Light barrier properties of paperboard, packages and plastic caps in packages

Ljusbarriär hos kartong, förpackningar och plastkorkar

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EXAMENSARBETE

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Abstract

The thesis started 15th January in 2013 at Tetra Pak Packaging Solutions AB in Lund.

Milk is a product that is particularly sensitive to light. In order to protect milk from light, its package can have aluminium foil. The laminated aluminium foil provides an excellent light barrier but is expensive and not a renewable material. To be able to remove the aluminium foil and not lose too much of the package´s light barrier it is important to obtain knowledge in light barrier properties of other packaging materials than aluminium foil. Aluminium also provides a barrier against other components that may harm the milk, for example moist and oxygen, however this report will only focus on light barrier.

The light barrier for ambient stored milk has been the focus during the thesis. Most of the light barrier is located in the paperboard for milk packages. For milk stored at ambient temperature, the light transmission (light that penetrates a sample) should not exceed 0.1%.

Two different kind spectrophotometers were available for the light barrier measurements. One of the machines was U-3010 spectrophotometer which is a dual beam spectrophotometer that were used to measure flat samples. The other spectrophotometer was a dome spectrophotometer that was designed to measure on three dimensional structures.

The investigation of paperboards for 1 litre packages showed that they had protection against light of wavelengths that induced off flavour reactions with Riboflavin (220-375, 410-475 nm). But the transmission for light within the range 650-700 nm was above 0.1%. Those wavelengths induce off flavour reactions with porphyrins and chlorins.

The plastic caps on packages are a rather small part of the total package in term of area. But the light barrier of the total package could be lacking due to the plastic caps which is why they have been investigated.

The light barrier properties of paperboard, plastic caps and packages available in the market were investigated.

The paperboards used for 1 litre milk packages have less than 0.1% light transmission for wavelengths up to 500 nm. This means that they give enough protection against light that induce off-flavour reactions with riboflavin, but may still be subjected to light induced off-flavour reactions with porphyrins and chlorins.

Physical properties such as grammage and thickness affect the light barrier in paperboard, because the thicker a sample, the lower the light transmission according to Lambert-Beer's law. Some layers in the paperboard contribute more to the light barrier than others, due to different chemical composition.

The pigment in the plastic caps affects the light barrier. The brown plastic cap supplied by Tetra Pak and one blue cap available in the market had sufficient light barrier against off-flavour reactions with Riboflavin and also had low transmittance for the wavelengths where chlorins and porphyrins cause off flavour reactions.

The printing on paperboard improved the light barrier and transforming the paperboard into a package by creasing and then folding didn't result in a weakened the light barrier. This means that the light barrier of a paperboard still remains or has improved after being transformed into a package.

Sammanfattning

Examensarbetet inleddes den 15:e januari 2013 på Tetra Pak packaging solutions AB i Lund.

Mjölk är en produkt, som är särskilt ljuskänslig. För att skydda mjölk från ljus, kan dess förpackning innehålla aluminiumfolie. Det laminerade aluminiumfoliet ger en utmärkt ljusbarriär, men är dyrt och är inte ett förnybart material. För att kunna ta bort eller ersätta aluminiumfoliet och samtidigt inte förlora för mycket av förpackningens ljusbarriär är det viktigt att få kunskap om ljusbarriäregenskaper för andra material än aluminiumfolie.

I det här examensarbetet har fokus legat kring ljusbarriärer för material, som kan användas för okylda mjölkförpackningar. För okyld mjölk får inte ljustransmissionen (andel ljus, som penetrerar ett föremål) överskrida 0.1%.

Två olika slags spektrofotometrar fanns tillgängliga för ljusbarriärmätningarna. En av maskinerna var en dubbelstråle spektrofotometer, som användes för att mäta plana prov. Den andra var en kupol spektrofotometer, som användes för att mäta tredimensionella strukturer.

Undersökningarna av papprena för 1 liters förpackningarna visade att de skyddade mot ljus med våglängder som gav upphov till bismaksreaktioner med Riboflavin (220-275,410-475 nm). Men transmissionen i våglängdsintervallet 650-700 nm var över 0.1%. Dessa våglängder ger upphov till bismaksreaktioner med porfyriner och chloriner.

Plastkorkarna på förpackningarna utgör en bråkdel av förpackningens totala area. Men ljusbarriären hos hela förpackningen kan försvagas på grund av plastkorken, vilket är anledningen till varför den har undersökts.

Ljusbarriären hos papper, plastkorkar och förpackningar från marknaden undersöktes.

Papper som användes för en liters mjölkförpackningar hade mindre än 0.1 % transmission för våglängder upp till 500 nm.

Fysikaliska egenskaper, som tjocklek påverkar ljusbarriären. De olika lagren i kartongen bidrar olika mycket till ljusbarriären.

Pigmentet i plastkorkar påverkar ljusbarriären. Den bruna korken från Tetra Pak och den blå kommersiella korken hade tillräckligt bra barriär mot bismaksreaktioner med Riboflavin, kloriner och porfyriner.

Tryckfärgen förbättrar ljusbarriären på papper. Detta kan användas som ett alternativt sätt att förbättra ljusbarriären i papper.

Preface

The thesis started 15th January in 2013 at Tetra Pak Packaging Solutions AB in Lund at the New Material Design division. Packaging is essential to be able to protect the food and beverage around the world. Different kinds of barriers are needed for different products. Ambient stored milk products need a physical barrier to prevent contamination, gas barrier to prevent oxidation and finally a light barrier to prevent light induced chemical reactions.

