Lappeenranta University of Technology
LUT School of Energy Systems
LUT Mechanical Engineering

Ndifreke Genesis

POSSIBILITY OF CONTROLLING THE ATMOSPHERE INSIDE A PACKAGE USING MICROPERFORATION

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ABSTRACT

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Possibilities of controlling the atmosphere inside a package using microperforation.

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This work focuses on the study of the determination on the possibilities of controlling the required moisture within the inside of film sealed packages. The task is based on the challenges faced by fresh food producers in actualizing a longer product shelf-life coupled with the growing complex desires coming from consumers in the aspect of quality. One way to realize this is by proper evaluation on the use of the flexible plastic films through permeation measurements on the required amount of moisture penetrating through the plastic film with the application of microperforation. A packaging material requires proper interaction on moisture transmission, between the product and the outside environment. The plastic film material that stands between, fresh fruits, vegetables and the outside environment could have appropriate respiration rates through possible micro holes. This work simulates similar process with the aid of water vapor transmission rate (WVTR) experiment using anhydrous $CaCl_2$ as the desiccant, in studying the WVTR values of various perforated film materials at different conditions of storage (standard, fridge, and tropical conditions). However, the results showed absorption rates of water vapor at various conditions in grams of $H_2O/m^2/24h$.

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ABBREVIATIONS

ASTM	American Society for Testing and Materials
ATP	Adenosine Triphosphate
BOPP	Biaxially Orientated Polypropylene
EMAP	Equilibrium Modified Atmosphere Packaging
EVOH	Ethylene Vinyl Alcohol
HACCP	Hazard Analysis including Critical Control Points
MAP	Modified Atmosphere Packaging
MP	Microperforation
PE	Polyethylene
PET	Polyethylene Terephthalate
WVTR	Water Vapor Transmission Rate

DEFINITIONS

Additives	Substance added to food to preserve and enhance flavor and taste, for examples sodium ascorbate with bacon and sulfur dioxide with wine.
Atmosphere	This is air or the invisible mixture of mainly oxygen, carbon dioxide and nitrogen gaseous substance surrounding the earth.
Asphyxiant	Substance that could cause suffocation
Bacteriostatic	The biological or chemical agent that hinder the growth or reproduction of bacteria. Same applies to fungus: Fungistastic
Chamber	An enclosed cavity or surrounding with controllable conditions
Condition	The state of a situation with respects to it appearance and measurable quantity and quality.
Contaminant	Any minor, unwanted constituent or impurity present in food substance.
Carcinogenic	Having that tendency of becoming a substance or process that encourages the cause of cancer.
Desiccant	Any hygroscopic substance use to sustain dryness in its surrounding.

Headspace	This is the unfilled space between the content and the sealed cap of a package
Humidity	This is the amount of water vapor in the air
Non-climacteric	A stage of fruit ripening that is not associated with the production of ethylene. Citrus and strawberries are non-climacteric
Penicillium expansum	This is an after harvest deterioration that affects apples, citrus, pears and cherries
Photosynthesis	Process by which green plants converts the light energy obtain from the sun to chemical energy.
Relative Humidity	The sum of water vapor present in air and expressed in percentage of sum needed for saturation to occur without any change in temperature
Shelf-life	The duration of time a product can be kept before expiring.

1 INTRODUCTION

Antimicrobial wrapping is an evolving and demanding knowledge in the food business that is used to regulate the microbiological deterioration of perishable food products. There are several organic and inorganic active antimicrobial mediators that are combined within the film matrix of packages in order to avoid unwanted microbial decay transpiring throughout the storage of the packed fresh foods. Chlorine solutions also have been extensively utilized in cleaning of fruits and vegetables, which however, has raised questions on the association of chlorine with fresh foods due to result of possible formation of carcinogenic chlorinated compounds on reacting with water. (Ahn, Grun & Mustapha, 2004, p. 151.)

On the other hand it has been observed that consumers have been much more critical over the use of man-made additives in processing of fresh foods and other enhancements processes such as in flavor and color. Natural contaminants like microorganisms attack fresh foods, which arises from various sources during post-harvest handling and processing.

This work centers on how to control the atmosphere in food packages especially in fruits and vegetables that are easily perishable due to the humidity, temperature, air and other gaseous content in the package. The intended package to be used is for checking these properties and the effective influences the possible control of these properties can aid in the desired shelf-life of these products.

1.1 Problem Discussion

Life as an entity to every human being is highly dependent and subjected to what is taken into our body called food. Food can be fresh or processed, either from life stocks or green plants. Foods from green plants are usually vegetables and fruits, which are highly perishable. World’s net output of fruit production is estimated to be about $370x10^6$ megatons. The output from India positions first in World ranking with a yearly production of $32x10^6$ megatons, accounting for almost 8% of the planet's fruit output. India also comes out next of leading vegetable producers (ranked next to China) with about 15% of world total output, which is over $71x10^6$ megatons (Sandhya, 2010 p. 381).

Huge or enormous production of these products may not just be enough, but the preservation and transportation to other customers in various locations is a major problem in this kind of industry. Considering other influences like weather and seasonal conditions, there is definitely a need to look into issues that may limit or enhance the consumption of Tropical and Mediterranean produce in other locations like in Scandinavia. For reasons of cost, labor and hygiene, most cuisine operators in the food industry have aimed at the purchasing of fresh vegetables and fruits that were previously peeled, probably sliced, shredded or minimally processed. Coupled with customers progressively demand of convenience and set-to-use and set-to-eat fruits and vegetables through its original value including just natural constituents. The market share within Europe, mostly France and the United Kingdom has experienced an explosive growth in consumers demand for slightly handled fruits and vegetables since the beginning of the 1990s. (Day et al., 1993 p. 34.)

1.1.1 Objectives

The significance of this work is to evaluate potential measurements and test methods concerning the control of the atmospheric contents of fruit and vegetable packages, in enhancing the life span of these fresh foodstuffs.

Values, methodologies plus tools obtained from the results and observations of this study will aid in the fulfillment of the purpose of this work. The aim of this project centers on the following:

- The possibility of drilling through films with the use of laser and mechanical needle process
- The study of moisture transmission rates of various films with respect to the amount of perforations on them.

1.1.2 Delimitation

This study will deal with packages that are used in packing fresh products, which are basically fruits and vegetables. The intention is to empirically study the necessary processes that could be employed in the controlling and investigation of the atmospheric and humidity conditions of the fresh food packages using various means: Modified Atmosphere Packaging (MAP), water vapor transmission, oxygen transmission, microperforation (MP), ripening of fruits, and microbial growth.

1.2 Modified Atmosphere Packaging

The technique called MAP can be cultivated to use for the delaying of the storage period of slightly handled fresh foods. Using this storage method, the atmosphere around the product inside the pack remains altered by changing it to another composition. Applying this will encourage the original condition (in freshness) for the produce to be extended. The shelf-life for fresh edibles including meat products and fishes can all be extended using MAP due to its ability of slowing the natural deterioration process of these products. The description of MAP for food business can be described as the packing device for fresh produce and other foodstuffs in a contained air that is already altered to have a desired composition of the needed gases that makes it different from the ordinary air. (Hintlian & Hotchkiss, 1986, p. 73.)

Stuffing of foods with MAP is capable of bringing about prolonged shelf-life plus enhanced food appearance inside a suitable pack, causing the food to be eye-catching to the consumers. Though, MAP will never enhance the value of a low value fresh produce. It is of great importance to know that foodstuff of high value prior to storing so as to improve the gains of altering the package air. Suitable hygienic application and proper control of temperature during the chilling phase of fresh produce remains essential in preserving the value gain with prolonged life span of MAP foodstuffs. (Coles, McDowell & Kirwan, 2003, p. 317.)

MAP stands as the direct spare of packed air technique having a solo or collective gas mix; each fraction from every element of these gases remains fixed during the introduction of the mixture inside the pack. The gas composition changes through time due to transmission of air getting inside and outside of the good, the infusion in and out of the pack with the consideration of microorganism growth. (Church, 1994, p. 349.)

Mixtures of gases inside packages of various products are different based upon the kind of produce to be packed, material used and packing temperature. Since fresh foods are goods that respire, there is a necessity to focus on the interaction between packaging material used and the product.

1.2.1 History of MAP

The first recorded use of MAP was in the year 1927 by the extending of the shelf-life of fruits by the use of air with minimized O_2 and amplified amount of CO_2. During 1930s it was applied into the MAP for conveying fruits for holding in transport vessels and adding to the CO_2 amount in volume around meat to remain for long distance transportation. This was seen to enhance the product lifespan significantly to about 100%. (Davies, 1995, p. 312.)

During the past 70years, MAP has developed immensely by paying considerably in the extension of post-harvest life of green plants and maintenance of the value property for various fresh foods. For the conservation of the products inside of the packs, certain factors that influences the permeability of the package must be combined or put to use for the occurrence of atmospheric changes from the inside and outside, in order for the product to achieve good respiration. Achieving such balance would be when the breathing of the product guzzles the equal volume of oxygen gas getting inside of the parcel with the creation of carbon dioxide by respiration is equivalent to the quantity getting out of the package (Day, 1993, p. 118.)

1.2.2 Benefits and Limitations of MAP

Benefits of MAP (Mattos, Moretti, & Ferreira, 2012, p. 107.):

1) It increases the life span by permitting regular stacking of retail display shelves
2) It reduces retail waste
3) It reduces manufacturing and packing cost owing to well utilization of labor, area-space and apparatus
4) It gives good arrangement for cut harvests
5) It provides centralized packaging and portion control
6) It reduces transportation cost due to less delivery and increases the distribution area
7) It offers the use of little or no use of chemical preservatives

Limitations of MAP (Mattos, Moretti, & Ferreira, 2012, p. 107.):

1) High capital expenditure of gas wrapping equipment
2) Acquiring price of gases and packing materials

3) Expenditure for investigative tools used to guarantee that precise gas mixes are applied
4) Expenditure for quality assurance systems to avoid supply of leaks, etc.
5) Adverse effects on transportation cost and retail display space from increased packed volume
6) Possibility of increased food-borne microbes because of temperature mismanagement of the package by customers.

1.2.3 The use of EMAP

In food packing business storing with equilibrium-modified-atmosphere (EMAP) is primarily used for fruits and vegetables. As packing foods requires not just air but atmosphere with the right proportion of gases needed which favors lowered level of oxygen and raised level of carbon dioxide gas. The aim of this kind of package is to slowdown the usual or normal respiration of the products so as to lengthen the life span. EMAP usage (see figure 1) contains certain percentages of gases (2-5% O_2, 3-8% CO_2 and balanced level of N_2). The EMAP has shown to slowdown in ripening as well as vegetable softening and delaying the degradation of chlorophyll, microorganism decomposition with the browning of enzymes. Gas transmission rates of the packaging system needed are a key factor in the designing and modeling of the desired EMAP to be used. Other influences are the harvest respiration rate that gets altered by factors like temperature, food type, ripeness, size, film permeability, package capacity, the area of the sealed top, and occupied bulk size and light intensity. (Day, 1993 p. 120.)

Figure 1. Equilibrium Modified Atmosphere Packaging (EMAP) (Bemis Europe, 2015).

1.2.4 The gases Applied with MAP

General gases often applied to MAP technology remains carbon dioxide, oxygen and nitrogen gas. Selection of these gases is precisely reliant on the fresh food to be packaged; they are either applied solely or combined together so as to prolong the safe life span of the fresh food. Some dry foods such as coffee and snacks are commercially preserved with inert gases of which this study is limited to its benefits and application. (Sandhya, 2010, p. 382.)

One fundamental concept of MAP for fresh produce can be understood as the substitute of the air around the product inside a pack with a combine fractions of that air. Table 1 below shows the percentage make-up of air

Table 1. Gaseous content of pure air in the atmosphere (Day, 1993).

Gas	Percentage (%)
Hydrogen	0,01
Carbon Dioxide	0,03
Argon	0,94
Oxygen	20,99
Nitrogen	78,03

1.2.5 Carbon dioxide gas

Carbon dioxide can be described as a colorless gaseous material that has a small strong scent when applied at excessive amounts. It is also seen as an asphyxiant that yield a weak acid when exposed to moisture, it forms a weak carbonic acid (H_2CO_3) due to its solubility rate in water and in lipids and it is also not an anti-bacteria or anti-fungi substance but bacteriostatic and fungistatic in the sense that it hinders bacteria from reproducing by not harming them and upon removal the bacteria can start growing again. It is used also as antibiotic, and for disinfectant, antiseptic and preservative purposes. At the initial phase the effect seems greater. Hence, as bacteria moves from their lag to log stage, their inhibition effect gets decreased making possible suggestions on gas packing of the product early enough due to CO_2. (Church, 1994, p 351.)

1.2.6 Oxygen gas

Oxygen can be described as a very significant gas as regards to metabolic context, because aerobic spoilage microorganisms and plant tissues are using it, and it has a role to play in some of the enzymic reactions of food compounds like flavors and minerals. Due to these reasons oxygen usage with MAP is then omitted or the set gauge placed so minimum as probable. Omissions of oxygen gas arise when oxygen stands effectively required for the breathing of fruits and vegetables, fresh produce color retention and in some cases of red meat and white fish in preventing anaerobic conditions on them. (Day, 1993, p. 129.)

1.2.7 Nitrogen gas

Nitrogen gas can be described as a gas without flavor; it offers either minimal or none of its identifiable antimicrobial activities. Due to its lower solubility rate in fluids like water and lipids, nitrogen existence in MAP application would avoid package failures, which usually occur as a result of excessive amount of carbon dioxide usage. Furthermore, the ousting of oxygen gas by nitrogen gas inside the package, can pause oxidative rancidity (which is associated with the degradation by oxygen in the air) and equally prevent the development of aerobic microorganisms. With foodstuffs like nuts, eradicating oxygen to almost <%1 with nitrogen flushing assists in preventing oxidative rancidity of lipids. Nitrogen also have the ability to impact microorganisms passively in fresh foods by hindering the development of aerobic decaying entities. Nitrogen plays another role in MAP as filler and keep polymeric packs occupied. The actual mixture of gases to be used varies on numerous considerations; examples are the kind of produce, the desired packing materials and storing temperature. The chosen packing technique need to ensure enough headspace to offer sufficient air that will accommodate the whole produce. The headspace also needs to include a chamber for CO_2 to counterbalance for the gas used up by the produce and lost through the packing material. (Day, 1993, p. 118). The more the desired shelf-life the more headspace of the pack there must be.

1.2.8 Carbon monoxide (CO) and other gases

In some MAP systems, carbon monoxide is one very effective gas used in the maintaining of the freshness in the red appearnce of meat as a result of the formation of carboxymyoglobin. Owing to the great toxicity of carbon monoxide it is not encouragingly used commercially. Due to the possibility of it causing great health hazard to packaging machine operators, the regulatory authorities do not approve the use of it. CO nurses tiny preventive influence on microbes; The United States has sanctioned its use in preventing browning of packed lettuce. Some gases like chlorine, ethylene oxide, ozone, nitrogen oxide, propylene oxide and sulfur oxide, also have the potential of been used in MAP. Having been investigated experimentally but the unlikely approval by regulatory authorities, hinders the full application of these gases commercially. (Day, 1993, p. 121.)

1.2.9 MAP Applications

The use of MAP encompasses all forms of fresh foods. Modified atmospheres could be achieved inactively amid plant material and seal parcel or actively using appropriate amounts of gases. In this aspect, MAP is created as an effect of vegetable breathing, meaning it guzzles CO_2 to liberate O_2 in wrapped packet. (Mattos, Moretti, & Ferreira, 2012, p. 96.)

1.2.10 Vegetable

One important fact to put in mind when dealing with vegetables is such that they are in living state and will remain breathing as the availability of their desired nutrients stays on. There is continuous breathing and moisture exchange after they have been harvested and separated from their means of obtaining photosynthesis, minerals and water. Vegetables now depend solely on their own food stocks and moisture content. Reduction in moisture content creates reduced marketable profits and consequently an express non-profit for the cultivator. A lot of vegetables appear faded and wrinkled by some 5% loss in weight, also inappropriate packaging systems with warm dry conditions can shrink vegetables within little time. Relative humidity inside the packaging system relates or gets manipulated by the amount the vegetables gives up moisture with the rate the moisture gets transmitted through the flexible seal. There will be achievable expansion in the life span with the proper utilization of designed packs that allows an optimum atmosphere concentrations and controlled water vapor transmission, with the use of packaging films that reduces the accumulated energy of the vegetables by reducing its breathing speed. (Aharoni et al., 2007, p. 93.)

Consequences regarding the application of the super-atmospheric oxygen with MAP with vegetable breakdown, the organoleptic significance and microbe development of slightly treated young spinach have been considered by Allende (Allende et al., 2004 p. 55). The amount of oxygen transmitted with the original stage of the super-atmospheric oxygen of packaging film inside a parcel drastically affects the variations of the inner atmosphere of the package throughout the storage and therefore the quality of young spinach leaves. There are suggested gases content for some fruits and vegetables (see table 2).

Table 2. Some suggested gas mixtures for MAP (Sandhya, 2010, p. 383).

Product	O_2 (%)	CO_2 (%)	N_2 (%)
Fruits			
Apple	1–2	1–3	95–98
Apricot	2–3	2–3	94–96
Avocado	2–5	3–10	85–95
Banana	2–5	2–5	90–96
Grape	2–5	1–3	92–97
Grapefruit	3–10	5–10	80–92
Kiwifruit	1–2	3–5	93–96
Lemon	5–10	0–10	80–95
Mango	3–7	5–8	85–92
Orange	5–10	0–5	85–95
Papaya	2–5	5–8	87–93
Peach	1–2	3–5	93–96
Pear	2–3	0–1	96–98
Pineapple	2–5	5–10	85–93
Strawberry	5–10	15–20	70–80
Vegetables			
Artichoke	2–3	2–3	94–96
Beans, snap	2–3	5–10	87–93
Broccoli	1–2	5–10	88–94
Brussels sprouts	1–2	5–7	91–94
Cabbage	2–3	3–6	81–95
Carrot	5	3–4	91–95
Cauliflower	2–5	2–5	90–96
Chili peppers	3	5	92
Corn, sweet	2–4	10–20	76–88
Cucumber	3–5	0	95–97
Lettuce (leaf)	1–3	0	97–99
Mushrooms	3–21	5–15	65–92
Spinach	Air	10–20	–
Tomatoes	3–5	0	95–97
Onion	1–2	0	98–99

1.2.11 Fruits

Delay of fruit ripening is among the main advantages while using correlated physiological and biochemical variations with MAP. One main ecological influence for the inhibition of ripening is temperature. An increase in temperature results in production of more ethylene (C_2H_4) and thus ripening. In order to slow this maturing rate, the fruits must remain placed as nearby as 0°C with all provision of not wounding these fruits. MAP is used to supplement the temperature maintenance effect of some chilling sensitive fruits, but turns out to be advantageous to the fruits. Decreasing of the oxygen amount fewer than 8% while enriching that of carbon dioxide amount beyond 1% helps in retarding fruit ripening. Results from examinations show 2% level of oxygen anaerobic breathing could bring about the improvement of off-taste-and-aromas. Fruit crops may lose the ability to achieve uniform ripening when exposed to low O_2 when taking out from MAP. (Sandhya, 2010, p. 384.)

