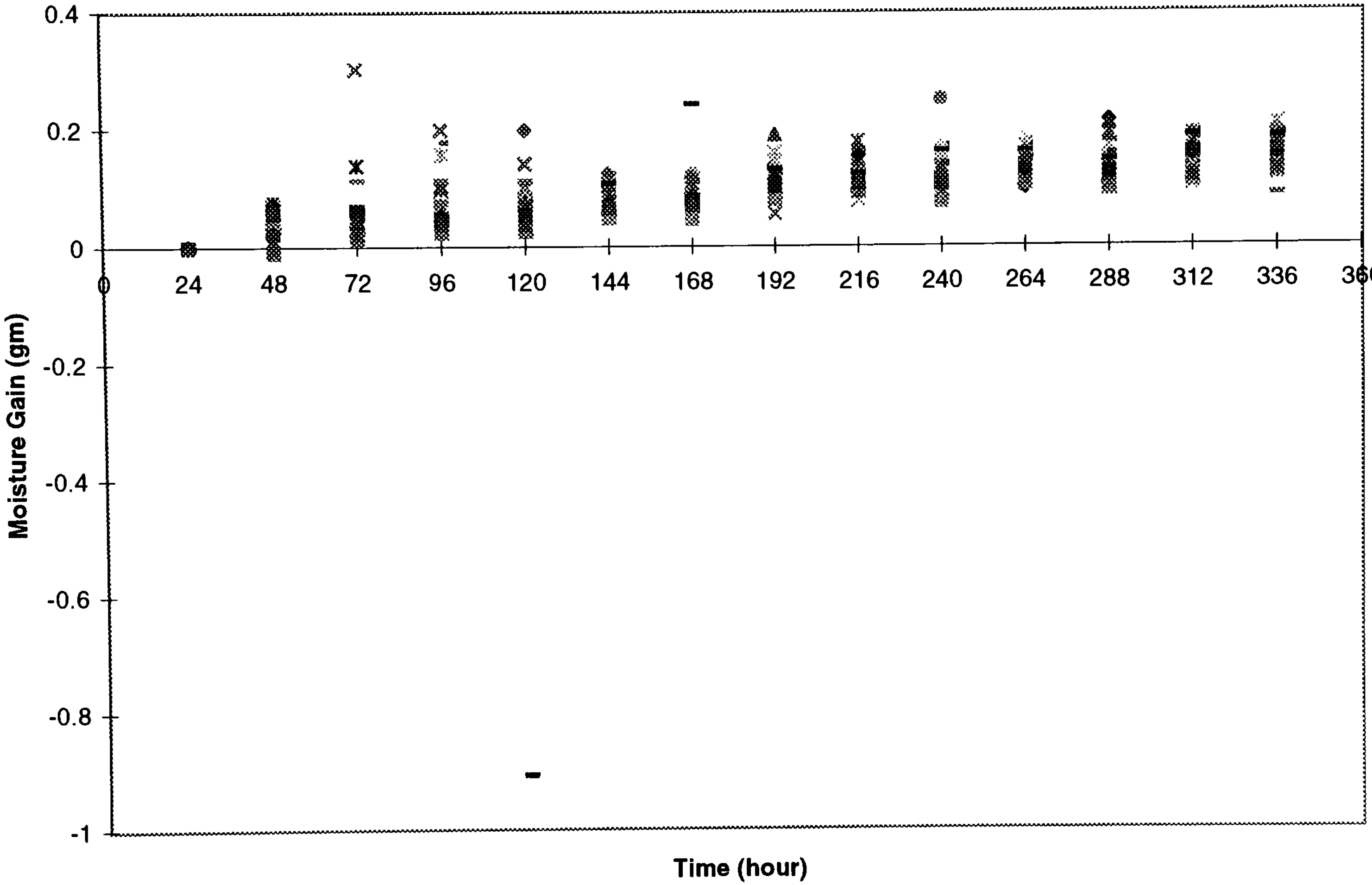
A- Graph of Changes in Total Weight



B- Table of Moisture Gain (gm)