When aluminium is removed the gas and light barrier is put at risk. In this study the focus will be on the light barrier properties of packaging material.

Acknowledgement

We take this opportunity to express our profound gratitude and deep regards to our advisor Joakim Balogh for his commendable guidance, valuable information and great support throughout the course of this thesis.

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And lastly we would also like to thank SMHI with their STRÅNG data, http://strang.smhi.se/extraction/index.php, for their valuable information that helped contribute to the task light exposure of paperboard.

Contents

1. Introduction

The introductory chapter begins with a background (section 1.1) to the project, explaining the role a milk package has in protecting the product from light. This is followed by a problem setting (section 1.2), describing the problems occurring when designing a milk package without aluminium foil used for ambient distribution and why such a package may be of interest. The objectives (section 1.3) explain the purpose and goals of the study. In section 1.4 the scope of the project will be explained together with the delimitations. Finally section 1.5 describes which target groups this project may be of interest for.

1.1 Background

Tetra Pak makes packages for various food and drinks. A large part of these packages are made for milk. It is important for Tetra Pak to make milk packages with as little environmental impact as possible and to reduce their material and energy costs as much as possible, without losing too much of the protective properties of their packages.

A milk package in general is supposed to protect the product from microorganisms, light, oxygen, moist, migration of odour, loss of aroma and loss of water. [1] Milk is particularly sensitive to light because light has the potential to induce chemical reactions which create off-flavours in milk and because light can degrade some compounds found in milk and thereby deteriorate its nutritional value. This is the case both for pasteurized milk [2] and UHT-milk.[3] High quality milk has a somewhat sweet flavour that should give a pleasant aftertaste. Milk containing off-flavours has more of a “wet-cardboard” taste, which is generally regarded as unpleasant. [4] Research has shown that a significant amount of consumers are able to detect off-flavours in milk, even if there is only a small concentration of off-flavours in it. [4]

Aseptic Tetra Pak packages for milk has been sterilised prior to filling with UHT (Ultra High Temperature), resulting in a product which is shelf stable for over 6 months. The package consists of the following layers laminated on top of each other starting from the outside of the package: 1) Plastic layer mainly to protect against outside moisture 2) Printing for visualization and marketing 3) Paper mainly for stability and strength 4) Plastic layer of LDPE mainly for adhesion between layers 5) Aluminium foil mainly to protect against light, oxygen and moist 6) Two layers of plastic, one mainly for adhesion and one mainly to seal the package.[1] These type of aseptically packed milk can be stored at ambient temperature for approximately six months.[5] Non aseptic packages for milk are stored chilled (4°C) and contain the same layers as the aseptic package, except it has no aluminium foil, which significantly decreases the light and oxygen barrier. These packages have a shelf-life of 5-15 days. [5] By storing the product chilled, the deterioration speed of the product is reduced because chemical reactions that induce off-flavours are slowed down by lowering the temperature. [4] The fluorescent lamp used indoors is weaker than sunlight and only transmits visible light and no UV-light which means the riboflavin in the milk does not get affected as much compared to sunlight. [32] Storing the milk indoors is there for preferred.

1.2 Problem setting

Both use of aluminium foil and storage at low temperatures prolong shelf-life and keep product quality but consume large amounts of money and energy. If aluminium is not used however, the light barrier mainly consists of the carton board and possibly a plastic cap.[6] Consequently, the light barrier is significantly decreased, leading to light induced off-flavour reactions to a higher extent. If no chilling of the product would occur, the shelf-life would decrease partly due to the fact that chemical reactions that induce off-flavours due to light exposure occur faster at ambient temperatures. [4] A milk package without aluminium foil stored at ambient temperature would start to develop detectable off-flavours within hours. [4] Thus, using milk packages without aluminium foil stored at ambient temperature, would lead to increased product losses due to decreased barrier properties of the package. This report will only focus on the product losses from the weakened light barrier..

In order to overcome the problem with decreased light barrier and obtain a more sustainable production, a milk package without aluminium foil stored at ambient temperature without too much decreased barrier properties is a solution. In order to develop such a milk package without increasing the cost it is of importance to obtain knowledge and understanding of light barrier properties in different packaging materials aimed for non-foil milk packages.

1.3 Objectives

1.3.1 Purpose

The first purpose of this study was to get an understanding of how creasing and folding of packaging material affect the light barrier properties of the packaging material and to investigate how colouring pigments affected light barrier properties in plastic caps. The other purpose was to see how two light barrier measurement methods differed from each other.

1.3.2 Goal

- Get an understanding of how two light barrier measurement devices differ from each other and in which situations they are most suitable to use
- Develop a method for measuring light barrier properties of paperboard, plastic caps and packages in two different spectrophotometer
- Define how paperboards from different suppliers differ in light barrier properties
- Determine how thickness of the paperboards affects light barrier
- Understanding how different layers in the paperboard contribute to the total light barrier of the paperboard
- Investigate how creasing affects the light barrier
- Define how folding the paperboard affect its light barrier
- Determine how the light barrier in paperboard is affected by exposing the paperboard to sunlight
- Determine if applied printing colour on paperboard improves light barrier
- Understand how different pigments in plastic caps affect the light barrier properties of the plastic caps

1.4 Scope and delimitations

The study is only aimed for light barrier properties in packaging materials that could be used for milk packages, stored at ambient temperature.

The study will investigate light barrier properties in paperboards from ten different suppliers. The paperboards were clay coated duplex boards except two of them that were duplex paperboards. The chemical composition of the paperboards will not be investigated.