Applicable success could be seen by the usage of MAP on fruits like apple, lemon, and oranges in various forms (intact, stripped, and cut). The usefulness of MAP and the utilized materials to the development of *penicillium expansum* which can be seen as a dominant deteriorating factor affecting apples and also contributes the production of *patulin* (Moodley, Govinden, & Odhav, 2002 p. 868). In order to inhibit the growth of *penicillium expansum*, polyethylene (PE) is seen as a brilliant packing tool for fruits like apple, thereby permitting the production of patulin, irrespective of the surrounding gases. Some successful studies have been seen with fresh cut pears wrapped in different conditions of MAP stockpiled inside refrigerator state with results of packing airs upon microorganism sustainability. Quality parameter were considered in investigating the effectiveness of MAP materials especially PE on the development of *penicillium expansum*. Polymeric carriers having penetrability rate of $15cm^3\ O_2/m^2/24h$ with original atmospheric pressure of 0 kPa oxygen prolonged the biological life of cubed pears to a minimum of 3 weeks after packing. (Robert, Marc, & Belloso, 2003, p. 369.)

1.2.12 Prepared Salads

Demands from consumers have always been associated with freshness and convenience which brings about the development and improved production of numerous varieties of minimally processed vegetables. There is usually short shelf-life for packed salads and mixed prepared vegetables as they depreciate quickly in quality due to the trouble of having some different vegetables packed together with extensively varying requirements and breathing rates. Chief necessities for minimally processed vegetables and salad are valued fresh resources (throughout the growing, collecting and storing), proper sanitization with good industrial processes that have an appropriate risk evaluation including critical regulatory points (HACCP). (Sandhya, 2010, p. 385.)

These demands also encourage the use of low temperature during the handling stages, thorough cleaning before peeling, good processing water, application of gentle additives for cleaning water used for decontamination with avoidance of browning, mild drying in spinning mode resulting to cleaning, mild cutting, peeling, slicing and chopping, precise packing provisions with packing techniques, precise temperature with moisture throughout delivery and trading. (Sandhya, 2010, p. 385.)

There are successful applications of MAP with some vegetables like slaws, shredded soy mix, leaf salad, stir-fry mix etc. MAP devices that are intended to be used with mixed vegetable salads containing 75 g of carrot, cucumber of 55 g, 20 g of shared garlic and 50 g of an entire green pepper is another example in applicability (Lee et al., 1996, p. 8).

1.2.13 Flowers

Most problems often faced in the flowering business is associated with ethylene-induced abscission in ornamental plants, in the sense that little amount in concentration of ethylene can trigger great loss of flowers and leaves. Pollution resulting from ethylene on tulip bulb, during the marketing phase causes the flower from maturing; a circumstance is described as blasting. Small amount of oxygen and excessive amount of carbon dioxide inside the packed air decrease the degree of breathing and the buildup of ethylene as well. Another main cause that hinders the marketing value of the flowers is water loss, which raises an unattractive outlook of the flowers like tissue softening, wrinkling etc. (Legnani, Watkins, & Miller, 2004, p. 228.)

1.2.14 Films

Changes starts to take place on fresh produce after packing has taken place, due to the respiration produced inside the pack. An equilibration process starts taking place to balance he inside and outside gases found in the pack and the outside ambient atmosphere respectively, through permeation of the packet barriers with a level influenced by the difference in pressure available among the gases found at the top space and the gas outside ambient atmosphere. Therefore, with regards to these, it is very important to consider the wall to the provided water vapor and gases by the containing materials. It can be accepted that the triumph of any MAP device hangs on the packaging wall materials utilized. A packing device for fruits and vegetables needs to have or permit access for the oxygen to sustain the aerobic metabolism of the product packed inside. Also, there should be some exit for carbon dioxide from the pack in order to evade an increase of harmful level of the gas. Therefore, with regards to these requirements, there should be a plastic film with somewhat enough gas permeability. Other film material properties are as shown in table 3. (Mattos, Moretti, & Ferreira, 2012, p. 98.)

Table 3. Properties of Packaging film materials (Sandhya, 2010, p. 386).

Material	Properties
Paper	Strength; rigidity; opacity; printability.
Aluminum foil	Negligible permeability to water vapour, gases and odours; grease proof, opacity and brilliant appearance; dimensional stability; dead folding characteristics.
Cellulose film (coated)	Strength; attractive appearance; low permeability to water vapour (depending on the type of coating used), gases, odours and greases; printability.
Polythene	Durability; heat-sealability; low permeability to water vapour; good chemical resistance; good low-temperature performance.
Rubber hydrochloride	Heat-sealability; low permeability to water vapour, gases, odours and greases; chemical resistance.
Cellulose acetate	Strength; rigidity; glossy appearance; printability; dimensional stability.
Vinylidene chloride	Low permeability to water vapour, gases, copolymer odours and greases; chemical resistance; heat-sealability.
Polyvinyl chloride	Resistance to chemicals, oils and greases; heat-sealability.
Polyethylene terephthalate	Strength; durability; dimensional stability; low permeability to gases, odours and greases.

There are extensive lists of films with some still under investigation that are commercially used in MAP. These are amplified through the combined thought of smart and edible packages. The fresh-cut industry applies the use of smart packages often combined with certain indicators that reads the time, temperature, gases arrangement, leakages etc. (Rooney 2000 p. 32). Some of these packs vary the oxygen and carbon dioxide permeability using feedbacks from its temperature changes. There are even promising packages still in design phase with capabilities of finding pathogens with antibody revealing equipment that gives feedbacks through indicators attached at the top of the pack, in order to signal manufacturers of the presence of pathogens. Other promising packs are the ones with edible decomposable coats applied in the direct packing of some foods. An edible film comprises of four supplies: resins, fats, polysaccharides and proteins. Other materials are supplemented to modify the film for special use, like glycerol as a plasticizer, which enhances permeability and flexibility of the film; others are antimicrobials, antioxidants, and texture agents etc. These materials are appropriately measured for proper results from the packing system. Plasticizers increases water vapor permeability, fats based decreases water vapor transmission and this makes it necessary to obtain the needed water vapor characteristics of the needed film in order not to favor the unwanted growth of pathogens with surplus availability of moisture. That is why certain plasticizers like polyethylene glycol are used, which in-turn decreases film fragility. (Koelsch, 1994, p. 78.)

1.2.15 Film products

There are various materials used as materials in the processing of packaging films and other materials used in sealing food produce. The materials ranges from PET, PE, PP, BOPP to cellophane. These materials yield several film products in the market used in packing all sorts of goods in all forms of conditions whether dry, cold or fresh. There are a lot of packaging firms in the European market of film packaging in which companies throughout the region rely deeply on advantage of flexible packaging products to meet their complex loads of performance, cost and consumer demand. Some companies offer total commitment to innovation and customer's response towards certain range of products available. Certain packaging material firms create trademark products with patented know-how in order to contest with today's industrial challenges. The wide range of products from these companies' portfolio comprises a huge variety of demonstrated flexible packaging materials that are factory-made in dedicated facilities, based on the area of knowledge. (Bemis Europe, 2015.)

Some of the few products seen in the market are:

Cold seal

This is for heat-free solutions for sensitive products like chocolates (see figure 2) where two separate cohesive surfaces coming in contact and to adhere together to form a tight attractive seal, without any heat application. This cold seal wrapping is ultimate for products prone to heat destruction

Figure 2. Cold seal for chocolate sealing (Bemis Europe, 2015).

Easy-Peel products

This is a technology for an effortless opening which solves the problem of firmly joined packing seal that requires extra force to open (see figure 3). This technology can be applied in a variety of package configurations.

Figure 3. Easy Peel product for cheese packing (Bemis Europe, 2015).

Flow wrap

Bemis offer some range of flow wrap machinable films (as in figure 4) for better store impression and shelf-life. It offers brilliant clarity and gloss and provide outstanding print surface for rotogravure procedures.

Figure 4. Flow wrap package (Bemis Europe, 2015).

1.2.16 Packaging Parameters for MAP

The atmospheric arrangement inside MAP arises from the several factors, which includes permeability properties from the packing material, the breathing interaction of the fresh produce and the environment. With these criteria, certain packaging films are selected so as to match the required permeability and desired changes relating to temperature and humidity with respect to the expected lifetime of the product. Table 4 gives the permeability of various types of films used in MAP. The gaseous intensity of the pack can be influenced by the applied usage of the some of both known and unknown factors of the plant like; the species, the cultivation process, tissue type, harvesting process, handling etc. (Mattos, Moretti, & Ferreira, 2012 p. 99.)

Table 4. Types of film and their permeability used in packing of MAP product (Day, 1993).

Film	Permeability(cm³/m².d.atm for 25 mu film at 25 °C) Oxygen	Nitrogen	Carbon dioxide	Water vapor transmission, g/m²/day/atm (38 °C and 90% relative humidity)
Ethylene-vinyl alcohol (EVOH)	3-5	–*	–	16-18
Polyvinylidene chloride coated (PVdC)	9-15	–	20-30	-
Polyethylene, LD	7800	2800	42000	18
Polyethylene, HD	2600	650	7600	7-10
Polypropylene cast	3700	680	10000	10-12
Polypropylene, oriented	2000	400	8000	6-7
Polypropylene, oriented, PvdC coated	10-20	8-13	35-50	4-5
Rigid PVC	150-350	60-150	450-1000	30-40
Plasticized PVC	500-30000	300-10000	1500-46000	15-40
Ethylene vinyl acetate (EVA)	12500	4900	50000	40-60
Polystyrene, oriented	5000	800	18000	100-125
Polyurethane (polyester)	800-1500	600-1200	7000-25000	400-600
PvdC-PVC copolymer (Saran)	8-25	2-2.6	50-150	1.5-5.0
Polyamide (Nylon-6)	40	14	150-190	84-3100
Microperforated (MP)	>15,000[4]	–	–	-
Microporous, (MPOR)	>15,000[4]	–	–	Variable
Edible Films	**O_2 permeability (mL.mm/m².d.atm)**	**–**	**CO_2 permeability (mL.mm/m².d.atm)**	**Relative Humidity**
Pectin	57.5	–	–	87
Chitosan	91.4	–	1553	93
Wheat (gluten)	190/250	–	4750/7100	91/94.5
Na caseinate	77	–	462	77
Gluten-DATEM	153	–	1705	94.5
Gluten-beeswax	133	–	1282	91
Na casenate/Myvacet	83	–	154	48
MC/MPMC/fatty acids	46.6	–	180	52
MC and beeswax	4	–	27	42
Gluten-DATEM and beeswax	<3	–	15	56
Gluten-Beeswax and beeswax	<3	–	13	56
Methylcellulose-palmitic acid	78.8	–	–	100
Zein	0.36[2]	–	2.67[2]	0.116[3]
Cozeen	0.89[2]	–	5.25[2]	0.407[3]
Polyethylene	8.3[2]	–	26.1[2]	-
Polypropylene	0.55[2]	–	–	0.00065[3]
Sucrose polyester	2.10[2]	–	–	0.00042[3]

Smart Films

- O_2 scavengers with O_2 indicators
- antibody based detection systems for detection of microbial pathogens

Antimicrobial films

(i) *Edible*

- Chlorinated phenoxy compound with biocide incorporated into the polymer layer (that is, nisin, lysozyme)
- Chlorine dioxide with biocide incorporated into polymer layer$Edible films with sorbic acid, sodium benzoate, benzoic acid and potassium sorbate
- Pine based volatiles added to edible film$Horseradish extract added to edible film

(ii) *Non-edible films/products*

- Propyl paraben dispersed in a polymer emulsion (Permax 801 or Carboset)
- LDPE with Imazalil
- LDPE with grapefruit seed extract$Gas, as produced by sachets or other materials to produce sodium metabisulfite to obtain the production of sulfite

1.2.17 Water Vapor Transmission

Water vapor transmission rate can be described as the measure of the passage of gaseous moisture through a barrier. A critical factor for delaying of the life span of fresh products (fruits and vegetables) is the moisture controlling exchange effect because of their moisture sensitivity. This is also true for some processed foods (candies, cookies, snacks and frozen foods). Huge water loss of fresh products can result in an unattractiveness of the product during the marketing. Water stands on its own with various functions to plants: as it maintains plant cell turgidity of the harvested growth structure; aids in the transmission of nutrients and other organic matters through the plant; serves as a basic raw material for the various chemical reactions taking place inside the plant during photosynthesis, transpiration and safeguarding the plant during fluctuation of temperature.

Today, one of the greatest worries in food and nutrition industry is the deterioration of food from the penetration of oxygen, water and some other gases. The keeping of food products in appropriate environment reduces this deterioration and protects the goods. The life span of these good products is further enhanced with the application of plastic films material like vinyl polymers, polystyrene, polyethylene, with all forms of films sourced from cellulose. These films perform the role of creating a wall that shields the inner content parameters from the outside. (Smith & Peppas, 1991, p. 1221.)

The choice of the plastic films used in most food packs are usually decided based on economic respects, benefits in both physical, chemical and mechanical properties above other packaging materials. Water vapor infuses film seal materials during storage, reducing food quality. In some cases, the food changes texture, color and the sensory quality of the food. Also, the diffusion of moisture and other organic molecules influence the wall and physical characteristics of the polymeric film seals. The permeation properties derived from a packaging system and storage conditions can be utilize in the accurate prediction of the shelf-life of a giving product. (Rubino et al., 2001, p. 3042.)

As dehydrated food consequently absorbs moisture, water vapor penetrates into the food. The surrounding oxygen gas of the food reacts with the food surface causing effects of rancidity by which food get an unpleasant smell and taste caused by, enzymatic and non-enzymatic browning processes occurring on the fresh products. The physical and transport properties of the film seals influences the time required for these processes to occur. The desired film seals that are decided for a certain food packing system also has to be strongly picked based on their useful lifetime and reliability. (Smith & Peppas, 1991, p. 1224.)

1.2.18 Permeability

Permeability is the ability of transmission of matter in gas and vapor form through some repelling seal material. This is strongly dependent on the headspace atmospheric condition with the lifetime of the product. In this sense when high concentration of carbon dioxide or lower concentration of oxygen is demanded, the materials should create a permeable allowance for the escape of such gases, due to the oxygen requirement from vegetables and fruits at the top of the headspace, in order to ensure good quality of the produce. In this case the transparency of the packing material has to be taken into account. Other choices to be considered about the permeability are that the material must be economical to produce; it should ensure lesser water vapor transmission rate, elevated gas walls, physical toughness that could endure mechanical handling and assuring loading and delivery system for the already processed goods, which ensures the usage of well designed seals with the capability of providing very good retention of the gases. (Fishman, Rodov, & Ben-Yehoshua, 1996, p. 958.)

There are actually two means of applying package seals with the use of films. First is the use of films that permits the atmospheric interaction with in and out of the package. The other is the application of holes or perforations. The difference in gas intensity across a continuous film is in direct relationship with the movement of oxygen and carbon dioxide gases through it. Perforated seals have the rate of gas movement through its perforated holes as the amount of gases and air penetrating through the polymeric film material. The diffusion of gas over the perforation is significantly more, compared to that moving over the polymeric film and this rate is much greater when its perforated as it is more suitable and conducive for fruits and vegetables due to their high demand for oxygen. (Mattos, Moretti, & Ferreira, 2012, p. 103.)

Barrier properties of the plastic film material can give measurable assessments in explaining the permeability concept. Most materials possessing no form of defects like pinhole and cracks usually has their mechanism of transmission based on activated diffusion. This explains why permeate fluids like water vapor and gases dissolve into and diffuse through the films at greater intensity before evaporating from the other side of the atmospheric seal. A big influence of this can be seen with the some gases solubility. Another phenomenon could be seen from the evaluation of diffusion based on the sizes, shapes, and polarities of the probing particles of the permeant, how the polymer matrix are segmented based on polymer chain, the degree of cross-linking and crystallinity. Certain fragments of gas are not able to infiltrate over some polymers due to their insolubility towards such materials. (Kofinas, Cohen, & Halasa, 1994, p. 1233.)

The use of Henry's and Fick's law can help in creating a comprehensible diffusion model; these laws are used in obtaining the approach that connects the rate of penetration to the actual area and thickness of the plastic seal. (Siracusa, 2012, p. 2.)

Using the mechanism in figure 5, considering a homogenous polymer material with known thickness of l, penetrating pressure of p where ($p1 > p2$) and c as the permeate concentration of fluids passing through the seal, where ($c1 > c2$), can be used to express Fick's laws.

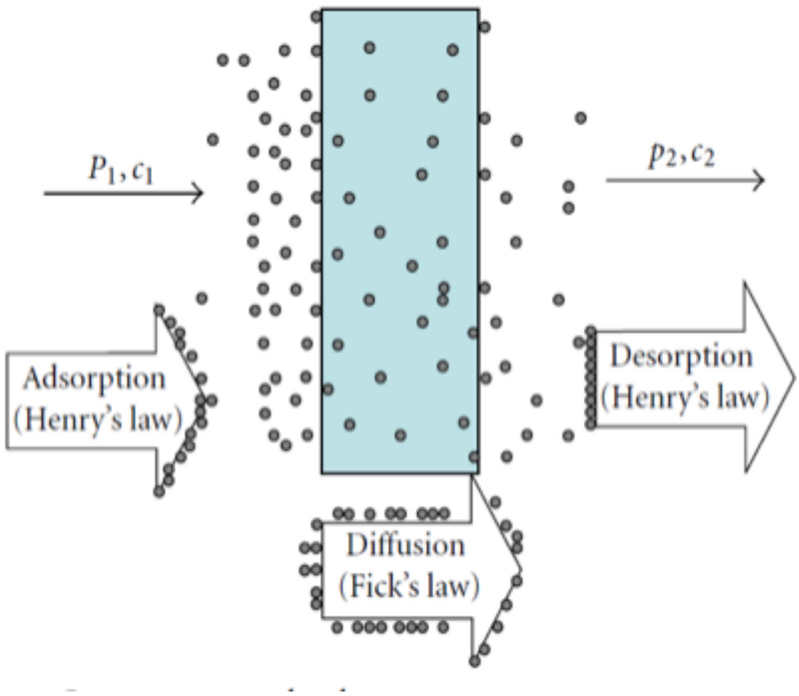

Figure 5. Penetration mechanism over polymeric film seal (Siracusa, 2012, p. 2).