Sample	Time (hours)													
Number	24	48	72	96	120	144	168	192	216	240	264	288	312	336
1	0	0.069	0.022	0.041	0.047	0.05	0.067	0.082	0.09	0.099	0.098	0.107	0.134	0.139
2	0	0.075	0.045	0.052	0.048	0.063	0.085	0.085	0.098	0.109	0.119	0.117	0.134	0.172
3	0	0.045	0.029	0.04	0.05	0.056	0.059	0.079	0.112	0.12	0.185	0.162	0.168	0.149
4	0	0.051	0.053	0.031	0.049	0.057	0.06	0.161	0.077	0.102	0.143	0.129	0.103	0.121
5	0	0.024	0.139	0.104	0.101	0.084	0.077	0.107	0.12	0.122	0.138	0.142	0.147	0.172
6	0	0.019	0.019	0.046	0.062	0.056	0.114	0.133	0.091	0.122	0.099	0.103	0.11	0.139
7	0	0.049	0.02	0.065	0.085	0.057	0.053	0.084	0.094	0.162	0.157	0.136	0.121	0.123
8	0	0.033	0.059	0.044	0.078	0.084	0.087	0.123	0.123	0.171	0.173	0.177	0.194	0.183
9	0	0.071	0.114	0.114	0.019	0.058	0.108	0.081	0.097	0.078	0.102	0.088	0.102	0.087
10	0	0.034	0.022	0.046	0.073	0.086	0.11	0.119	0.169	0.168	0.161	0.145	0.18	0.17
11	0	0.035	0.04	0.044	0.051	0.074	0.098	0.098	0.119	0.126	0.137	0.189	0.155	0.174
12	0	0.063	0.06	0.059	0.085	0.084	0.085	0.096	0.113	0.127	0.13	0.164	0.138	0.165
13	0	0.072	0.042	0.074	0.084	0.081	0.104	0.123	0.119	0.145	0.167	0.187	0.169	0.181
14	0	0.03	0.034	0.158	0.096	0.107	0.105	0.146	0.135	0.131	0.171	0.168	0.19	0.207
15	0	0.031	0.035	0.042	0.067	0.083	0.124	0.114	0.128	0.15	0.155	0.145	0.188	0.181
16	0	0.05	0.048	0.063	0.075	0.081	0.088	0.089	0.153	0.106	0.106	0.127	0.154	0.171
17	0	0.025	0.023	0.179	0.065	0.053	0.075	0.088	0.101	0.141	0.146	0.125	0.16	0.192
18	0	0.027	0.05	0.075	0.113	0.125	0.124	0.105	0.132	0.136	0.137	0.15	0.17	0.179
19	0	0.031	0.042	0.052	0.199	0.125	0.118	0.108	0.165	0.119	0.126	0.145	0.152	0.181
20	0	-0.01	0.013	0.025	0.035	0.049	0.047	0.079	0.097	0.075	0.106	0.107	0.121	0.133
21	0	0.03	0.046	0.039	0.063	0.077	0.077	0.103	0.148	0.129	0.136	0.188	0.172	0.168
22	0	-0.007	0.303	0.199	0.142	0.091	0.07	0.056	0.092	0.093	0.11	0.103	0.13	0.133
23	0	0.012	0.021	0.098	0.05	0.103	0.107	0.117	0.178	0.134	0.13	0.118	0.118	0.125
24	0	0.042	0.056	0.071	0.072	0.075	0.087	0.11	0.121	0.249	0.156	0.142	0.188	0.194
25	0	0.024	0.033	0.058	0.077	0.095	0.109	0.103	0.126	0.102	0.125	0.131	0.15	0.164
26	0	0.029	0.049	0.045	0.075	0.084	0.112	0.131	0.159	0.138	0.151	0.157	0.182	0.191
27	0	0.051	0.066	0.053	-0.908	0.108	0.243	0.132	0.124	0.163	0.162	0.147	0.188	0.185
28	0	0.073	0.058	0.054	0.054	0.074	0.086	0.116	0.153	0.116	0.128	0.213	0.163	0.157
29	0	0.058	0.062	0.043	0.055	0.065	0.074	0.101	0.107	0.105	0.136	0.125	0.157	0.16
30	0	0.062	0.043	0.038	0.038	0.065	0.07	0.19	0.11	0.13	0.151	0.208	0.118	0.17