When investigating how different layers affect the total light barrier of the paperboard, only three layers (top, middle, and bottom) will be investigated.

When creasing and folding the paperboard, only a creasing pattern used for 1 litre packages will be used. The samples used are small sheets, about 10 cm wide and 20 cm long, while in the production the paperboard is on rolls.

Light exposure effect on transmission will only be tested with paperboard from three different producers to see if it has any effect on light barrier properties.

When investigating if the light barrier could be improved by printing colour, only commercially available material was used. Only four types of printing colours were investigated. There are lots of other types of printing colours and evaluations of how they affect light barrier properties but this will not be the main focus in this project.

For the plastic caps two types of plastic caps will be investigated. The first one is a plastic cap made out of HDPE with addition of pigment while the second one is a plastic cap available in the market where the content is unknown. The light barrier properties of 14 different variants of the plastic caps supplied by Tetra Pak and one from the market will be investigated. Each variant is coloured with a specific pigment.

Two spectrophotometers were available for the light barrier measurements. One of them could measure light transmission from 200-850 nm. The other could measure light transmission from 410-760 nm.

1.5 Target groups and business description

The project is carried out at Tetra Pak in cooperation with Lund University. The study will be put together in a report which will be published and available for the scientific community and industry. The study is mainly addressed to the paper and plastic industry as well as the packaging and food industry. By having an understanding of light barriers in non-foil packaging material, possibilities to develop packages with good light barriers without aluminium foil may be obtained.

2. Frame of reference

Light triggers reactions that create off flavours and deteriorates nutritional value in milk. A description on some of these reactions and the wavelengths that cause them are found in section 2.1

In section 2.2 there will be a description of the composition of paperboard, its different structures and layers and its light barrier properties. Also there will be some theory on how light exposure and creasing might affect the paperboards light barrier properties.

Different pigments absorb and reflect light at different wavelengths. In section 2.3 there will be a description of how different type of pigments may affect the light barrier properties of the plastic cap.

2.1 How light affects milk

The composition of whole milk is approximately 87% water, 4% protein, 3% fat and 5.5% lactose and minerals. Milk also contains small amounts of vitamins and trace elements. [4] When milk is exposed to light there is a production of flavours that are not favoured by consumers. The main component, responsible for this is Riboflavin (vitamin B2).

Milk is a light sensitive product due to the fact that it contains chemical compounds that can act as photosenstizers. [4] A photosensitizer is a light-absorbing substance that initiates a photochemical or photophysical reaction in another substance, and is not consumed in the reaction. [7] The most commonly occurring photosensitizer in milk is Riboflavin (Vitamin B2), see Figure 1. [4] Other possibly occurring photosenstizers in milk are porphyrins and chlorins, such as chlorophyll [4].

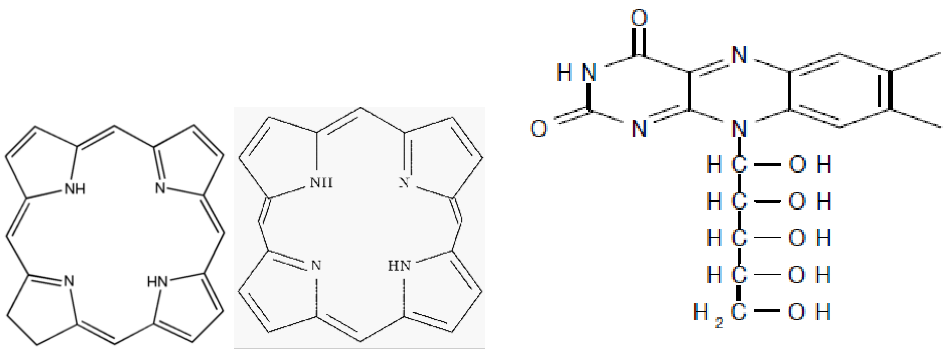


Figure 1. The chemical structure of some commonly occurring molecules that can act as photosensitizers in milk, from the left: general structure of a chlorin, general structure of a porphyrin and Riboflavin [4]

A photosensitizer has the potential to initiate chemical reactions in milk that lead to the production of off-flavours. The basics of this process are as follows, see Figure 2. First light is absorbed by a chromophore, which is a chemical bond that absorbs light in molecules in the photosensitizer.[8] This causes valence electrons to be elevated to a higher, more energetic orbital. Only specific wavelengths can be absorbed by specific compounds. This because the light energy is quantified and some compounds are only able to absorb energies of certain quantities. This excitation causes the molecule to enter it's so called singlet state. From here the electron can move back to the original energy state, while emitting light (fluorescence) or it can undergo intersystem crossing. Intersystem crossing means that electrons move to a lower energy orbital were the electron spins are parallel. This is called the triplet state. From here the photosensitizer can either go back to its ground state by emitting light, so called phosphorescence or it can induce a photo-oxidation in one of two ways [4].