Describing Fick's law with use of permeate flux of fluids through the films, denoted by J

$$J = -D \cdot \Delta c \qquad (1)$$

From the expression J is the diffusion flux (measured in $mol/cm^2/s^1$), D can be described as diffusivity constant (measured in cm^2/s) and Δc is concentration difference (measured in mol/cm^3). D reveals the speed of the permeant flowing over the film material. In the other way round, the permeant concentration c at the face of the film and the fluids pressure p observes Henry's law. It is very much affordable to gauge the vapor pressure p when the permeant is a gas (measured in *atm*), while Δc is replaced by $S\Delta p$ (the solubility coefficient S that reveals the amount of permeant in the film material by Δp as the differential pressure through the film. (Siracusa, 2012, p. 3.)

Therefore Equation (1) becomes

$$J = -D\left(\frac{S\Delta p}{l}\right) \qquad (2)$$

Multiplying DS from (2) gives permeation coefficient or permeability (P).

Therefore P the permeability becomes

$$P = \frac{-(J \cdot l)}{\Delta p} = DS \qquad (3)$$

This expression reveals that permeability P of a fluid (gas or water vapor) is directly proportional with the speed of the permeant D and solubility coefficient S.

Having a mass flux of F (g/s^1) in relation to the differential pressure through the film area of A.

$$F = P \cdot A \cdot \Delta p \qquad (4)$$

Considering a thin film with gas transfer rate properties which is defined by its permeance PR (m^2/s^1)

$$F = PR \cdot A \cdot \Delta p \qquad (5)$$

This gas transmission rate TR ($g/m^2/s^1$) with regards to the differential pressure Δp can now be defined as:

$$TR = PR \cdot \Delta p \quad (6)$$

Having a specific gas like water vapor (WV), therefore; the water transmission rate WVTR relates to the amount of vapor by mass or volume that infiltrates a unit square area of a film sample with specific thickness with respect to time of penetration.

$$Fv = WVTR \cdot A \quad (7)$$

1.2.19 Respiration rate

The breathing process that utilizes a chemical process of oxidizing carbohydrates and lipids, which produces water and carbon dioxide in order to generate energy, is called respiration. Some part of the energy in the respiration is stored in chemical form of adenosine triphosphate (ATP) the remaining gets released by heat. This process has a high dependence on numerous basic factors like the mass of the product, tissue, maturity, specie, coupled with other extrinsic factors like temperature, intensity of oxygen and carbon dioxide gas and other physical and mechanical impairments. For maintaining the safety of food, it is very vital to understand the possible risks of every produce, the film penetrability and the degree at which the product respires. (Mattos, Moretti, & Ferreira, 2012, p. 103.)

1.2.20 Temperature

Considering microbial evolution and the visual appearance of fresh produce this is amongst the most significant parameters that affect the marketing life span of some fruits and vegetables during storage. Every product has an ideal storage temperature. Permeable polymeric film seals are not independent of the temperature functions and its changes. The management of temperature for fresh goods is governed by continuous circulation of the desired temperature of air around the exterior of the pack. The headspace between the polymeric seal and contained product creates an effective tendency of refrigeration, whereby the distance from the center pack is derived by the function of the respiration rate and heat removed from the cooling air. An example can be observed by considering a packed broccoli with a required radius of 14 cm to keep it cool around 1°C from refrigeration. (Mattos, Moretti, & Ferreira, 2012, p. 102.)

Non-climacteric fruits like grapes, citrus and strawberries are associated with their determined properties towards the rate of ethylene production and respiration. They tend to resist the softening changes during the post-harvest periods, which give them the possibility of storing them for longer period of time. Although, there are two main challenges facing the storage of non-climacteric fruits: the first challenge is centered on pathological and physiological breakdown, which brings about decomposition and the second is concentrated on the weight loss of these kinds of fruits especially limes. Other than decomposition of citrus fruits during storage as a result of respiration and transpiration, some other local methods like the use of waxes that limits transpiration, respiration and gas exchange. With the interests shown towards packages by the use of permeable films seals have been modified to gain the required oxygen and carbon dioxide levels surrounding the fruits during the storage and transportation periods. Due to the fluctuation of temperature in the storage phase of these fruits there have come limitations on the improvement of MAP as the fruits get damaged from the high amount of carbon dioxide or oxygen gas resulting from this temperature effect. The application of pin-hole and microperforated plastic films are employed as strategies of decreasing this kind of risk. (Purvis, 1983, p. 564.)

1.2.21 Oxygen Transmission

The lifespan of many fresh foods are determined by the rate of oxygen transmission through plastic film seals utilized in the containing food during storage duration. There are various methods in determining the rate of oxygen transmission. Today's most commercially used method is the ASTM (American Society for Testing and Material) official technique with the use of flowing gas systems. The shelf-life of food produce that has undergone certain antimicrobial treatment (e.g., purification, disinfection, chilling) rely strongly on the original food quality and design of the package. (Church, 1994, p 352.)

When a package falls in a reduced oxygen level (less than 21%) in a packed seal it is usually referred to as reduced oxygen packaging (ROP). Sometimes when complex level of oxygen is introduced, the concentration can still drop below the nontoxic level for storage due to microbial and chemical activities within the sealed food. The drop of oxygen from the nontoxic level encourages anaerobic conditions to take place inside in the pack. This anaerobic condition also encourages the growth of *Clostridium botulinum* which is the botulinum toxin that have the tendency to cause severe flaccid paralytic diseases in humans and animals, it overpowers typical aerobic spoilage organisms that are responsible for certain organoleptic effects on foods. Due to this effect, the anaerobic condition foods, may look acceptable even with the existence of pathogens and contaminants which may pose as danger to the consumer as they often rely or judge the food they eat by certain spoilage indications like taste and smell. (Cameron, Talasila, & Joles, 1995, p. 28.)

There is a need for that purpose to have a measurement on how oxygen transmission rate fluctuates with respect to the conditional temperature and relative humidity of various available film seals that can be considered in the packing of food products.

1.2.22 Interaction between package, environment, and content

One important purpose of having a package is to keep the precise proportion of air inside the package and the creation of a suitable barrier for harmful gases from the surrounding environment that permeates into the package. The recognition of these different surroundings with their biological factors along with their chemical interaction and how they affect the organisms around them is an important way to appreciate the interactions between them. The gases available in the pack and that of the surrounding environment are unalike, as the packed good inside requires the right proportion of gases in order to assure precise organoleptic and mechanical characteristics. The required gases for the inside package content are usually carbon dioxide and nitrogen while that of the environment is usually oxygen gas which is typically harmful to the green contents of the pack. With the use of permeability as one the important parameters in MAP, the interactions can be described with the aid of such properties as: solubility, diffusion, permeation, absorption, desorption, migration and transmission rates. Figure 6 shows the interactions around the package wall as the middle layer of the content and the outer environment. The transmission rate determines the amount gases going through the packaging material. Other properties complying with Fick’s law as seen in figure 6 and 7, consist of three processes; the absorption of the permeating moisture into the packaging wall, the diffusion over the plastic seal and desorption of permeating moisture from the wall of the polymeric seal.

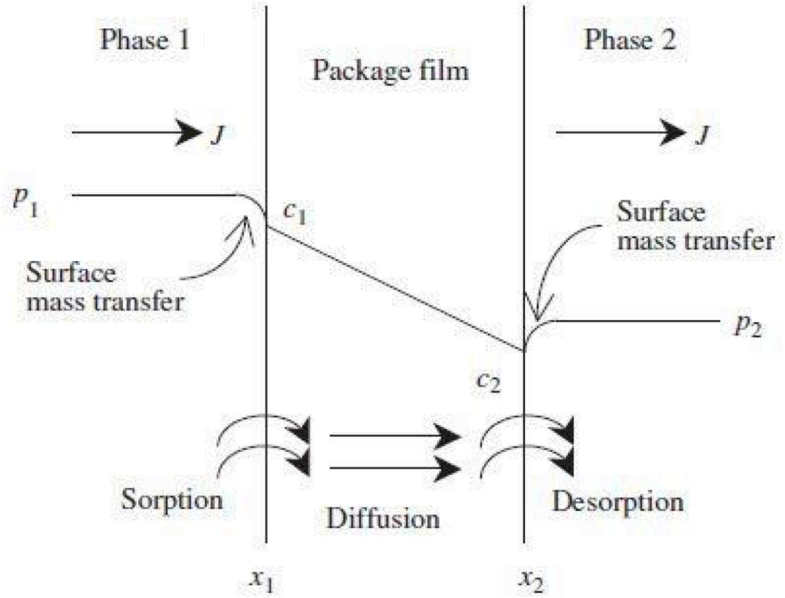

Figure 6. Gas permeation through packaging material, where p=pressure, c= permeant concentration (Siracusa, 2012).

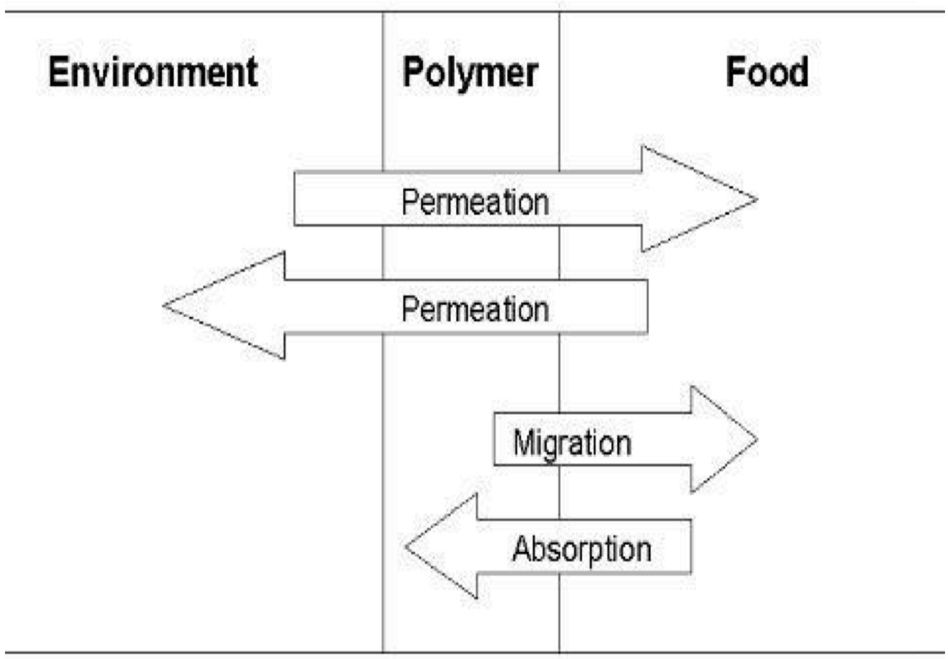

Figure 7. Typical transmission types between atmospheres, food and packaging materials (Siracusa, 2012).

1.3 Microperforation

It is very common in the fresh produce business that the guiding of packaging modifying atmospheric state and temperature inside a food parcel stand as the most significant elements that sustains and lengthens freshness and life span for harvested goods. By properly using right volume of oxygen gas, carbon dioxide gas and water vapor inside the pack at the proper storing temperature, MAP empowers the harvest to have lengthened life by slowing breathing, maturing and accumulation of ethylene. There have been utilization of numerous procedures in order to alter the air around these foods packs, with several sorbents used for absorbing undesirable gas and moisture in forms like envelopes or laminated films combined within the packs. This means, though, has not been common due to them having added components in their packs that may poses threat and is also subjected to users' mismanagement. A widespread methodology can be observed in the application of polymers that are specially blended from co-extruded and monolayer films that are exclusively designed to incorporate the precise quantity and volume for oxygen gas transmission. However, packs with different respiratory rates are needed due to the fact that every fruit and vegetable with their varieties are different, and requires different oxygen permeability. The industry becomes more matured as more fresh produce are supplied. Packaging gets more sophisticated with variations in antifog coverings and eye-catching printing etc., and all of these vigorously affect the pack's penetrability. Due to the variation of foods rise along with requirements for marketing variations becoming extra frequent, there will be a clear picture of the catastrophes that have been faced in the logistics of these packs. Having these nightmares around logistics one has to think or simply put an urgent need for the existence of packs with flexible atmospheric adjustment process that permits them to lessen the stock of films, however, lessens the ability to offer the precise kind of atmospheric settings at the treating phase which is influenced by the kind of products to be packed. This is the main reason why microperforation are applied, in this process, tiny micro holes are put through the plastic films post-printing and post-converting which in turn labels it as an appealing method. In this kind of application consistency of the holes are very important. (Christopher, 2002, p. 1-2.)

In food packaging industry, the act of perforation involves the provision of small holes on a film seal. Normal mechanical sheets may be perforated or punctured in various ways with the use of lasers (see the figure 8), die, punch, pin or needles. The use of needles can be made desirably with heat application or not. Handling with hot needles takes excess amount of time making the processing of this method time-consuming and the holes measurement tends to be noticeably large. Regarding cold needle perforation there is usually some setback due to the collapsing of sheared material back into the holes, which results in very uneven holes shapes. Other means is the use of electrostatic discharge whereby packing film lids are spread over some high electrostatic voltage, which produces sparks through the films that eventually makes very tiny holes in microns. On the other side the drawback surrounding the use of electrostatic discharge is its slow process and it is limited to polymer materials of very small thickness. Also there is difficulty in handling the arching process as to the required amount holes in order to match the desired flow rate. (Christopher, 2002, p. 1-3.)

Figure 8. Laser perforation process on a printed web (Packaging-Labelling, 2015).

Newer method of producing holes of micro diameters comes with the use of laser. Operating with laser, the light intensity gets absorbed when the beam is focused on the polymeric film seals. During light absorption on the film, the beam deposits heat, which then melts and immediately vaporizes the spot, creating consistent holes depending on the material, well-defined heat affected zone around the holes are generated. The challenges faced by the use of laser in perforation of industrial films in web position is the tendency of having a mismatched speed that does not correlate with the speed of 300 ft/min laser light energy and the speed of the film web, which in turn results in the formation of oblong holes another greater challenge is that laser beam energy per unit areas diminishes. (Christopher, 2002, p. 1-3.)

According to Christopher (Christopher, 2002), Preco Laser System from Preco, Inc. has introduced a procedure for beam compression that enables the laser to be used on speeds exceeding 1000 ft/min (see the figure 9). The beam compression here is a technology in which laser pulses are converged and guided to focus and emit its intensity on a single point of the film. This gives a final micro hole on the film that is proportionally round, that gives the film a constant flow rate value. Also the energy from the laser is independent on the film web speed meaning that each spot could be perforated freely on any speed. The figure below shows Preco's corresponding flow rate with regards to the laser energy for beam compression perforating system. With the use of a web speed of 1000 ft/min, the flow rate measurement is cm^3/min.

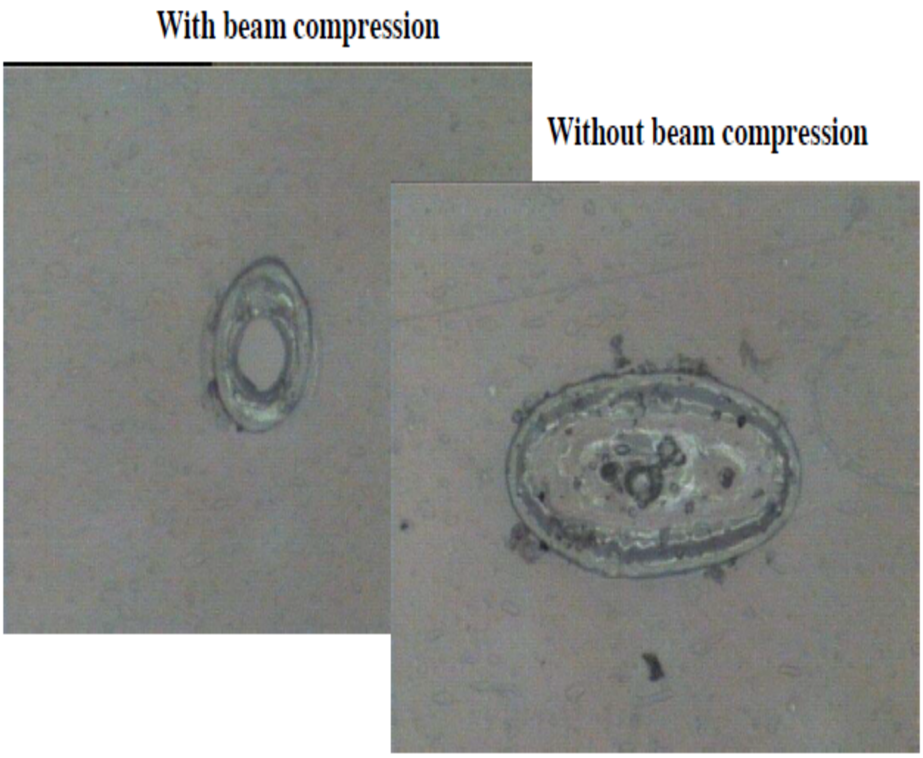

Figure 9. Evaluation of microperforating holes between beam compression and normal beam (Christopher, 2002).

Figure 10 illustrates the chat relationship between flow rate and the relative laser energy using the compressed laser beam mode. At higher flow rates much more energy is required under 1 atmosphere of pressure. Figure 11 expresses the relationship of flow rates and the hole diameter of the perforated films. With the result showing higher flow rates with increasing size of holes.