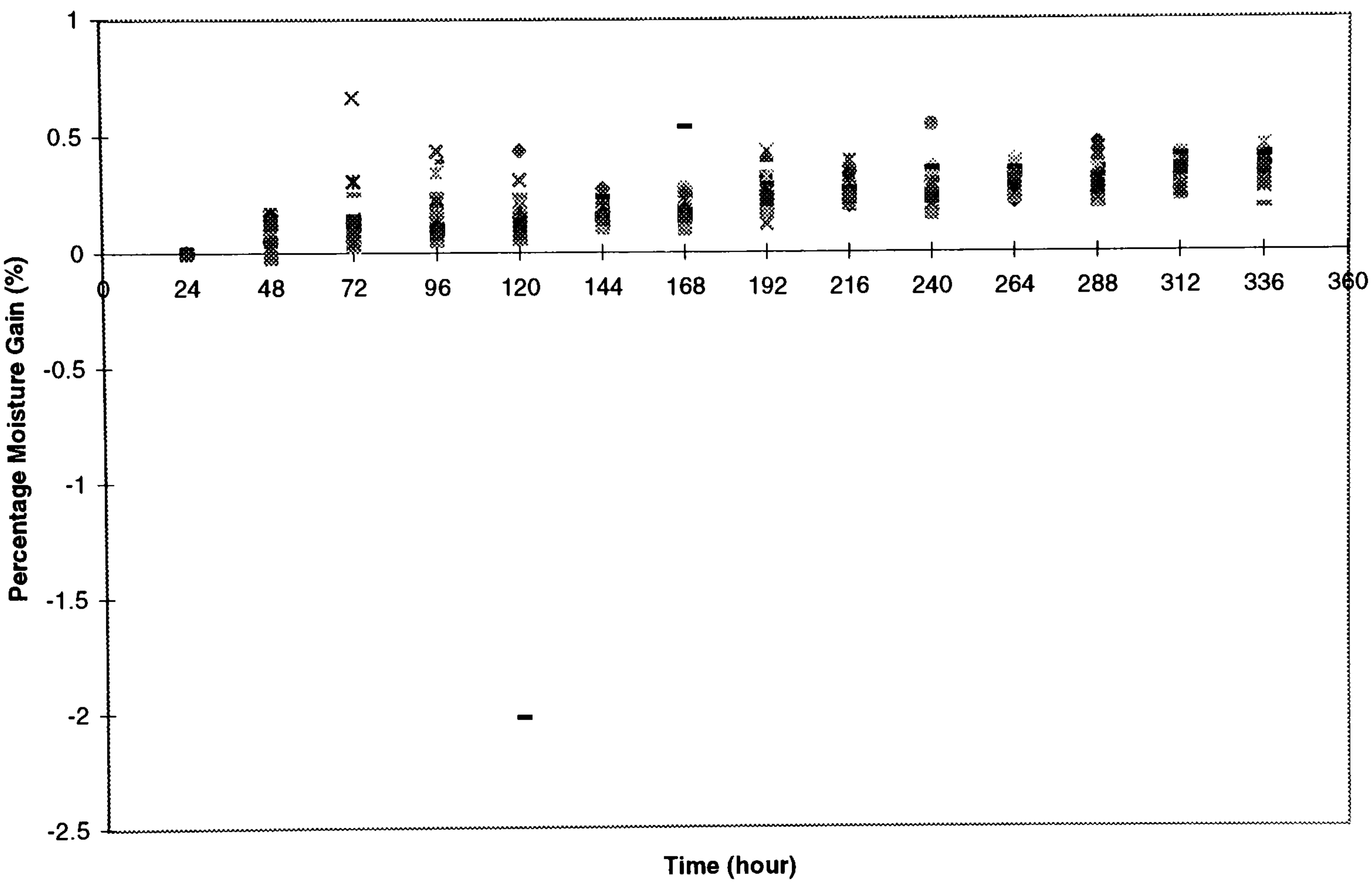
C- Graph of Moisture Gain



D- Table of Percent Moisture Gain

Sample	Time (hours)													
Number	24	48	72	96	120	144	168	192	216	240	264	288	312	336
1	0	0.1515	0.0483	0.09	0.1032	0.1098	0.1471	0.18	0.1976	0.2174	0.2152	0.2349	0.2942	0.3052
2	0	0.167	0.1002	0.1158	0.1069	0.1403	0.1893	0.1893	0.2183	0.2428	0.265	0.2606	0.2985	0.3831
3	0	0.1005	0.0648	0.0893	0.1117	0.1251	0.1318	0.1764	0.2501	0.268	0.4131	0.3618	0.3752	0.3327
4	0	0.1385	0.1439	0.0842	0.1331	0.1548	0.163	0.4373	0.2091	0.277	0.3884	0.3504	0.2797	0.3286
5	0	0.0534	0.3092	0.2314	0.2247	0.1869	0.1713	0.238	0.267	0.2714	0.307	0.3159	0.327	0.3826
6	0	0.0456	0.0456	0.1104	0.1488	0.1344	0.2737	0.3193	0.2184	0.2929	0.2376	0.2473	0.2641	0.3337
7	0	0.109	0.0445	0.1446	0.189	0.1268	0.1179	0.1868	0.209	0.3603	0.3492	0.3025	0.2691	0.2735
8	0	0.0673	0.1203	0.0897	0.1591	0.1713	0.1774	0.2508	0.2508	0.3487	0.3528	0.361	0.3956	0.3732
9	0	0.1578	0.2534	0.2534	0.0422	0.1289	0.24	0.18	0.2156	0.1734	0.2267	0.1956	0.2267	0.1934
10	0	0.0756	0.0489	0.1022	0.1622	0.1911	0.2445	0.2645	0.3756	0.3733	0.3578	0.3222	0.4	0.3778
11	0	0.0787	0.0899	0.0989	0.1146	0.1663	0.2203	0.2203	0.2675	0.2832	0.3079	0.4248	0.3484	0.3911
12	0	0.1385	0.1319	0.1297	0.1868	0.1846	0.1868	0.211	0.2484	0.2791	0.2857	0.3605	0.3033	0.3627
13	0	0.1572	0.0917	0.1616	0.1834	0.1769	0.2271	0.2686	0.2598	0.3166	0.3646	0.4083	0.369	0.3952
14	0	0.0659	0.0747	0.347	0.2108	0.235	0.2306	0.3206	0.2965	0.2877	0.3755	0.3689	0.4172	0.4546
15	0	0.0691	0.078	0.0936	0.1494	0.1851	0.2765	0.2542	0.2854	0.3345	0.3456	0.3233	0.4192	0.4036
16	0	0.1124	0.1079	0.1416	0.1686	0.182	0.1978	0.2	0.3439	0.2382	0.2382	0.2854	0.3461	0.3843
17	0	0.0551	0.0507	0.3945	0.1433	0.1168	0.1653	0.1939	0.2226	0.3108	0.3218	0.2755	0.3526	0.4231
18	0	0.0596	0.1104	0.1656	0.2496	0.2761	0.2738	0.2319	0.2915	0.3003	0.3026	0.3313	0.3754	0.3953