- Type I photo-oxidation: The photosensitizer in the triplet state reacts with a substrate (most likely a lipid) and forms a free radical [4]
- Type II photo-oxidation : The photosensitizer reacts directly with O_2 and forms singlet oxygen (oxygen with an excited valence electron) [4]

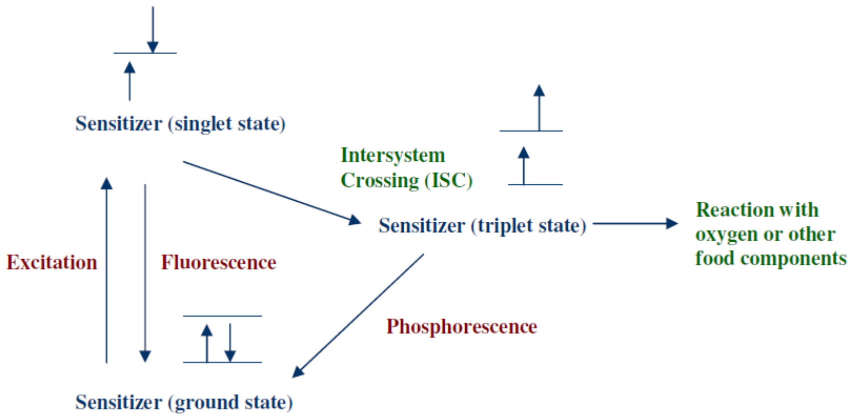


Figure 2. A schematic picture of photosenzitation [4]

In the case of type I photo-oxidation, Riboflavin in its triplet state is reduced by extracting an electron from a substrate that becomes oxidized. This is most likely a lipid that is oxidized. Further on, the reduced Riboflavin (^{2}Rib*-) reacts with O_2 and forms super-oxide anion radical (O_2*-), which continues free radical reactions that create off-flavours in milk. See Figure 3. Products from these reactions that create the off-flavors are mainly propanal, n-pentanal, n-hexanal, heptanal, nonanal, 3-methyl butanal, 2-methyl propanal, 2-butanone, 2-pentanone, 2-hexanone, 2-heptanone, 1-octene-3-one, 2-nonanone. [4]

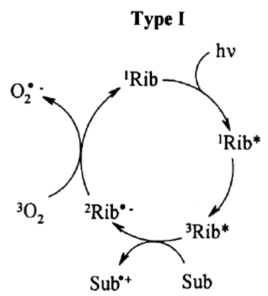


Figure 3. A schematic picture of general photo oxidation type 1 by Riboflavin [4]

In type II photo-oxidation Riboflavin is also excited to its triplet state. The triplet sensitizer then reacts with molecular oxygen to form singlet oxygen. [4] See Figure 4.

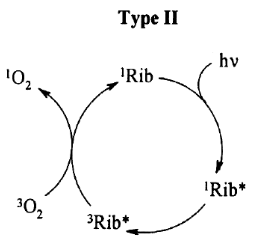


Figure 4. A schematic picture of general photo oxidation type 2 by Riboflavin [4]

Singlet oxygen is highly reactive and forms hydroperoxide from unsaturated lipids through a pathway that does not include the production of free radicals. Secondary oxidation products are then formed by free radical side reactions, which induce off-flavours in milk. These side reactions include 1) The production of allylperoxides. 2) Production endoperoxides through Diels-Alder reaction. 3) Singlet oxygen undergoes several reactions and carbonyls are formed. 4) Compounds containing sulphur and/or nitrogen (such as proteins and amino acids) react with singlet oxygen and forms sulfoxides or nitroxides [4] .An example of such a reaction is the photo induced reaction of methionine to methional.[9] See Figure 5.

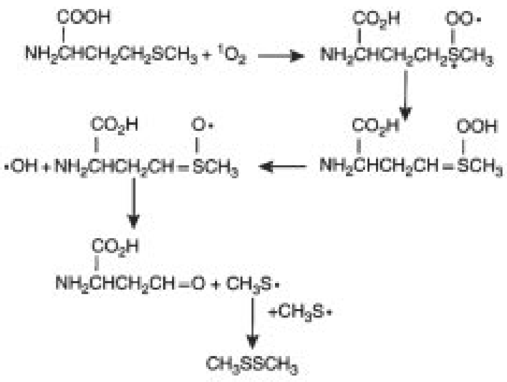


Figure 5. The reaction of methionine to methional caused by singlet oxygene, formed from type 2 photo oxidation [9]

Lipid oxidation can occur both through type 1 photo-oxidation and type 2 photo-oxidation, whereas oxidation of an aminoacid and/or a protein is more likely to occur through a type 2 photo oxidation. The off-flavours that are created from lipid oxidation causes a “wet cardboard” taste, whereas the degradation of proteins and/or aminoacids can be described to induce a “burnt protein” flavour. Protein/aminoacid degradation due to light exposure is a faster process than light induced lipid oxidation and is therefore usually noted first, by the milk consumer.[4]

After a molecule has acted as a photosensitizer, its electrons can return to their ground state and the molecule is available for sensitazion once again. Theoretically this process would then go on in infinity and degrade all lipids and proteins, but in reality some of the photosensitized molecules are degraded by light. [4] In the case of photosenzitation of Riboflavin, luminocrom and lumiflavin are produced as some Riboflavin molecules are degraded by light.[10] See Figure 6. There is no literature on the exact mechanisms on photo oxidation of porphyrins and chlorin, but it is generally believed that it occurs in similar ways to Riboflavin. [4]