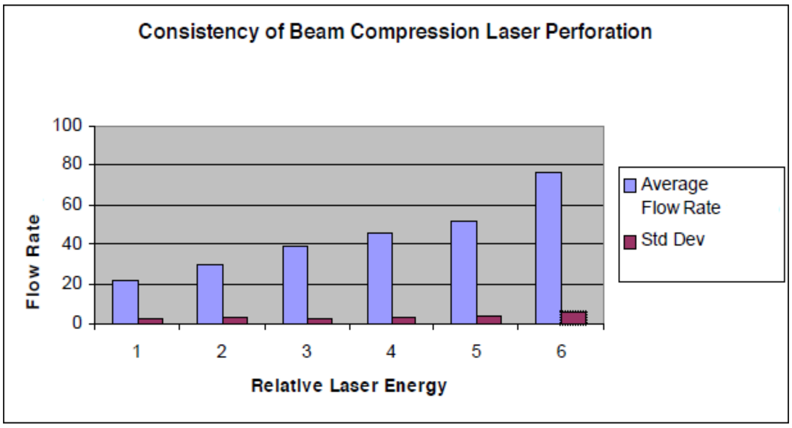

Figure 10. Flow rate ($g/m^2/h$) with respect to the relative laser energy (Joules) for the Beam Compression Laser (Christopher, 2002).

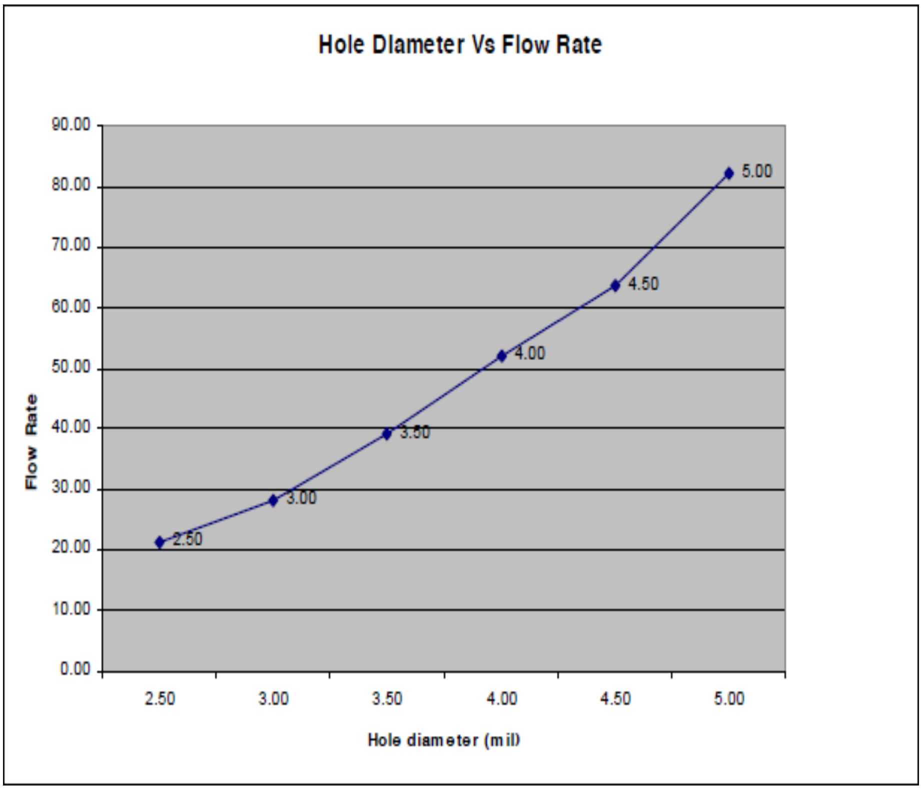

Figure 11. Flow rate (g/m^2/h) with respect to hole diameter for a film laminate (Christopher, 2002 p. 4).

In fresh produce using MAP, laser perforation is the suggested process to be used due to their advantages in producing smaller holes with consistency compared to mechanical and other methods of perforation. The lasers are often placed on roll slitting machines where flexible packaging materials (biaxially orientated polypropylene BOPP) as the printed material webs are slit down to the finished roll. According to a review by Larsen & Liland, (2013, p. 273) there is need for an easy and economic way of altering and accurately determining the gas transmission rate of various food packages. This has created an opportunity to test various perforated polymeric films of PET and BOPP, using the aid of laser beam and acupuncture needle (see the figure 12).

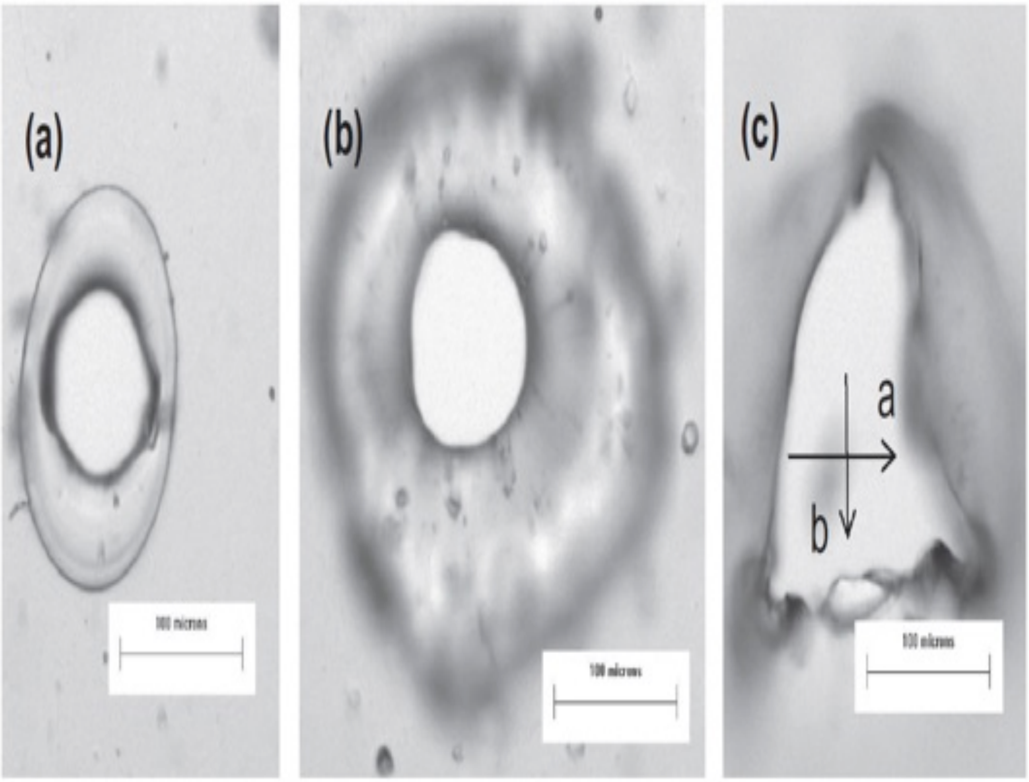

Figure 12. Comparative images for: (a) Microperf-BOPP, (b) Microperf-PET and (c) Mechperf-PET. a and b give the various diameters in x-y-direction. (Larsen & Liland, 2013, p. 275.)

The exchange of gases between the surrounding and the inside of the package is achieved virtually with the microperforations of several simulations placed in describing this effect through the perforations but there is a collective view on the Fick's law which makes it widespread in the measure of gas flow rates like oxygen penetrating microperforated plastic seals. Hole size is one other factor to be looked at while operating with laser punctured film packs in connection with the storing states. Larsen & Liland, (2013 p. 274) investigated the various microstructures of plastic films that are microperforated using their gas transmission properties. They witnessed a direct rise in both oxygen and carbon dioxide gas transmission rates with the perforated holes diameter ranging from 30-100 µm. The study revealed that microperforated holes with diameter higher than 55 µm have a tendency of losing their diffusion coefficient in the presence of convection, the most stable results on transmission rates were realized using smaller holes instead of some few outsized ones. Figure 13 describes the changes in gas volumes observed using various film materials within a period of storage.

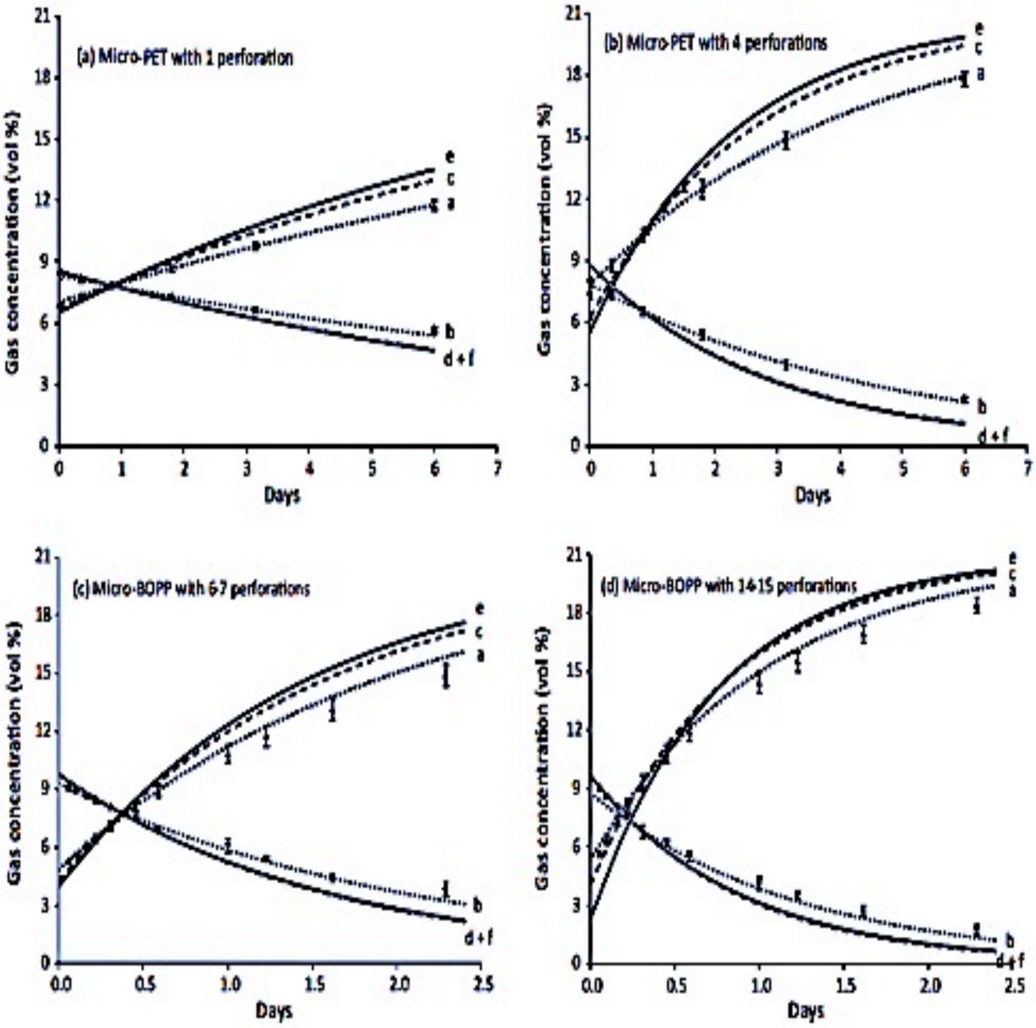

Figure 13. Observable change in the amount of gases with respect to the holes used in period of storage. (Fishman, Rodov, & Ben-Yehoshua, 1996.)

The transmissions of gas in three different forms of packages were examined and results for single perforated and whole packages were observed and presented in Table 5 and 6.

Table 5. Transmission rate evaluation ratio for oxygen and carbon dioxide with regards to their respective amount of holes at selected temperature (Larsen & Liland, 2013, p. 275).

Package	Perforations	Temperature	OTR/pkg (mL d^{-1})	CO_2TR/pkg (mL d^{-1})	Ratio CO_2TR/OTR	OTR/perf. (mL d^{-1})	CO_2TR/perf. (mL d^{-1})	Ratio CO_2TR/OTR/perf.
Mech-PET	1	4	284 ± 20	257 ± 34	0.9	279 ± 19	242 ± 33	0.9
Micro-PET	0	5	5 ± 1	15 ± 3	3.1			
	1	5	103 ± 5	108 ± 5	1.0	98 ± 5	92 ± 5	0.9
	2	5	185 ± 20	172 ± 13	0.9	90 ± 10	78 ± 7	0.9
	3	5	274 ± 17	241 ± 15	0.9	90 ± 6	75 ± 5	0.8
	4	5	366 ± 27	322 ± 26	0.9	90 ± 7	77 ± 7	0.8
Micro-PET	0	10	5 ± 1	19 ± 4	3.7			
	1	10	134 ± 18	124 ± 13	0.9	129 ± 18	105 ± 13	0.8
	2	10	193 ± 7	171 ± 3	0.9	94 ± 4	76 ± 2	0.8
	3	10	279 ± 8	251 ± 7	0.9	91 ± 3	77 ± 2	0.8
	4	10	368 ± 12	329 ± 8	0.9	91 ± 3	77 ± 2	0.9
Micro-PET	0	23	10 ± 1	41 ± 4	4.3			
	1	23	131 ± 22	137 ± 6	1.0	121 ± 22	96 ± 6	0.8
	2	23	224 ± 25	218 ± 28	1.0	107 ± 12	89 ± 14	0.8
	3	23	309 ± 14	295 ± 17	1.0	100 ± 5	85 ± 6	0.8
	4	23	374 ± 21	354 ± 18	0.9	91 ± 5	78 ± 5	0.9
Micro-BOPP	0	4	155 ± 39	267 ± 86	1.7			
	6 or 7	4	745 ± 51	693 ± 84	0.9	88 ±5	63 ± 13	0.7
	11	4	1083 ± 68	1013 ± 22	0.9	84 ± 6	68 ± 2	0.8
	14 or 15	4	1434 ± 137	1229 ± 145	0.9	88 ±6	66 ± 8	0.8

Table 6. Transmission rate for oxygen and carbon dioxide compared to static method (Larsen & Liland, 2013, p. 275).

Sample	*a*	*b*	Area	Fishman et al. (1996)		Gonzalez et al. (2008)		Measured – static method	
				OTR	CO_2TR	OTR	CO_2TR	OTR	CO_2TR
Micro-BOPP	76	77	4582 ± 472	127 ± 7	98 ± 6	114 ± 7	101 ± 6	87 ± 5	66 ± 8
Micro-PET	95	86	6425 ± 376	160 ± 5	123 ± 4	139 ± 5	122 ± 4	99 ± 16	84 ± 11
Mech-PET	175	92	12576 ± 4417	241 ± 39	185 ± 34	204 ± 39	179 ± 34	279 ± 19	242 ± 33

1.4 Ripening of Fruits

The ripening is the process when fresh produce most especially fruits achieves their desirable flavor, quality, color, tasty nature and other textural properties; it therefore represents the coordinated development and biochemical growth that proceeds to maturity. Fresh fruits coming in various sizes, shapes and colors, possesses different characteristics due to their belonging species. Some fruits have diverse ripening programs, for example, a fruit like avocado ripens after harvest and some other fruit like mangoes could ripen before harvest. In ripening process, ethylene plays a key role as a gaseous hormone, including the contribution in other important areas like in nutrition and the building of edible fibers that serves as diets for human consumption. (Barry, & Giovannoni, 2007, p. 144.)

The quality of fruits improves mostly during storage, which gives proper consideration on the accountability of the storage method utilized and other pre-harvest factors. Storage methods have huge influence on the quality of specific products such that the transportation and housing results in some physiological and biochemical damages of the products. When considering fully matured fruits, there exist two conflicting factors; there is an increasing desire from the consumers in area of quality and at the same time, there is also strong challenge on the producers for storage of the product as its storability decreases. The graph below (see figure 14) portrays how fruits gets ripen, value features like colors and flavors rises, as however, the appropriate storage phase falls. (Watkins, & Nock, 2012, p. 4.)

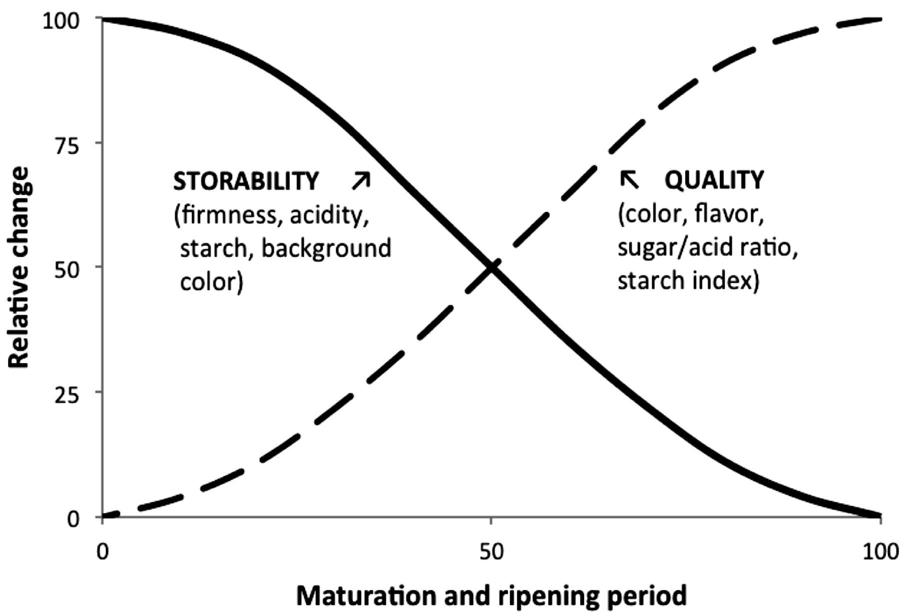

Figure 14. Correlation between the ability to store a ripening food with the quality properties required by consumers (Watkins, & Nock, 2012, p. 4).

This relationship can be explain with the picking of apples at full ripeness, it will appear, mature in color, low starch content and high aroma, however, it will posses low shelf-life. In order to decide the one with prolonged shelf-life, it has to get picked up beforehand especially periods with huge starch in it and low aroma volatiles.

Due to the lack of natural uniform ripening of fruits in the food industry (see the figure 15), there has been a challenges faced by producers. This has led to the adaptation of various technologies applied in effecting uniform ripening of fruits, under natural circumstance ethylene plays that key role as ripening hormone when its filled in pressurized cans promote fruits ripening in 24-48 hours. (Barry, & Giovannoni, 2007, p. 147.)