19	0	0.0687	0.093	0.1152	0.4408	0.2769	0.2614	0.2392	0.3655	0.2636	0.2791	0.3212	0.3367	0.4009
20	0	-0.022	0.0286	0.0549	0.0769	0.1076	0.1032	0.1735	0.2131	0.1648	0.2328	0.235	0.2658	0.2922
21	0	0.0661	0.1014	0.086	0.1389	0.1697	0.1697	0.2271	0.3263	0.2844	0.2998	0.4145	0.3792	0.3704
22	0	-0.0154	0.6678	0.4386	0.3129	0.2006	0.1543	0.1234	0.2028	0.205	0.2424	0.227	0.2865	0.2931
23	0	0.0264	0.0462	0.2154	0.1099	0.2264	0.2352	0.2572	0.3912	0.2945	0.2857	0.2594	0.2594	0.2747
24	0	0.0917	0.1223	0.155	0.1572	0.1637	0.1899	0.2402	0.2642	0.5436	0.3406	0.31	0.4105	0.4236
25	0	0.053	0.0729	0.1282	0.1701	0.2099	0.2408	0.2276	0.2784	0.2254	0.2762	0.2895	0.3314	0.3624
26	0	0.0638	0.1077	0.0989	0.1649	0.1847	0.2462	0.288	0.3495	0.3034	0.3319	0.3451	0.4001	0.4199
27	0	0.1135	0.1469	0.118	-2.0207	0.2404	0.5408	0.2938	0.276	0.3628	0.3605	0.3271	0.4184	0.4117
28	0	0.1601	0.1272	0.1184	0.1184	0.1623	0.1886	0.2543	0.3355	0.2543	0.2807	0.467	0.3574	0.3442
29	0	0.1299	0.1388	0.0963	0.1232	0.1456	0.1657	0.2262	0.2396	0.2351	0.3046	0.2799	0.3516	0.3583
30	0	0.1366	0.0947	0.0837	0.0837	0.1432	0.1542	0.4186	0.2424	0.2864	0.3327	0.4583	0.26	0.3746

E- Graph of Percentage Moisture Gain



Appendix D: Minitab Printout

MINITAB PRINTOUT

```
MTB > set c1
DATA> 0.1486
DATA> 0.2000
DATA> 0.2710
DATA> 0.3841
DATA> 0.4295
DATA> 0.4765
DATA> 0.5816
DATA> 0.5728
DATA> 0.6861
DATA> 0.7815
DATA> 0.8467
DATA> 0.9106
DATA> 0.9562
DATA> end
MTB > set c2
DATA> 0.0892
DATA> 0.1221
DATA> 0.1517
DATA> 0.0888
DATA> 0.1741
DATA> 0.2095
DATA> 0.2431
DATA> 0.2704
DATA> 0.2866
DATA> 0.3074
DATA> 0.3221
DATA> 0.3373
DATA> 0.3607
DATA> end
MTB > twosample 95.0 c1 c2;
SUBC> alternative 0.

TWOSAMPLE T FOR C1 VS C2
     N    MEAN     STDEV   SE MEAN
C1  13    0.557    0.268   0.0745
C2  13    0.2279   0.0954   0.0264

95 PCT CI FOR MU C1   MU C2: ( 0.1599,  0.4989)

TTEST MU C1 = MU C2 (VS NE): T= 4.17  P=0.0009  DF=  14
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