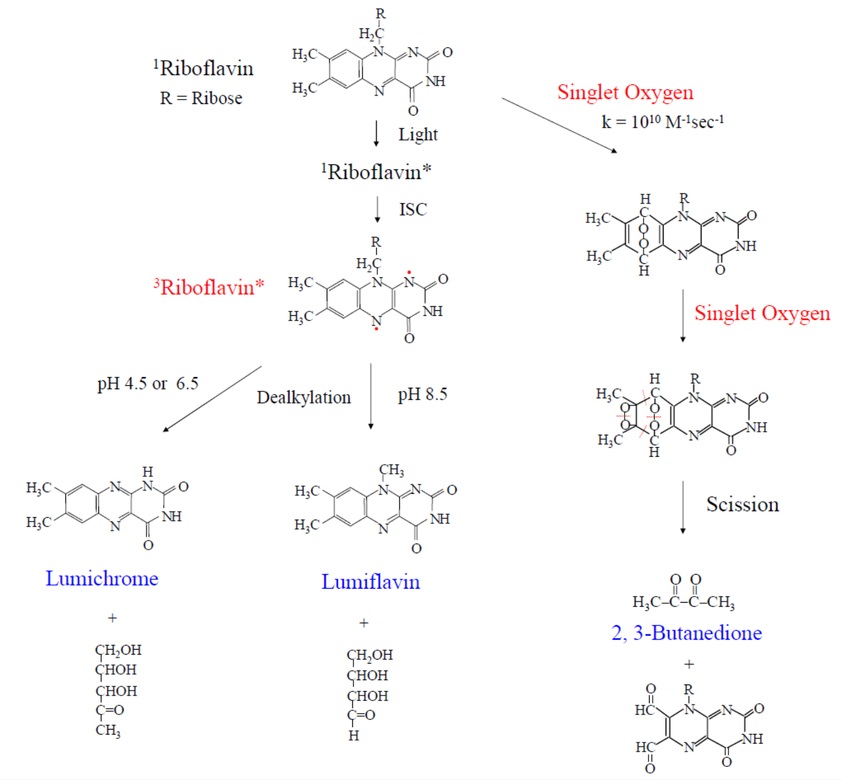


Figure 6. The breakdown of riboflavin by light[10]

Other components that are somewhat sensitive to light are vitamin A, vitamin B12, vitamin C, vitamin D, vitamin K, folic acid and tocopherol. These compounds do not initiate off-flavour reactions, but are rather destroyed by too heavy light exposure, which deteriorates the nutritional value of the milk.[11] Figure 7 summarizes creation of off-flavours in milk caused by light.

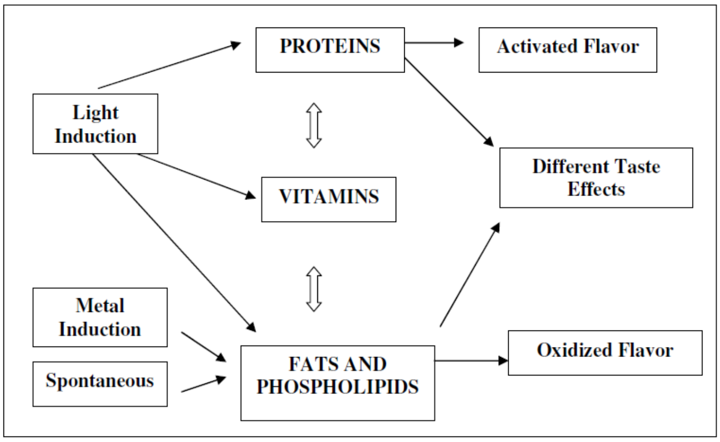


Figure 7. Summarization of light induced off-flavours in milk [4]

2.1.1 Wavelengths that causes off-flavour reactions in milk

Light energy is quantified and photosensitizers can only absorb light of specific energy. That means that only light of specific wavelengths has the ability to induce a photosenzitation and thereby trigger off-flavour reactions. This in turn leads to the fact that a packaging material for milk only has to exclude light of wavelengths that is harmful to the milk. [12] The specific wavelengths and components affected will be described in this part.

Food is exposed to light of wavelengths within the ultraviolet area of the electromagnetic spectrum (10-380 nm) and within the visible area (380-760 nm), [13] both from sunlight, if stored outside and only the visible area (380-760 nm) from indoor light sources if stored inside.

Riboflavin has a maximum absorbance at 223 nm, 268 nm and 359-375 nm in the UV-spectrum. In the visible spectrum all light between 415-455 nm has the ability to induce a photosenzitation. [12] Riboflavin has two absorption peaks in the visible range of the electromagnetic spectrum, 446 nm and 475 nm. Consequently milk needs extra protection against light of wavelengths from 220-375 nm in the UV-spectrum and light of wavelengths between 410-475 nm in the visible part of the spectrum. 410-480 nm corresponds mainly to blue and green light. Milk packages are often exposed to visible light from lamps during storage in warehouses or supermarkets, but it may need protection against UV-light if it is sold in an outdoor market, for example in Asia.

In 2004 a study was performed and published in the International Dairy Journal in order to investigate which wavelength that could cause off-flavour reactions due to photosenzitation of chlorins and porphyrins. The results indicated that porphyrins and chlorins absorbed light within a range from about 650-700 nm with peaks at 661 nm and 672 nm. A sensory test was carried out in samples that had been susceptible to red and orange light and a significant amount of the test panel could characterize sun-flavour and oxidant odour. This means that milk also should be protected against orange and some red light (~650-700 nm). [14]

The International Dairy Federation (IDF) recommends that the light transmission for a package used for pasteurized milk, stored chilled, should not exceed 2% at 400 nm and should not exceed 8% at 500 nm. [15] This report is only aimed for packaging material used for ambient storage, which means that the upper limit for light transmission must be set much lower, because light-triggered off-flavour reactions occur at higher speed at higher temperatures. [4]

2.2 Paper and light

Paperboard is a layer structure. This means that the board is not a homogenous structure, but rather a structure that consists of many layers on top of each other. In this study, the light barrier properties of so-called clay-coated duplex boards will be described since those are common types used in Tetra Pak packages. The duplex paperboard used by Tetra Pak consists of three to five layers. Thinner paperboard used for portion packs, might however only have three layers. [16]

The pulp consists of softwood sulphate pulp for strength and tensile stiffness and hardwood sulphate pulp for optical properties and smoothness. [16] Softwood is wood derived from gymnosperm trees (trees that give naked seeds) and hardwood is wood from angiosperm seeds. [17] Sulphate pulp is pulp where the wood has been converted to wood pulp by letting sodium hydroxide and sodium sulphide break the bonds between lignin and cellulose. [18] Thereby the pulp consists of almost exclusively cellulose.