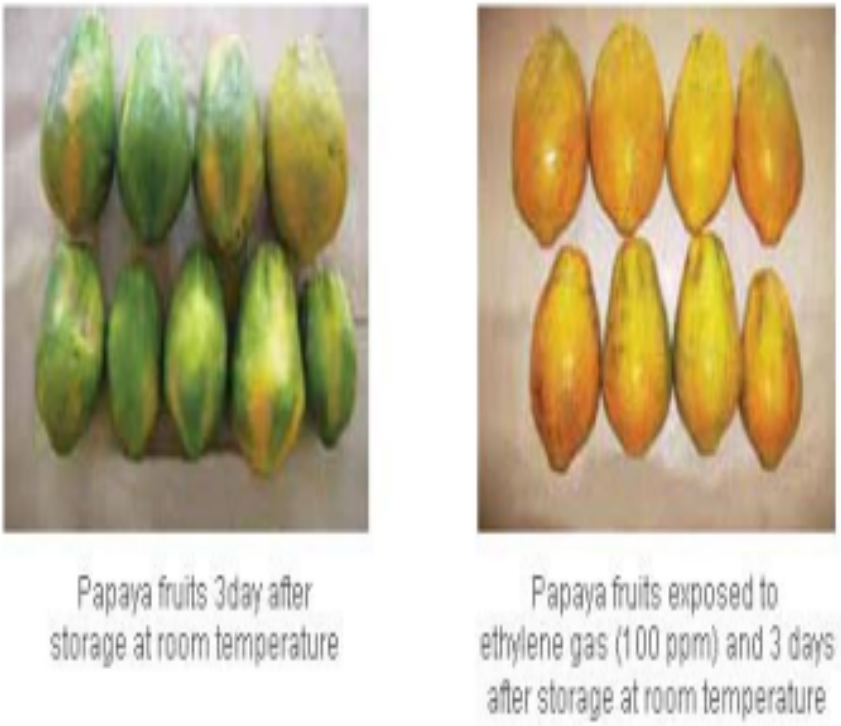

Figure 15. Uniform ripening of papaya fruits using ethylene gas (ISOPAN, 2015).

Another method of fruit ripening is with the use of paddy straw, where unripe fruits are spread over wheat and paddy straws for a week to ripen (see the figure 16). (ISOPAN, 2015.)

Figure 16. Mango ripening using straws (ISOPAN, 2015).

1.5 Conclusion of theory

As earlier sections have described, there is strong need for the prolonging of fresh foods shelf-life. In order to achieve this there has to be some significant changes applied to the packaging material by affecting the right packaging parameters that are adequately needed for the fresh foods to be packed.

The quality of fresh food products varies significantly during the shelf-life period. Proper monitoring of the products during transportation and storage chain provides supplementary indications for predicting the quality of the product, which will in turn assist in the logistic control throughout the phase.

2 METHODS

As stated earlier, one of the aims of this work was to apply various studies and tests on ways of understanding the interactions of the atmospheric content of packages with the use different plastic film materials. The plan was to produce perforated film seals from different materials and then carrying out tests on them. Several parameters were measured. Lastly, these provisions permitted the measurement of possible gas transmission rates as function of the permeability of the used films in relations to the rate and amount of moisture passing through these films. The layout below (see the figure 17) portrays the outcome of the methodology for carrying out the needed experiments for this work. This is divided into three sessions.

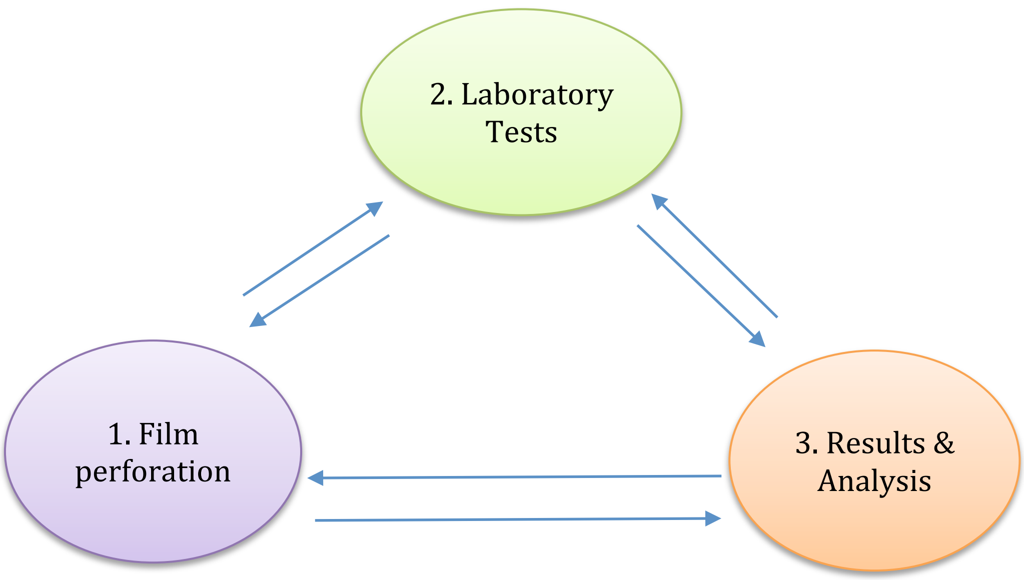

Figure 17. Outline of the experimental methods of this work.

Each session of phase appears in a triangulation form with influences from other sessions. The first phase of this work involves the perforation of the available plastic films and the microscopic study of their symmetrical holes formed, heat affected zones generated, and absorbability of the materials. The second session of the work involves the use of these microperforated film samples in the necessary laboratory tests. And the final phase needed in carrying out this work involves the collection of the results and analyzing them. The results gained after the tests determines the parameters used while perforating the polymeric films, as such, these parameters influences the tests procedures used in the laboratory and in turn with these tests the result is obtained.

2.1 Film Perforation

Due to the nature of this work several samples of plastics film from various manufacturers were collected. These materials were all drilled through with a fiber laser of varying wavelengths and powers (see the figure 18). The plastic film materials are:

Film A: TER HB 50 PET EZ PEEL from Bemis

Film B: TER HB 50 EZ PEEL from Bemis

Film C: PE NP film by Flextrus

Film D: BIALON 3 T PEEL by Wipak

Film E: WESTOP 405 B PET by Westpak

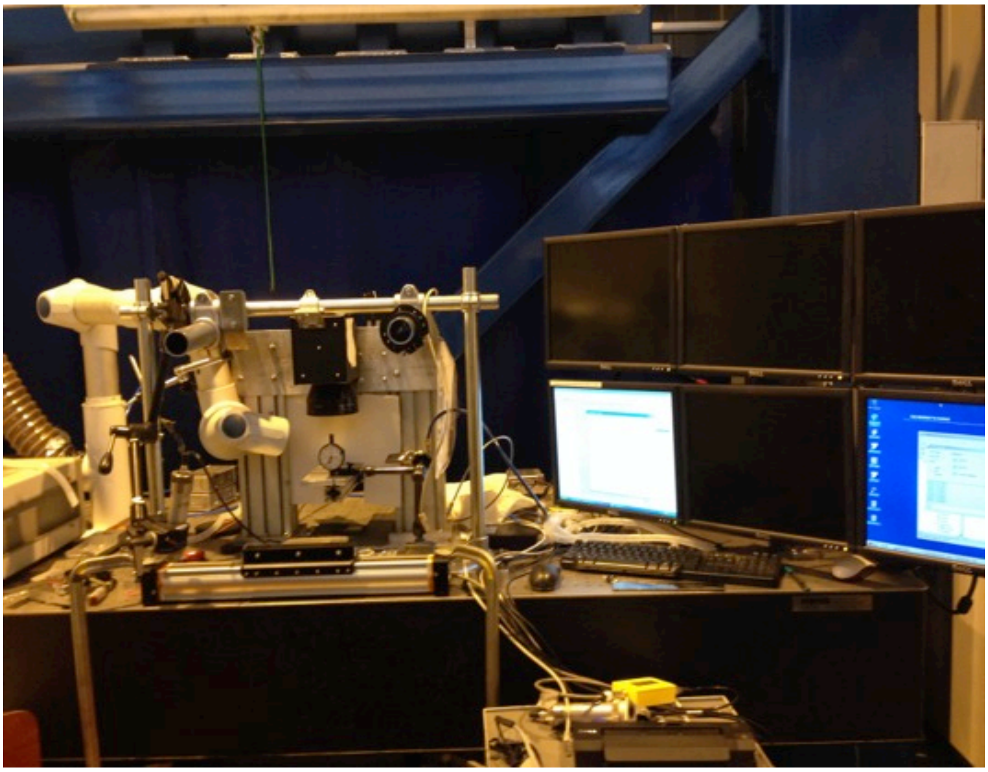

Figure 18. LUT future factory's fiber laser assembly used in perforation.

Before the perforation exercise some piece of laboratory film membranes were checked under microscope (see the figure 19) and the resulting for membranes and the result showed an average diameter of 21µm on the membrane. In order to achieve much symmetrical micro holes the laser was used to drill the five sets of different polymeric film materials listed above.

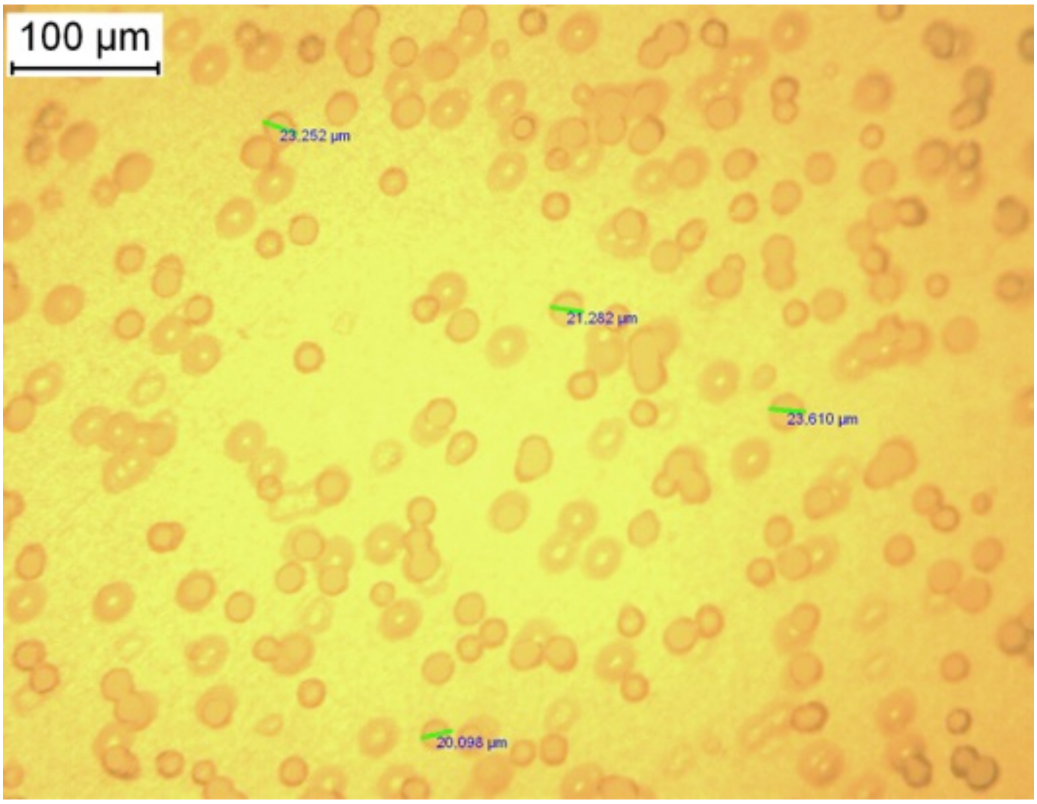

Figure 19. Microscopic view of 20 µm diameter holes of a polycarbonate membrane.

2.1.1 Objective

The objective of the laser drilling process was to create some tiny holes on films before being used for sealing. This will help in creating polymeric films with similar perforations like that of the laboratory film membrane. The aim is to get the right film material to be used for water vapor transmission rate analysis.

2.1.2 Laser drilling

The input parameters on the fiber laser were tried on few set pieces of films each from the polymeric films listed above. The parameters were:

- Power = 20W
- Frequency (pulse repetition rate) = 20 kHz
- Repeats = 1, 3 and 5   Time for 1 repeat = 6 s
- Drilling mode duration = 2000ms (40000 pulses/repeat)
- Area = 0,001017876 ⇒ 0.001018 m^2 (the top of the 50 ml laboratory flask used)

In order to achieve much smaller holes the film set pieces were drilled in various numbers of repeats of 1, 5 and finally 3 gave some much tinier holes. After series of drilling tests the Film B: TER HB 50 EZ PEEL from Bemis was selected as the actual sealing film for the laboratory exercise and to undergo 3 repeats each of two sets of samples. One of the samples was with 2 holes and the other with 4 holes respectively on an area of the selected 50 ml laboratory flask's top used.

2.2 Water vapor transmission tests with film

For the purpose of carrying out this laboratory exercise, based on the experimental setup and apparatus available a modified ISO 2528 standard method was selected. The actual standard features use the gravimetric (dish) approach in determining moisture flow rate. With the modified method, dish was replaced with a 50 ml laboratory flask.

2.2.1 Objective

This test is to determine the transmission rate of moisture through specific plastic film materials. This process was done at a controlled relative humidity using a conditioning chamber. The test was conducted by employing modified widely used ISO-standards.

2.2.2 Standard

ISO 2528: 1995-09-01 ISO Standard test specifies an approach to determine water vapor transmission rate (often erroneously called "permeability") across polymeric film sheets by the conditioning chamber.

This standard describes a test method that can in theory be practiced with any sheet material. In practice its main use is for flat, usually thin, materials that can be processed to form a vapor-resistant barrier, as used in packaging such as plastic films, paper, board or laminate of paper.

This test is intended to give reliable values of water vapor transmission rate (WVTR) with the application of simple apparatus. The transmission rate here is not a linear function of temperature nor, generally, of relative humidity difference. A determination carried out under certain conditions is not, therefore, necessarily comparable with one carried out under another conditions. The test conditions should, therefore, be chosen to be as close as possible to the condition of use

2.2.3 Test Conditions

Three conditions of the same process were carried on a particular desiccant ($CaCl_2$). This desiccant was put inside flasks, closed by the polymeric film material to be examined and positioned inside a controllable atmosphere. These flasks were balanced to check their masses for various time gaps and flow rate of absorbed moisture was evaluated using inputs from observable change in masses of the corresponding time gaps.

Condition A.

- Temperature 23 °C
- Relative Humidity 50%
- Pressure 760 ±10 mmHg
- Desiccant size 25 ± 0.1 g

Condition B

- Temperature 5 °C
- Relative Humidity 35%
- Pressure 760 ±10 mmHg
- Desiccant size 25 ± 0.1 g

Condition C

- Temperature 23 °C
- Relative Humidity 90%
- Pressure 760 ±10 mmHg
- Desiccant size 25 ± 0.1 g

Time interval for each condition: 30 min, 1 h, 2 h, 4 h and 24 h. The jeiotech temperature and humidity chamber displays all temperature and relative humidity readings (see the figure 20)

Figure 20. Display unit of the conditioning chamber.

2.2.4 Apparatus and material

Due to omission of certain apparatus like the test dishes for 50 ml laboratory flasks, the experiment utilizes a modified standard procedure, which has a been proven equally satisfactory in use. The materials used are:

The 50 ml laboratory flasks

This is a shallow glass flask with a wider bottom and smaller internal diameter of 0.001018 m^2 (see the figure 21). Each flask has a grooved top to enable the sealing of the test piece of film with glue. The sealing of the grooved profile of the flask is done so as to avoid the escape of moisture through the edges of the test pieces. In this case the surface area of the bottom of the flask is not equal to the exposed surface of the test piece and each flask is specially assigned with a number.

Figure 21. 50 ml Laboratory flask.

Test pieces

Three sets of the chosen films with corresponding perforations of 0 holes, 2 holes and 4 holes respectively. Each piece is marked to the corresponding flask with which it is to be used.

Glue gun sealant

In order to create an adhesion between the flask and the polymeric film samples a glue gun (see figure 22) was used in producing the needed seal that is not brittle at ordinary temperature, not hygroscopic and not susceptible to oxidation. It was expected that freshly melted glue when exposed for 24 hours of the selected condition of A, B and C will not possess any change in mass greater than 1 mg.

Figure 22. Glue gun used.

Desiccant

Anhydrous drying salt of calcium chloride ($CaCl_2$) in the form of granules of about 3-6 mm in maximum size was grinded and kept oven dried in the last 24 hours (see figure 23) before filling and capping the flasks.

Figure 23. Lumps and powder of calcium chloride salt used.

Weighing balance

The balance in figure 24 (Presica 290) was used in determining the mass of each flask, film, the used glue and contained salt to an accuracy of 0.1 mg

Figure 24. Weighing balance.

Conditioning Chamber

Jeiotech Temp and Humidifying Chamber TH Series (see the figure 25) was the chamber in which the required controlled atmosphere can be set and air continuously circulated. It was controlled in such a way that the specified condition would not be very much affected and can be re-established within 15 min after opening and closure periods.

Figure 25. Jeiotech temperature and humidity chamber.

2.2.5 Conditioning

Setting of the desired conditions using the Jeiotech temperature and humidity chamber was achieved within 30 min. The total temperature range that is attainable in the chamber is -35°C to 150°C without humidity control and +15°C to 90°C with humidity control (see figure 26). Relative humidity can be achieved from 20% to 95%. Having condition of 5°C temperature and a relative humidity of 35% at the same time requires constant drying and humidifying from the chamber in order to keep the conditions at that level.

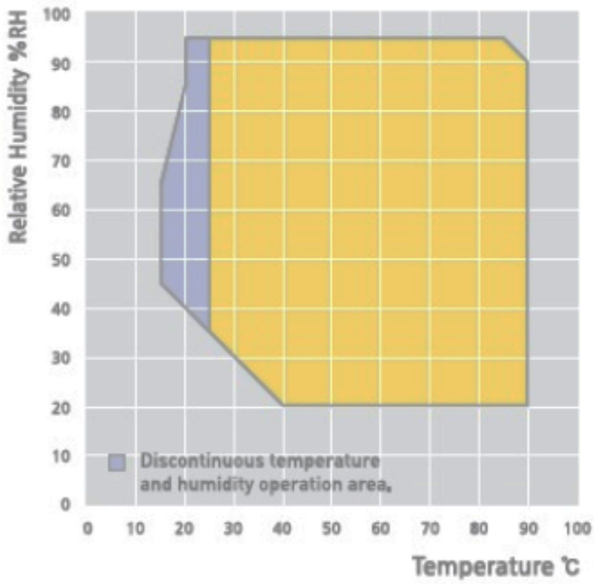

Figure 26. Temperature & Humidity Control Range (Jeiotech, 2015).

2.2.6 Preparation of test pieces and flasks

The test pieces of the films were carefully cut out to avoid all damaged areas of the film sample with the aid of a cutting template prepared from the measured top surface area to fit the appropriate top diameter of the 50 ml laboratory flask used. Few set pieces were tried and tested to check the tightness and leakage of the glued surface between the flask and the polymeric film using brilliant blue solution (as in figure 27).