Generally the paperboard structure can be described with the “I-Beam” structure. See Figure 8. The top layer (top layer in this case means the layer which is closest to the outside of the package) provide the stiffness of the board and give a good printability. The middle layer(s) give the paperboard high bulk and internal bonding strength. The bottom layer (the layer closest to the product in the package) provides high stiffness.

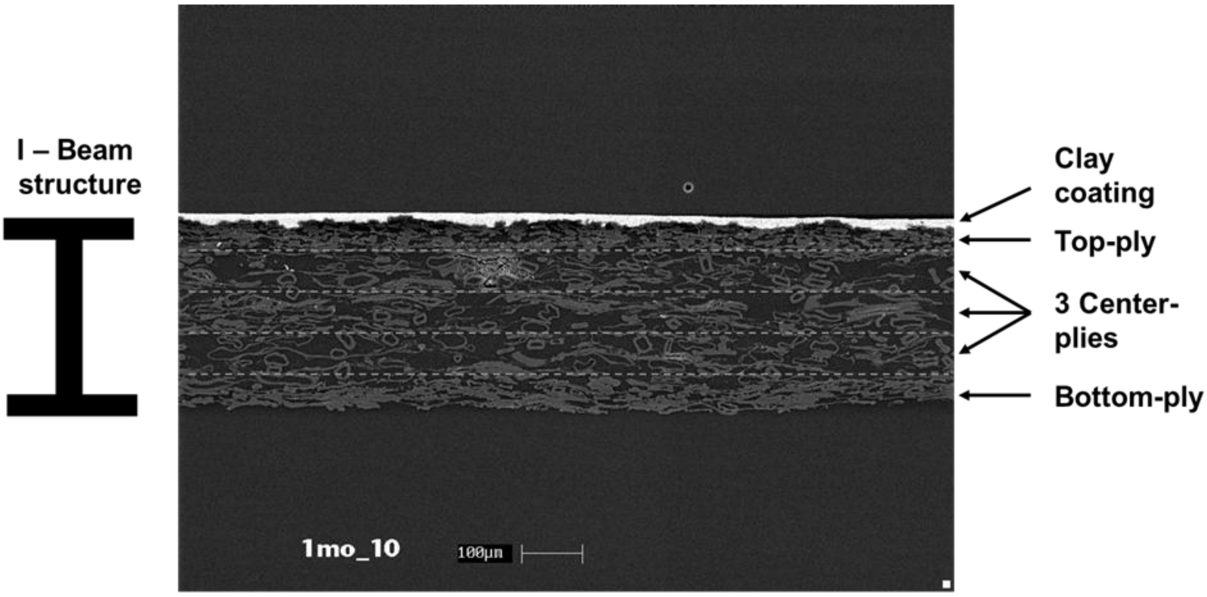


Figure 8. Shows the I-beam structure of a paperboard [16]

The 3 layered structures of duplex boards consists of the following layers: The top layer is a bleached layer that is made out of a mixture of hardwood and softwood. This layer is followed by a layer of unbleached softwood and broke (discarded paper). The final layer is an unbleached layer of softwood. [16] See Figure 9. Duplex board with more than 3 layers differs by having additional middle layers that consists of unbleached softwood and broke.

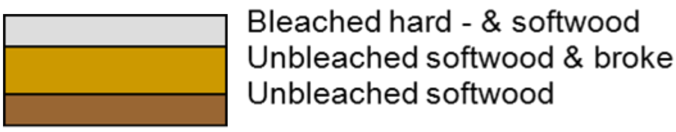


Figure 9. Shows the three layered structure of a Duplex board. Starting from the top, a bleached layer followed by two unbleached layers [16]

Some duplex boards have a layer of clay coating on top. These boards are referred to as CLC C duplex boards. [16] See Figure 10.

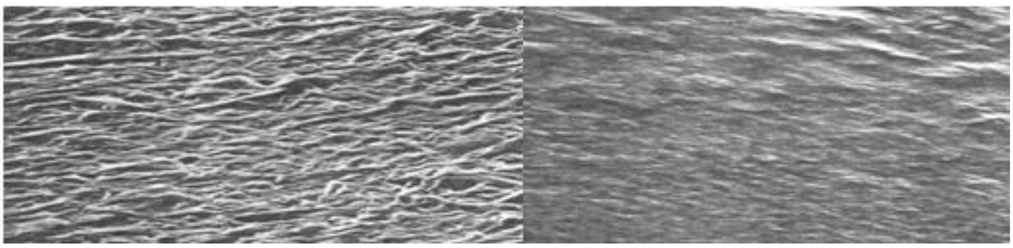


Figure 10. Shows the top layer of a duplex paperboard. Left: Uncoated, Right: Clay coated [16]

2.2.1 Mechanical pulp and chemical pulp

The pulp produced could be divided in different categories such as mechanical and chemical pulps. The difference between them is mainly how the raw material is dissolved into a sludge.