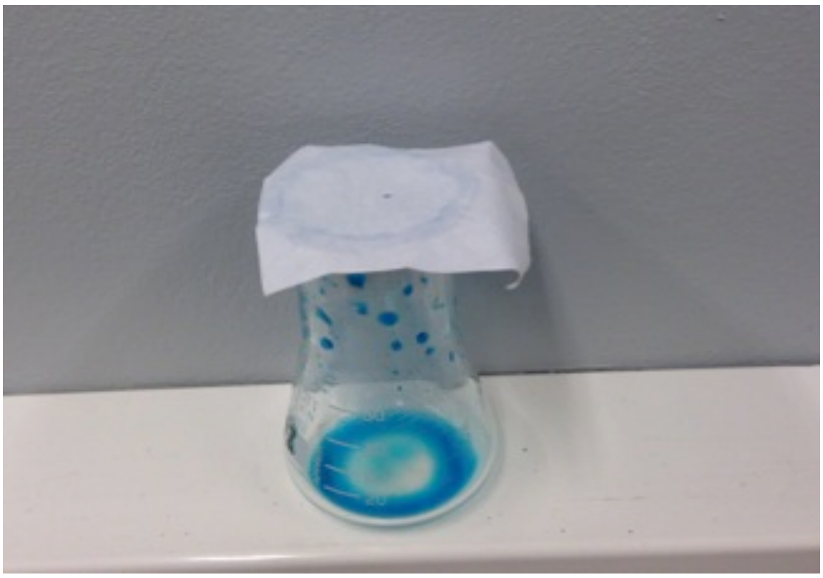

Figure 27. Leakage and tightness test.

This solution makes it possible to see if there are any leaks around the glued surface in order to enhance the glue application technique.

The method of preparation of the flasks begins with the careful cleaning and drying of the flasks and the test pieces templates. It also accompanies the use of a metallic ring placed on the sealed films to avoid unnecessary bulging of the glue when placed inside the humidifying chamber.

A quantity of about 25 ± 0.1 g of the desiccant was introduced into the flasks and the test piece of the film was placed on the flask with the required face upward and then glued appropriately to create a vapor-tight seal between the test piece and the flask. On using the glue gun, the molten glue flowing out of the gun was run onto the circular groove round the top of the flask such that a small meniscus of the glue appears on the inside diameter. Immediately after the pouring of the glue the test piece was placed, the metallic ring was place to support the joining and placed upside down to run another backup gluing on the outside surface between the flask and the test piece to avoid unseen leakage. This task was carried out rapidly to avoid or keep the absorption of moisture by the desiccant at minimum. After these the assembly was numbered together with the correspond number of the flask. These flasks are labeled in groups of 3-each corresponding to the number of holes.

2.2.7 Experimental procedure

The experiment began with the preparation of the desiccant by grinding and drying over 24 hours in the oven to the insertion of this desiccant into the flasks and completely sealing it to form the available numbered assembly. The whole assembly includes the flask, test piece, glue and desiccant as numbered was weighed using the weighing balance to the nearest 0.1 mg. and marked $\boldsymbol{M_0}$.

These assemblies after measured were placed uprightly enclosed inside the temperature and humidity chamber (see figure 28) that was controlled to the required test conditions. After placing in the chamber, successive weighing of the flask assemblies were carried out with their attached test pieces of films at suitable intervals of time. Shorter time interval was used in order of 30 min, 1 h, 2 h, 4 h, and 24 h. Each of the consecutive time intervals was also marked with a corresponding weight of $\boldsymbol{M_1}$, $\boldsymbol{M_2}$, $\boldsymbol{M_3}$, $\boldsymbol{M_4}$, and $\boldsymbol{M_5}$.

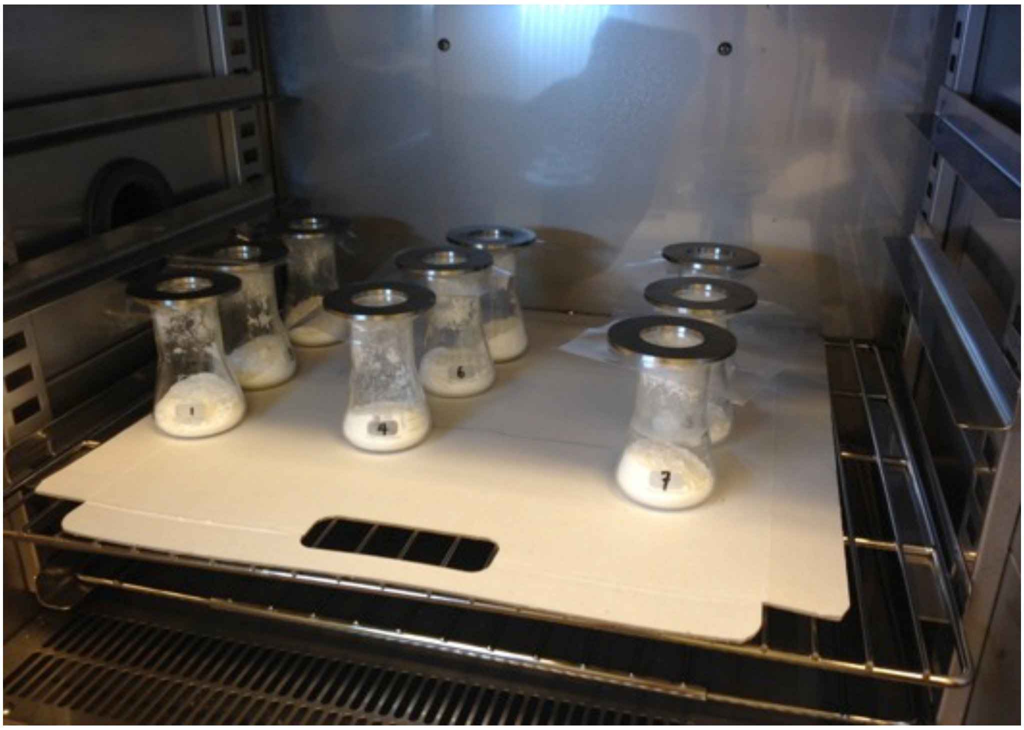

Figure 28: Marked assemblies inside of the temperature and humidifying chamber.

Three sets of measurements were taken for test pieces containing 0, 2 and 4 holes and their mean value was taken to calculate for the water vapor transmission rate. Therefore; WVTR was calculated using the following equation:

$$\text{WVTR} = \frac{w/t}{A} \tag{8}$$

Where, w is change in mass (g), t is time (s) and A is test area (m^2).

3 RESULTS AND ANALYSIS

The tests results of this work are based on two parts, which features the tests from the laser process of perforations on the available films and the transmission test involving the selected film as a test piece using water vapor transmission rate (WVTR) process.

3.1 Laser perforation test

The laser tests carried out on the films were done to show the laser effects on different film materials and to prove the selection of the desired film that could be used for the laboratory test on WVTR. Using the earlier stated laser parameters with an average power of 20 W and frequency (pulse repetition rate) of 20 kHz on the available film materials yielded different and almost similar results.

The following images give a clear-drilled profile of the films with the same laser parameters (see the figures 29 – 33). The ability of the films to have been perforated is as a result of their absorbability to the fiber laser beam used.

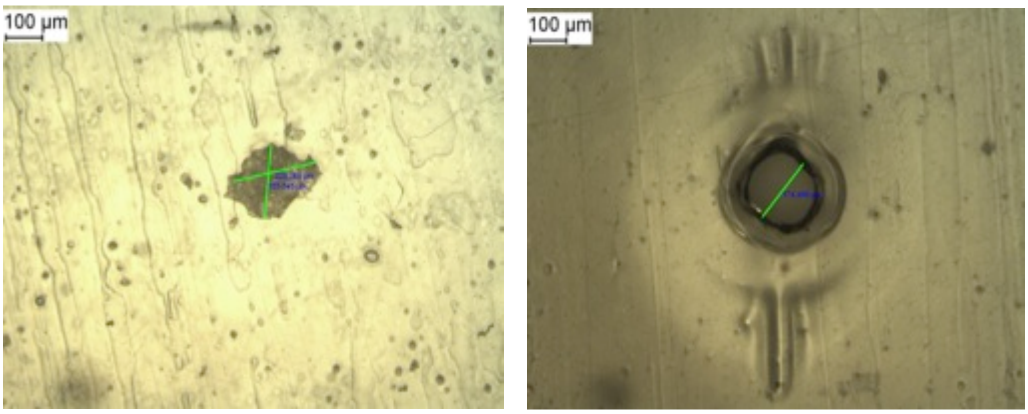

Figure 29. Film A: TER HB 50 PET EZ PEEL from Bemis after 1 repeat and 5 repeats Penetration = No and Yes, Diameter of holes = 0 µm and 174.496 µm.

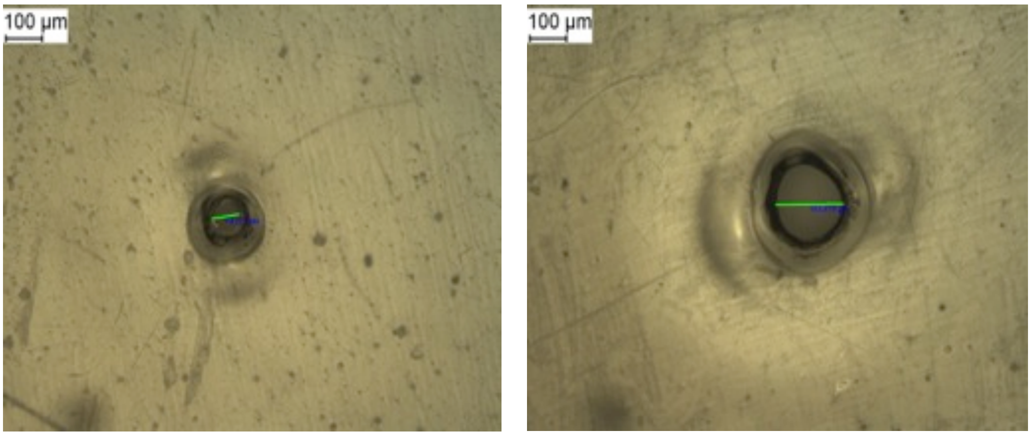

Figure 30. Film B: TER HB 50 EZ PEEL from Bemis after 1 repeat and 5 repeats

Penetration = Yes, Diameter of holes = 74.077 µm and 183.819 µm.

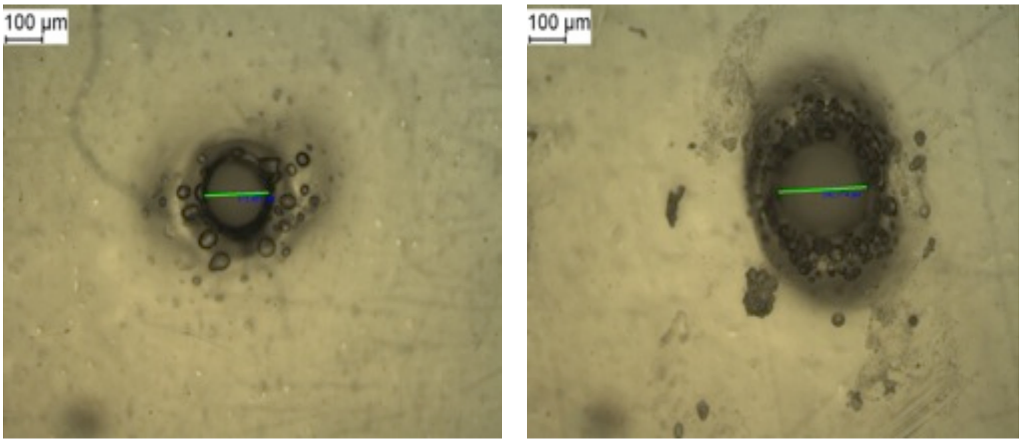

Figure 31. Film C: PE NP film by Flextrus after 1 repeat and 5 repeats

Penetration = Yes, Diameter of holes = 173.461 µm and 242.174 µm.

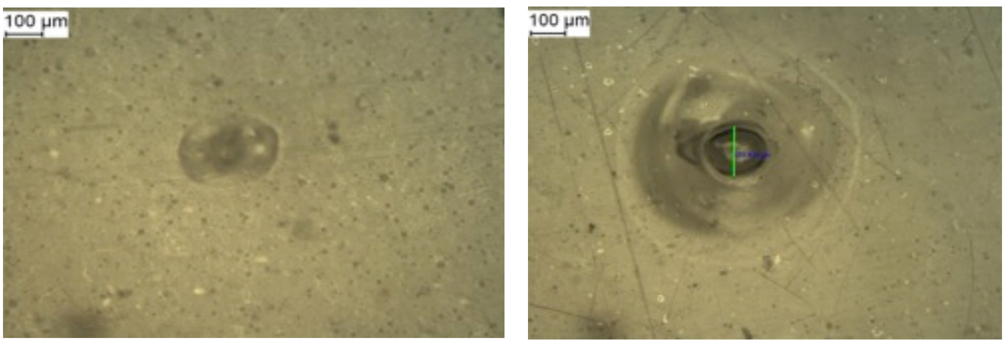

Figure 32. Film D: BIALON 3 T PEEL by Wipak after 1 repeat and 5 repeats

Penetration = No, Diameter of holes = 0 µm and 151.431 µm.

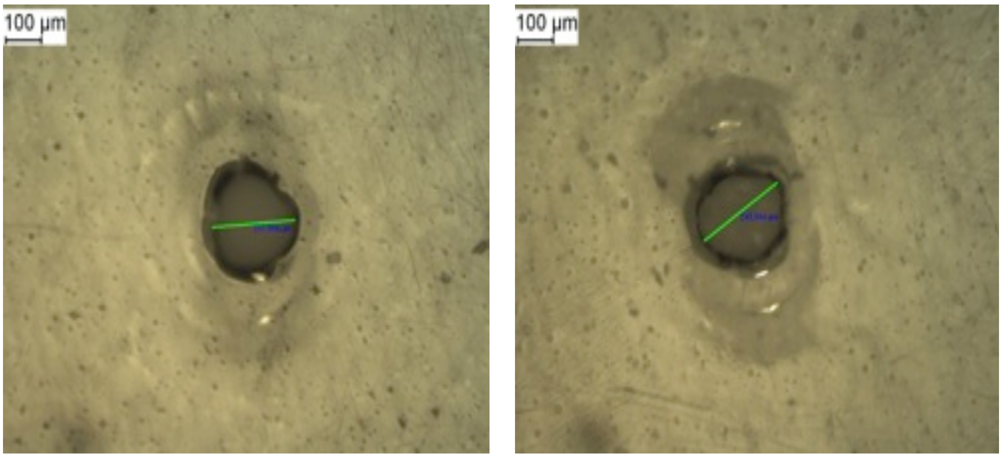

Figure 33. Film E: WESTOP 405 B PET by Westpak 1 repeat and 5 repeats
Penetration = Yes, Diameter of holes = 231.994 µm and 245.944 µm.

The criteria used in the film selection are focused on achieving a clear-drilled hole of smaller microns compared to that of the laboratory membrane shown earlier in Figure 19. Every single drill amounts to drill-duration of approximately 6 s, which contains about 40000 pulses of laser beam in every repeat.

Considering the first film sample in Figure 29, as a PET material from Bemis, it showed no absorption with a single drill of the set laser parameters and further drills created a hole of 174.496 µm with a bulging heat affected zone around the surface of the hole. The second film sample has material combination of PET, EVOH and PE. The result came out with a fine heat affected zone around the drilled hole, a single repeat and fifth repeat yielded holes of about 74.077 µm and 183.819 µm respectively. That of the third sample showed very good absorption of the laser beam with splatters and it also showed a great symmetrical hole. Interestingly on the fourth sample there was no absorption up till the fifth repeat with only a deep relief of about 151.431 µm without any penetration through the film material. This proves the material having almost similar properties to that of glass that do not absorb laser pulses when focused on it. The final film material Film sample E, has a higher absorption rate for the laser beam, with a single repeat alone producing a hole of 231.994 µm.

Base on film selection, the film sample with clearer symmetrical drill and diameter falling a bit under 100 µm gets selected for the WVTR measurements. The film B falls under the criteria of selection as the test piece, with the a single repeat drill producing 74.077 µm and a third repeat on same polymeric film product produced an average hole size of 80 µm on the produced samples of the test pieces of films drilled in sets of 2-holes and 4-holes.

3.2 Water vapor transmission rate

With the use of the modified standard method of ISO 2528 for determination of water vapor transmission rate through sheet materials like polymeric films products using anhydrous salts like $CaCl_2$ as desiccants for the absorption of water moisture through the film and into the flask assembly, water vapor transmission rate result could be achieved in the desired and possible atmospheric states.

Water vapor transmission rate is the continuous flow of vapor over time across the exposed surface of the test piece of the polymeric film used with use of modified standard (**ISO 2528: 1995-09-01**). In this study, the results of this test proves that desiccants at various atmospheric conditions can absorb certain percentage of moisture and summarizes the data collected from the use of different test pieces of specified amount of holes perforated on them. The water vapor transmission rate was measured at different condition of 23°C at 50%, 5°C at 35% and 23°C at 90% in temperature and relative humidity, of which the film showed various moisture transmission rates at these conditions with respect to their amount of perforated holes. During this process the level of moisture in the temperature and humidifying chamber was assumed to be adequate and precise enough as set throughout the experiment as long as there was always water in its reservoir tank.

3.2.1 Condition A

This first tested condition has the parameters of standard condition process with test parameters of 23°C and 50%, the weight gained value by moisture absorption from the salt versus the storage time of all the nine flask assemblies within a 24 h period are enlisted in the table below. All three members of each hole-group gets accounted for with their average weight gained throughout the 24 h time of the experiment (see tables 7-11). Average weight gained and transmission rate results by the test pieces (see figures 34 & 35) appeared to show uniform increase until the last measurement where sample 9 has a weight change of a bit over 0,09 g.

Table 7: Corresponding weight gained by flasks assembly with respect to time in Condition A (Standard Condition).

S/N	Holes	M_0 (0min) g	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
1	0	74,9646	74,9655	74,9707	74,9726	74,9729	74,9758
2	0	77,6039	77,6052	77,6095	77,6115	77,6119	77,6156
3	0	73,0485	73,0496	73,0539	73,0563	73,0567	73,0820
4	2	74,7244	74,7289	74,7348	74,7397	74,7422	74,7678
5	2	79,4144	79,4186	79,4260	79,4307	79,4341	79,4618
6	2	74,2554	74,2594	74,2653	74,2705	74,2726	74,3005
7	4	74,3520	74,3586	74,3649	74,3714	74,3728	74,4122
8	4	73,8775	73,8837	73,8926	73,8956	73,8996	73,9398
9	4	73,0417	73,0473	73,0536	73,0607	73,0643	73,1950

Table 8: Average weights-gained of moisture with respect to time in condition A.

Holes	M_0 (0min) g	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
0	75,2057	75,2067	75,2114	75,2135	75,2138	75,2245
2	76,1314	76,1356	76,1420	76,1470	76,1496	76,1767
4	73,7571	73,7632	73,7704	73,7759	73,7789	73,8490

Table 9: Average weights-change by moisture with respect to time in condition A.

Holes	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
0	0,0010	0,0057	0,0078	0,0081	0,0188
2	0,0042	0,0106	0,0156	0,0182	0,0453
4	0,0061	0,0133	0,0188	0,0218	0,0919

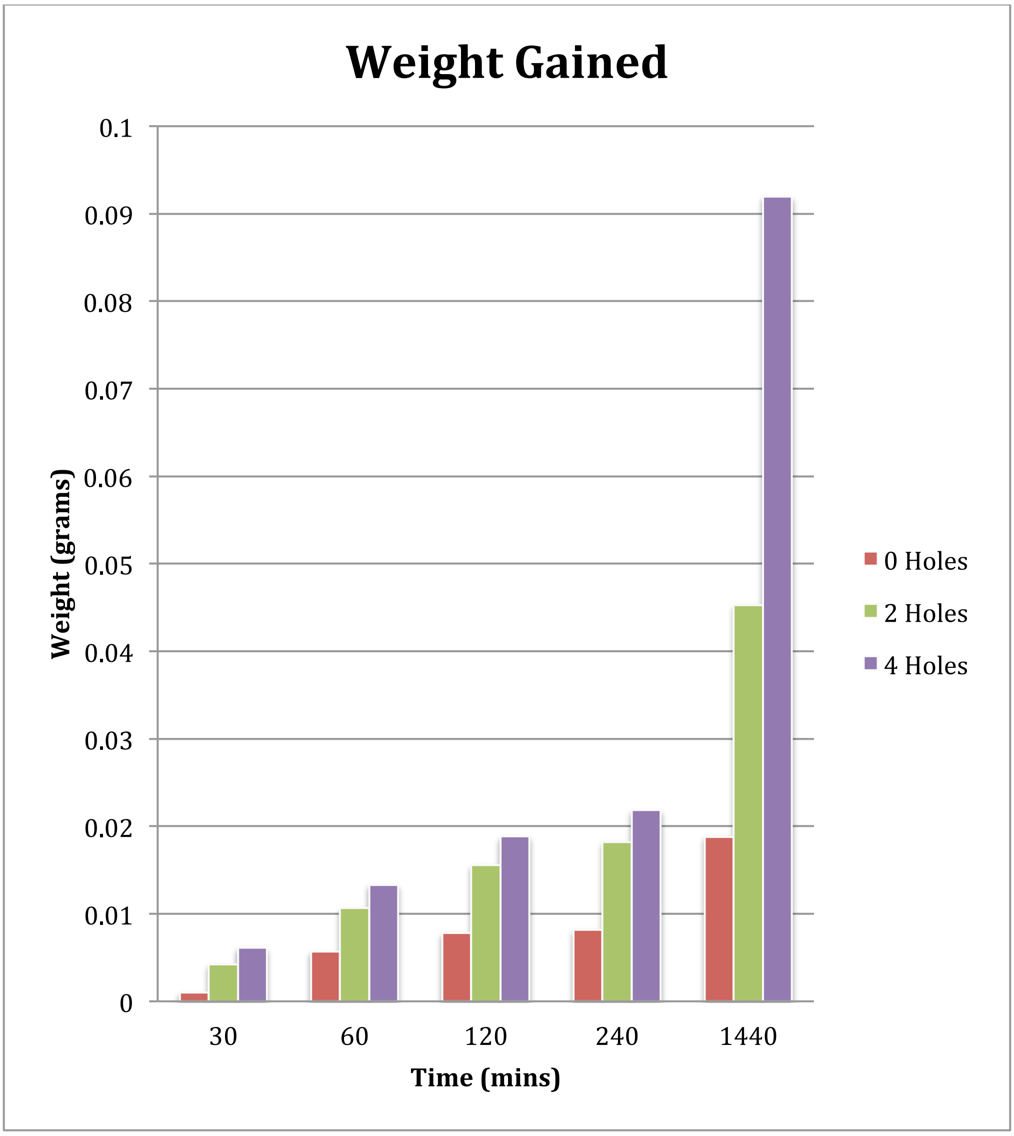

Figure 34. Average weight gained of moisture for Condition A.

Table 10: WVTR at various times with 24 h of Condition A (Standard condition).

Sample S/N	Holes	M_1 (30mins) g/m^2/24h	M_2 (1 h) g/m^2/24h	M_3 (2 h) g/m^2/24h	M_4 (4 h) g/m^2/24h	M_5 (24 h) g/m^2/24h
1	0	0,8842	5,9929	7,8595	8,1542	11,0033
2	0	1,2772	5,5017	7,4665	7,8595	11,4945
3	0	1,0807	5,3052	7,6630	8,0560	*32,9117*
4	2	4,4210	10,2174	15,0313	17,4874	42,6378
5	2	4,1262	11,3963	16,0137	19,3540	46,5676
6	2	3,9298	9,7261	14,8348	16,8979	44,3080
7	4	6,4841	12,6735	19,0593	20,4347	59,1428
8	4	6,0911	14,8348	17,7821	21,7119	61,2059
9	4	5,5017	11,6910	18,6663	22,2031	*150,6077*

The transmission rates using standard condition showed some precise measurements within the early hours. After 24 h, there were some inconsistent measurement from sample **3** and **9** as suspected from the average weight gained value and due to their high transmission rates value compared to others of same group. In order to actually get the precise measurement of WVTR, these values were omitted and other precise readings were then used in getting the average measurement of WVTR.

Table 11: Average WVTR at various times with 24 h for standard condition.

Holes	**M_1 (30mins) $g/m^2/24h$**	**M_2 (1 h) $g/m^2/24h$**	**M_3 (2 h) $g/m^2/24h$**	**M_4 (4 h) $g/m^2/24h$**	**M_5 (24 h) $g/m^2/24h$**
0	1,0807	5,5999	7,6630	8,0232	***11,2489***
2	4,1590	10,4466	15,2933	17,9131	44,5044
4	6,0256	13,0664	18,5026	21,4499	***60,1743***

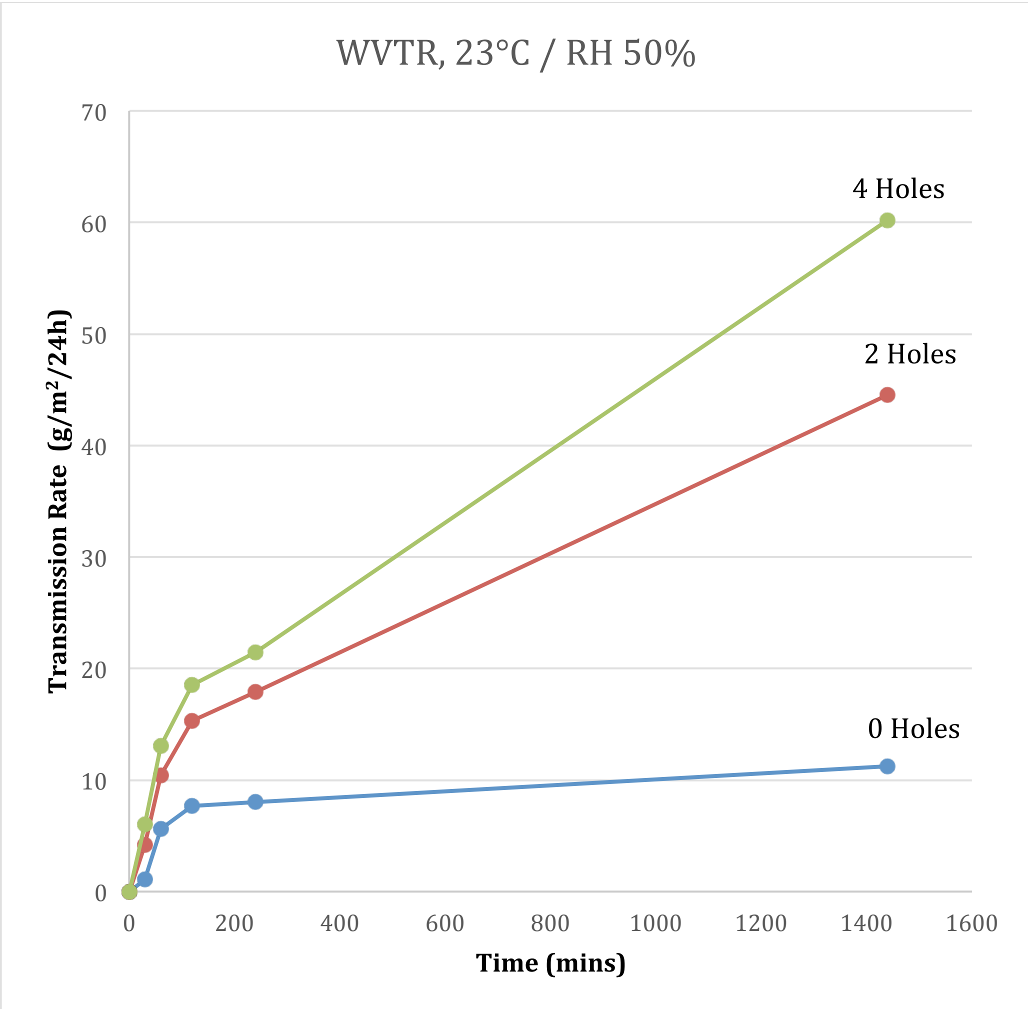

Figure 35. WVTR measurement with various test pieces with 24 hours at Condition A (Standard Condition).

At standard condition using the selected sets of test pieces the WVTR values showed a precise result based on assumptions of the relationship between transmission rate versus amount of holes and diameter of the holes. Bigger diameter produces more transmission rate likewise number of holes. After 24 h times the maximum transmission rate for 0-holes is 11,2489 g/m^2/24h and other results could be seen also in figure 35.

3.2.2 Condition B

The fridge condition has parameters of 5°C and 35% relative humidity. Within the measured time of 24 h, the results came out as expected and all readings were taken by repetition of the same process and recorded (tables 12-16)

Table 12: Corresponding weight gained by flasks assembly with respect to time in Condition B (Fridge Condition).

S/N	Holes	M_0 (0min) g	M_1 (30mi) g	M_2 (1h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
1	0	76,5400	76,5510	76,5578	76,5597	76,5609	76,5617
2	0	78,0635	78,0749	78,0819	78,0842	78,0853	78,0877
3	0	72,2862	72,2954	72,303	72,3041	72,3049	72,3068
4	2	73,5758	73,5948	73,6007	73,6019	73,6042	73,6095
5	2	74,2793	74,3009	74,3045	74,3058	74,3096	74,3125
6	2	72,4547	72,4735	72,482	72,4841	72,4857	72,4891
7	4	72,8466	72,8712	72,8734	72,8753	72,8779	72,8918
8	4	73,3905	73,4169	73,4186	73,4205	73,4231	73,4413
9	4	79,5182	79,5445	79,5462	79,5477	79,5503	79,5679

Table 13: Average weights-gained of moisture with respect to time in condition B.

Holes	M_0 (0min) g	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
0	75,6299	75,6404	75,6476	75,6493	75,6504	75,6521
2	73,4366	73,4564	73,4624	73,4639	73,4665	73,4704
4	75,2518	75,2775	75,2794	75,2812	75,2838	75,3003

Table 14: Average weights-changed by moisture for Condition B.

Holes	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
0	0,0105	0,0177	0,0194	0,0205	0,0222
2	0,0198	0,0258	0,0273	0,0299	0,0338
4	0,0257	0,0276	0,0294	0,0320	0,0485

The weight-changed values show some valid results without any doubt of distrust and when displayed in bars (as in figure 36) show some uniform increase in weight within the whole hours of the experiment. The weight-changed values for 0-holes may hang on within the average of 0,023 g for the next duration of 24 h, as it can be observed that within the hours of 4-24 there was just 0,0017 g increase which is lesser compared to the initial increase after 30mins storage in the chamber. That shows the transmission rate for 0-holes assemblies shows signs of some saturation during storage in fridge condition within 48 h (see figure 37).

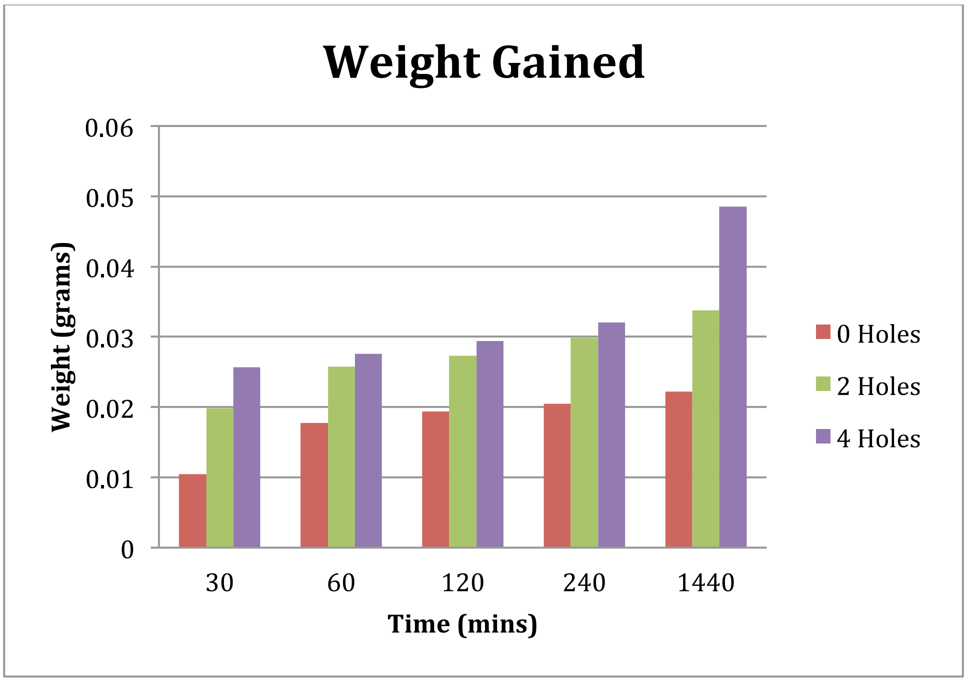

Figure 36. Average weight gained of moisture by flask assemblies within 24 hours of Condition B (Fridge Condition).

Table 15: WVTR at various times with 24 h of Condition B.

Sample S/N	Holes	M_1 (30mins) $g/m^2/24h$	M_2 (1 h) $g/m^2/24h$	M_3 (2 h) $g/m^2/24h$	M_4 (4 h) $g/m^2/24h$	M_5 (24 h) $g/m^2/24h$
1	0	10,8068	17,4874	19,3540	20,5330	21,3189
2	0	11,1998	18,0767	20,3365	21,4171	23,7750
3	0	9,0384	16,5050	17,5856	18,3716	20,2382
4	2	18,6663	24,4627	25,6416	27,9012	33,1082
5	2	21,2207	24,7574	26,0346	29,7679	32,6170
6	2	18,4698	26,8206	28,8837	30,4556	33,7959
7	4	24,1680	26,3293	28,1960	30,7503	44,4062
8	4	25,9364	27,6065	29,4731	32,0275	49,9078
9	4	25,8381	27,5083	28,9819	31,5363	48,8272

Table 16: Average WVTR at various times with 24 h for Condition B.

Holes	M_1 (30mins) g/m²/24h	M_2 (1 h) g/m²/24h	M_3 (2 h) g/m²/24h	M_4 (4 h) g/m²/24h	M_5 (24 h) g/m²/24h
0	10,3484	17,3564	19,0920	20,1072	21,7774
2	19,4523	25,3469	26,8533	29,3749	33,1737
4	25,3142	27,1480	28,8837	31,4380	47,7137

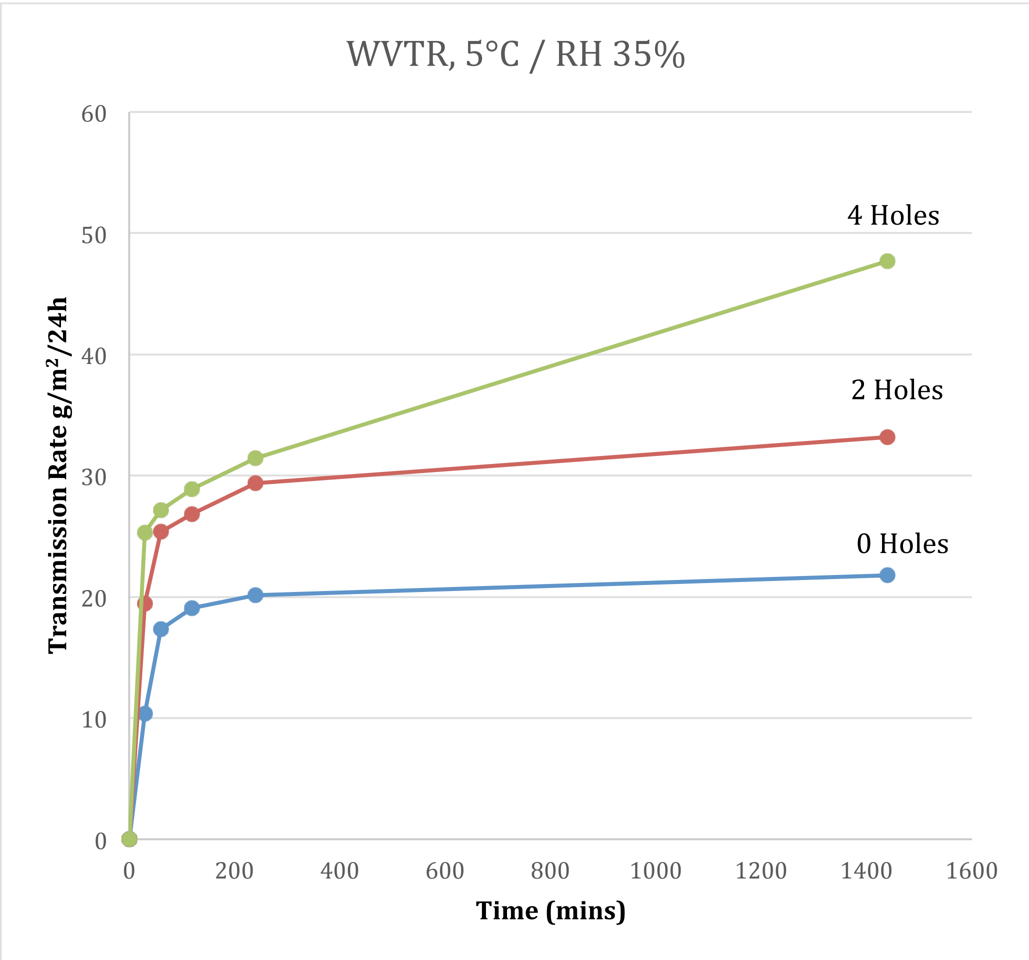

Figure 37. WVTR measurement with various test pieces with 24 hours at Condition B (Fridge Condition).