The difference between the productions of the paper could be interesting when investigating the light barrier properties and are therefore described in this section.

Mechanically pulping uses heat and mechanical forces while chemical pulps are cooked with chemicals under high pressure. In chemical pulping lignin is removed. [19]

Chemical pulps contain less contaminants and are therefore better suited for food packages or pharmaceutical packages. It also has a surface that is more suitable for printing since after bleaching it becomes white. [20]

The paper produced from mechanical pulp has a grey/yellowish colour and also have higher opacity than chemical pulp. Mechanical pulping gives a higher yield and is therefore also cheaper to produce. [19] But the tensile strength for paper produced from mechanical pulps compared to chemical pulps are lower while the stiffness is higher [19], [20]

By using paper from mechanical pulping in multilayered paper where it is used in the middle layers the stiffness could still be achieved while at the same time obtaining the needed tensile strength. The impurities from the mechanical pulps are avoided from coming into contact with the product inside the package while also keeping a printable surface. [20]

2.2.2 Paper composition and its optical properties

Paper is a network of fibres that consists of cellulose, hemicelluloses, lignin and other components. The pores between the fibres are also a part of the structure and are important when printing. How different factors can affect the paper's light barrier will be described below.

When a ray of light comes into contact with paper several things can happen. Part of the light could be reflected while the other part passes into the paper. The light that passes into the paper is partially absorbed and partially scattered. The partially scattered light comes out either from the surface where it passed initially or through the other side of the paper. The paper's appearance depends on which light of different wavelength that is reflected and absorbed. [21] The transmittance, which is a measurement of the fraction of incident light that passes through a sample, through the paper can be expressed by Beer-Lambert law, which states that the intensity of the transmitted light I divided by the intensity of the original light I_0, depends on the absorbtion coefficient (α) and the thickness x of the sample: [13]

$$T = \frac{I}{I_0} = 10^{-\alpha x} \quad (1)$$

The phase separations between the fibres and pores are important since it leads to opacity by the dispersion of light. [22] If light passes through multiple samples the fraction of light that passes through the initial sample can be expressed as

$$I_i = I_0 * n^{-i} \quad (2)$$

, were I_i is the intensity of the light after passing through all the samples, I_0 is the initial intensity, n is the number of samples and i is the fraction of light that passes through each sample. [23] The light dispersion in paper depends on the difference in refractive index between the particles in paper and the air (pores) and also if they are in optical contact. Optical contact is the distance between two surfaces. The distance must be larger than half the wavelength of light in order for the light to penetrate. [21] Filling material such as clay often increases the light absorption, k, which means it also increases the opacity, [22] which can be seen when moving upwards in the diagram provided in Figure 12. The diagram in figure 12 describes how the opacity and reflectance varies with the absorption (k) and light scattering (s). However the diagram is illustrated for paper with 60 g/m^2 while paper board have higher than 180 g/m^2. [24] The principle of the diagram should be the same but with difference in the steepness of the curves.

The pulping and bleaching are processes that reduce the light absorption. For mechanical pulps, mechanical beating of the pulp, the refining process leads to a great number of small particles which in turn increases the light scattering, s, that increases the opacity which can be seen when moving horizontally to the right in the diagram in Figure 11. [21]

In the case of chemical pulps the beating initially leads to a great number of particles but the process leads to the particles bonding together and comes closer to each other enough to come into optical contact. This leads to a lowered light scattering, moving horizontally to the left in diagram in Figure 11, which decreases the opacity. [21]

This means in theory that when creases are introduced the particles in paper are packed closer which leads to smaller or less pores and also decreasing of the distance between particles. Decreasing the distance between the particles could lead to optical contact. These things could lead to a reduction in light barrier properties.

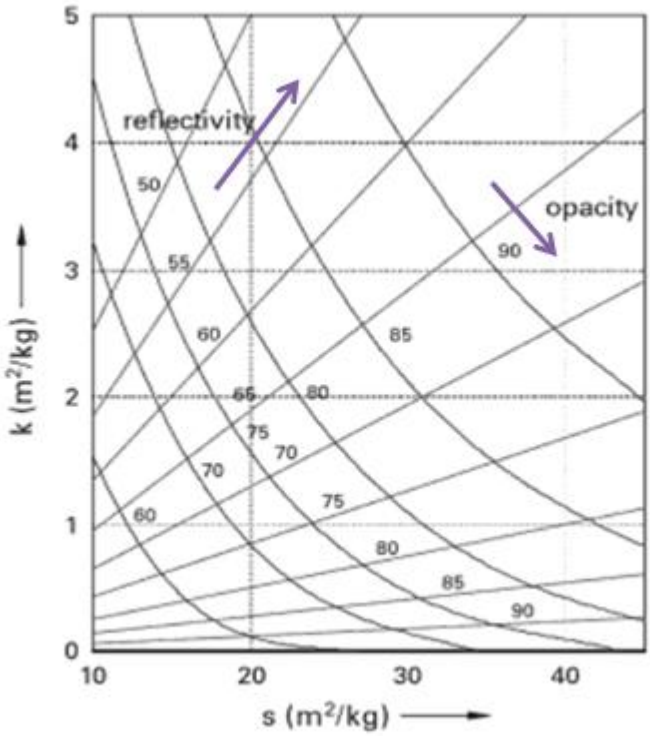


Figure 11. The relationship between the optical properties. The opacity data refers to paper of grammage of 60 g/m^2 [21]

2.2.3 Paperboards and light barrier properties

How the paperboards light barrier properties are related to the light scattering and light absorption of the material will be discussed in this section. Also what gives the paperboards its light barrier properties will be discussed.