3.2.3 Condition C

The third condition is a storage condition similar to that of the tropics of 23°C and Relative humidity of 90%. On this test, the results came out to be very interestingly precise just that sample 2 and 9 were discovered to have some leakage after 24 h (see table 17) and as such their values were omitted but used in finding the average weight-gained by the flasks assemblies (see the tables 18-19).

Table 17: Corresponding weight gained by flasks assembly with respect to time in Condition C (Tropical Condition).

S/N	Holes	M_0 (0min) g	M_1 (30min) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
1	0	76,2731	76,2755	76,2763	76,2776	76,2791	76,2808
2	0	78,5213	78,5262	78,5269	78,5273	78,5282	*78,5403*
3	0	72,6809	72,6842	72,6857	72,6859	72,6876	72,6887
4	2	73,8413	73,8439	73,8448	73,8454	73,8473	73,856
5	2	74,8007	74,805	74,8065	74,8083	74,8114	74,8321
6	2	72,9374	72,9428	72,9433	72,9442	72,9462	72,9509
7	4	73,584	73,5886	73,5898	73,5902	73,5956	73,6215
8	4	73,8974	73,9019	73,903	73,9062	73,9104	73,9396
9	4	79,9569	79,9623	79,9632	79,9646	79,9668	*79,9858*

Table 18: Average weights-gained of moisture with respect to time in condition C.

Holes	M_0 (0min) g	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
0	75,8251	75,8286	75,8297	75,8303	75,8316	75,8366
2	73,8598	73,8639	73,8649	73,8660	73,8683	73,8797
4	75,8128	75,8176	75,8187	75,8203	75,8243	75,8490

Table 19: Average weights-changed of moisture with respect to time in condition C.

Holes	M_1 (30mins) g	M_2 (1 h) g	M_3 (2 h) g	M_4 (4 h) g	M_5 (24 h) g
0	0,0035	0,0046	0,0052	0,0065	0,0115
2	0,0041	0,0051	0,0062	0,0085	0,0199
4	0,0048	0,0059	0,0075	0,0115	0,0362

After this tropical storage condition, a sharp increase in weight of 0,0247 g of absorbed moisture was observed in the average weight-changed of the 4-holes group after the 4th hour. Though, the result should not really be compared to that from the standard condition within same time interval to be 0,0701 g. Also with the suspicious leakage from the marked samples of 2 and 9 gives special concern to the weight-gained values and the transmission rate as well (see the figures 38 & 39).

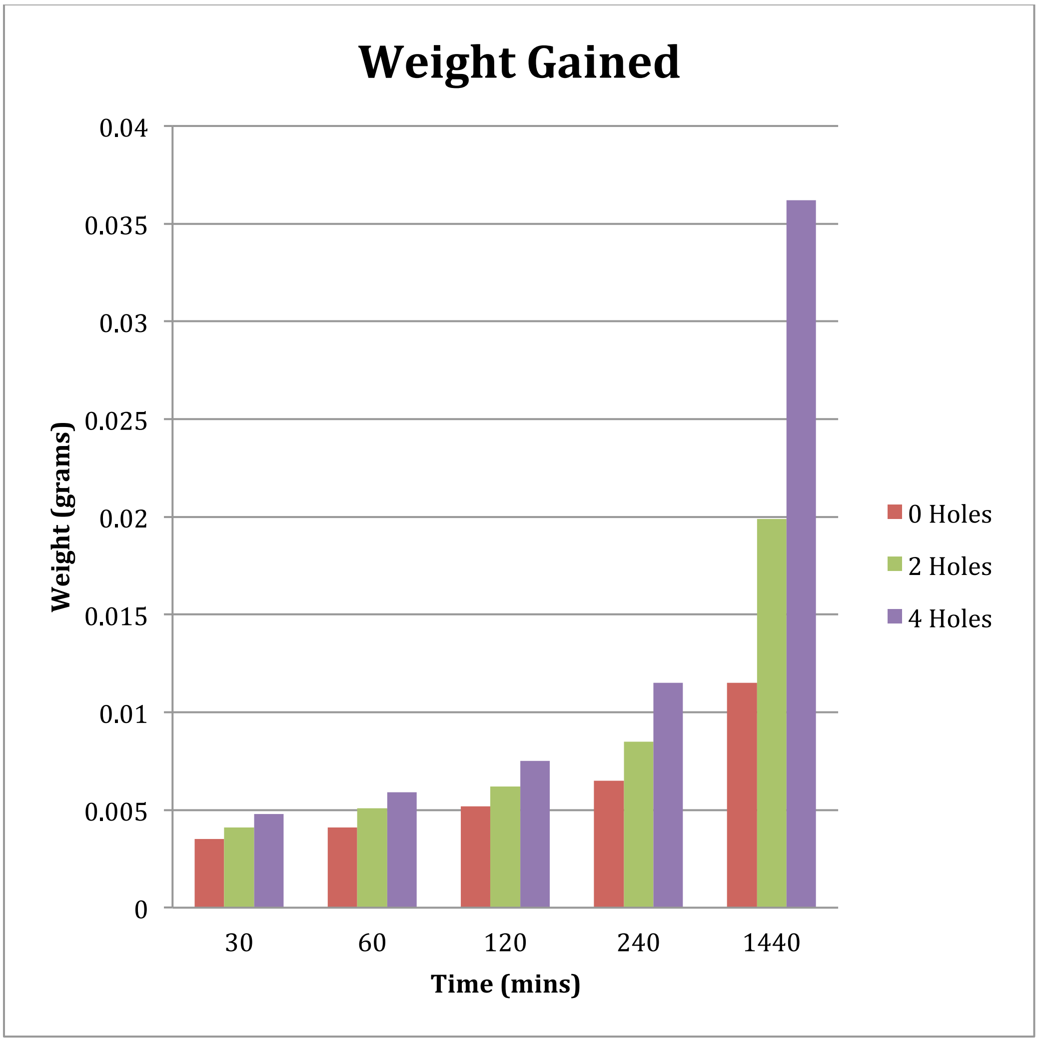

Figure 38. Average weight gained of moisture by flask assemblies within 24 hours of Condition C (Tropical condition).

Figure 38 above displayed some uniformed changes for the first 4 h and after that revealed a noticeable increase with the average of the 4-hole test pieces. Studying of the transmission rate would have yielded a WVTR value of 18,6663 $g/m^2/24h$ of water moisture with that of sample 2 after 24 h which is higher compared to the other samples of 1 and 3, both calculated average to be 7,6139 $g/m^2/24h$ (see table 21 & 22). Also that of sample 5 reveals a transmission value of 30,8486 $g/m^2/24h$ which appeared to be over double the other values from same group assemblies. Therefore, it has to be omitted from the main average transmission due to possibility of leakage after 24 h.

Table 20: WVTR at various times with 24 h of Condition C (Tropical Condition).

Sample S/N	**Holes**	**M_1 (30mins) g/m^2/24h**	**M_2 (1 h) g/m^2/24h**	**M_3 (2 h) g/m^2/24h**	**M_4 (4 h) g/m^2/24h**	**M_5 (24 h) g/m^2/24h**
1	0	2,3579	3,1438	4,4210	5,8946	7,5648
2	0	4,8140	5,5017	5,8946	6,7788	-
3	0	3,2420	4,7157	4,9122	6,5823	7,6630
4	2	2,5543	3,4385	4,0280	5,8946	14,4418
5	2	4,2245	5,6982	7,4665	10,5121	***30,8486***
6	2	5,3052	5,7964	6,6806	8,6455	13,2629
7	4	4,5192	5,6982	6,0911	11,3963	36,8414
8	4	4,4210	5,5017	8,6455	12,7717	41,4589
9	4	5,3052	6,1894	7,5648	9,7261	-

Table 21: Average WVTR at various times with 24 h for Condition C.

Holes	**M_1 (30mins) g/m^2/24h**	**M_2 (1 h) g/m^2/24h**	**M_3 (2 h) g/m^2/24h**	**M_4 (4 h) g/m^2/24h**	**M_5 (24 h) g/m^2/24h**
0	3,4713	4,4537	5,0759	6,4186	7,6139
2	4,0280	4,9777	6,0584	8,3507	13,8524
4	4,7485	5,7964	7,4338	11,2980	39,1502

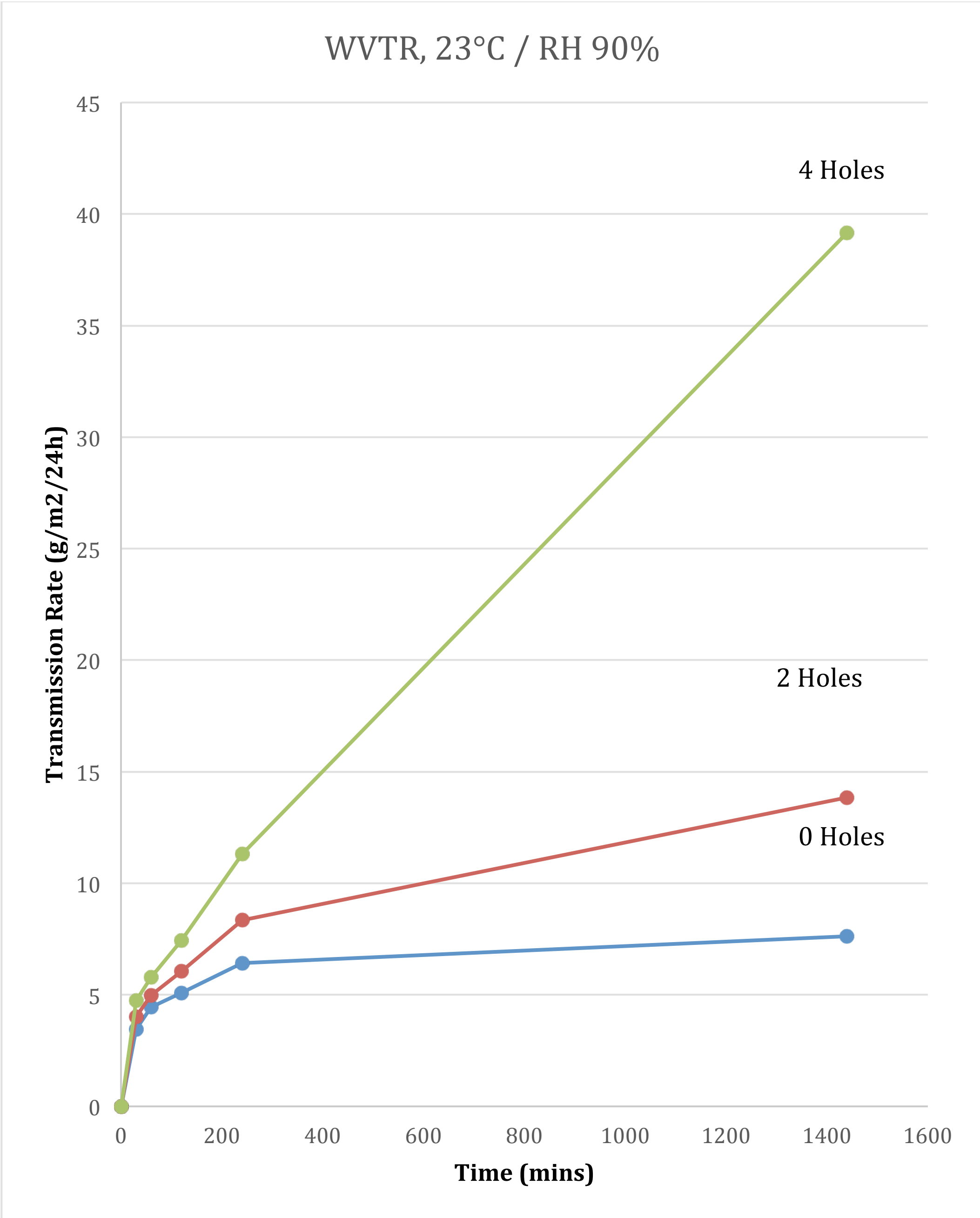

Figure 39. WVTR measurement with various test pieces with 24 hours at Condition C (Tropical Condition).

4 DISCUSSION AND CONCLUSION

The principal aim of this thesis is centered on the collection and study of critical information on how microperforations could be possibly use in influencing the moisture content of a fresh food package. The direction is based on the desired requirement of consumers with their growing wish for specially processed fresh products of mainly fruits and vegetables. A good understanding of packaging materials may give any producer long-term competitive advantage compared to competitors and improve its own production towards the future trends and challenges. Active development with consumers gives the key to cooperative improvement with customers, which will eventually draws profitability for all groups. Before the carrying out of this thesis, it was established that certain challenges like food wastage exists in the fresh food industries especially those located in remote locations in the World like in India with gross output of fruits and vegetables, where tons of waste are generated yearly due to mismanagement of these produce from their harvesting period, storage, delivering and marketing of the goods. During these phases of fresh food handling, the appropriate requirements of these goods have to be put in place; the proper harvesting methods will have to be applied, with the right logistic means in delivering of these goods. Fresh produce has been found to be more susceptible to disease organisms due to their increasing rate of respiration after harvesting. Therefore having a limited shelf-life under ambient condition. Although, the breathing rates of fresh foods could get affected or reduced by the use of countless maintenance procedures such as decreased temperature, dehydration, canning, freeze-drying, modified and controlled atmosphere, but most of these methods as they reduces the respiration rates drops the freshness of these produce.

In order to achieve the required moisture needed for these produce when packed there has to be this permissible passage of the required amount of gases and moisture needed. Even if the packaging material may tend to be permeable, there has to be some additional influence through the creation of micro holes to compensate for the needed amount of the continuing breathing of these fresh goods.

With numerous means of preparing holes on film packages, a key part of this thesis focused on the achievement of these micro holes with the use of laser technology. Bearing in mind that other possible means of attaining this film perforation could be achieved using mechanical needle process along with or without heat application because needles could be applied in various ranges of size and patterns, and the variability of the holes diameter could be achieved with the use of conical needles whereby the diameter of the holes produced is exclusively influenced by how deep the needle run through the films. Due to the setbacks studied with the use of needles, it was observed that sheared material parts usually collapse back into the hole to create an unevenness of the hole, which stand as one major criteria for the selections of films, this hole unevenness stand to interfere with the required transmission rate of gases and moisture for the fresh packed food.

A fiber laser unit was used in drilling the available film samples and the results came out successful on all films except that of Film D: BIALON 3 T PEEL manufactured by Wipak a subsidiary belonging to a Finland-based Wihuri Group that showed some poor beam absorption due to some similar laser characteristic with glass and as such it is suggested that good drill could be achieved with the means of needle perforation. Using the stated laser parameters, with the drill sets of 1 and 5 repeats, it was observed that not all the test pieces could achieve a clean drill with just 1 repeat alone and after 5 repeat the holes became bigger compared to the required range of hole diameter expecting to fall under 100 µm, and after several trials the 3 repeats yielded good drills based on the required criteria and the film B sample came out very clean with good evenness and clean heat affected zone around the holes.

The experimental part of this thesis was primarily centered on the measurement of moisture transferred into packages through polymeric films due to the respiration of the sealed fresh produced inside the pack, with the use of water vapor transmission rates tests, this process can actually be simulated. In this experiment, a certain amount desiccant made from anhydrous calcium chloride ($CaCl_2$) salt placed in a sealed flask acts as a fresh produce, which was stored under specific condition within the time of 24 h. The conditions selected during this experiment were chosen to possible similar storage conditions for fruits and vegetables with standard fridge and tropical conditions as much as it could be achieved with the temperature and humidifying chamber used. The results came out very positive as suspected except some suspicions of leakage after 24 h in sample 3 and 9 at standard condition and sample 2, 5 and 9 during tropical condition. With the use of the brilliant blue it emerges that the solution after been injected inside the flasks were noticed to be dripping out of the glued surface. During fridge condition there were no signs of leakage and it was observed that the gluing interface tends to lose its adhesive strength at standard and tropical temperatures of storage. Taking account of the actual measurements after the exclusion of the tampered sample, the results were still generated with other samples. The highest transmission rate measured occurred during standard condition with the 4-hole samples at 60,1743 $g/m^2/24h$. The lowest measured was in the tropical condition at 7,6139 $g/m^2/24h$ without any perforations. The fridge condition having low transmission rate with the 4-holes samples compared to standard condition may arise from possible hindrance to moisture flow through the perforated holes as a result of condensation. In actual fresh produce practice, freezing temperatures lower the breathability of fresh packed goods; therefore, moisture blocked holes for respiration may not actually stand as a challenge to the shelf-life of the good.

In conclusion, polymeric materials utilized in package sealing could also be developed from biological resources. Nonetheless, materials from biological sources have to put up a match out performance with effective functions so as to contest with already existing complex polymers in todays market. Characteristics of bio-based films compared to synthetically produced films shows a great potential of good performance in food packaging due to lapses that may arise from the use of synthetic petroleum-derive polymer materials. In breathable packing systems, laser technology has been exploited in the perforation of polymeric films due to their accuracy and short production time in order to facilitate gas exchange that elongates storage life span of fresh produce and meats by the elimination of condensation and gas buildup. For further consideration of this work, I will suggest an extended test carried out with fruits and vegetation in the consecutive study of moisture loss and ripening tests with actual fruits and vegetables. In general, there have been commencements of several works considering means of influencing the shelf-life of food packages. One typical feature of slightly processing of fresh foods is that its integrated approach offers the proper consideration of the raw material, handling, processing, packaging and the distribution to make a possible shelf-life period.

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