Bleaching reduces the lignin content, and thereby reduces the light absorption in paper, which leads to an increased light transmission. [25] This is because lignin absorbs much more light than cellulose. If lignin is removed, the transmittance, T is increased. [15] This means that higher lignin content decreases transmission.

Commercial liquid paperboard with thickness between 0.5-0.6 mm have relatively good light barrier properties which can be seen in Figure 12. In an experiment performed bleached paperboard showed a light transmittance of 4.3% for visible light, 400-700 nm, and 0.03% transmission for UV-light. The unbleached paperboard resulted in better light barrier properties than the bleached paperboard. Only 0.8% of the visible light was transmitted while it was 0% for the UV-light. Adding printing to the paperboard blocked even more of the light. Pink printed bleached paperboard transmitted 2.6% visible light. For pink printed unbleached paperboard the transmission of visible light was less than 0.1%. [26]

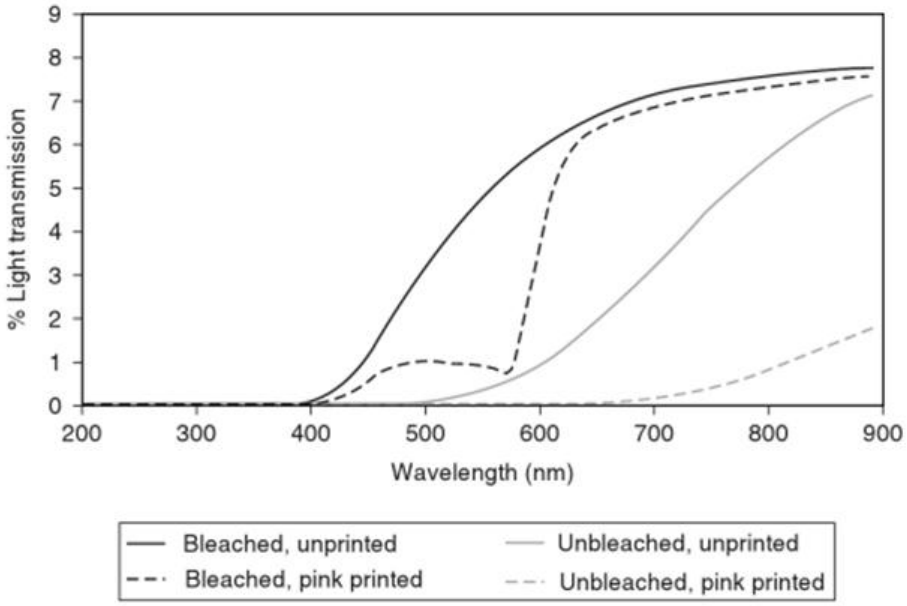


Figure 12. Light transmission differences regarding unprinted and printed paperboard and regarding bleached and unbleached paperboard [26]

2.2.4 The effect of light exposure on paperboard

The colour of paper is known to change during a longer period. This makes it interesting to see how those changes and the mechanism behind it affects the light barrier properties and will therefore be discussed in this section.

Paper exposed to light during a long period becomes darker or gives rise to a yellowish colour. Lignin and lignin products are photosensitive and contributes most to the darkening of paper. Lignin contains α-carbonyl groups, which can be excited photochemically and remove a hydrogen radical from a phenolic hydroxyl group, which becomes a fenoxyradical. The fenoxyradical further reacts and forms coloured products such as quinines and ferulic acid. [27] Since lignin is a light absorbing compound, breaking it down by light can possibly deteriorate the paper´s light barrier properties. It has been observed that wavelengths less than 340 nm (for example UV-light) leads to yellowing [28]. Papers that contain minerals, transition metal ions, coatings and optical brighteners leads to more darkening when exposed to light, heat, humidity, long time etc. The darkening of recycled paper during repulping at higher pH can lead to the darkening of the pulp especially when the pulp yield is higher which the case with mechanical pulps is. Therefore pulp of recycled paper at alkaline conditions should be done in combination with hydrogen peroxide followed by a reducing agent. This is needed in order to keep the high pulp yield. This treatment is often called lignin preserving bleaching. [28]

2.2.5 Creases effects on light barrier properties in paperboard

When paper is creased several things could happen. The main focus in this section is how the introduction of creases could affect the light barrier properties.

The introduction of creases will lead delamination (separation of the layers). Movement of the paper will also occur towards the creases since the forces will pull the paper from the sides of the crease. The changes in light barrier caused by this may be too small to give any effect.

If the creasing force is too high it could lead to cracking of the paperboard which will allow more light to penetrate.

When introducing creases it could lead to a more compact paper locally. A more compact material could maybe mean that it is harder for the light to penetrate if the material was porous to begin with since it could maybe reduce the light scattering effects.

But according to the theory for optical properties for paper, under section "Papers composition and its optical properties", the light barrier properties would not increase but instead decrease.

There are different theories behind what could happen to the light barrier properties but the effect will be investigated by performing experiments.

2.3 Plastic caps and light

Plastic caps on the cardboard packages could be the part which has the weakest light barrier. Often light exposure comes from above, were the caps are situated. Another important thing to consider is the cap's top area ratio against the package's top area. The role of the cap in light protection of a package will be discussed here.

The plastic caps on the cardboard packages might seem insignificant when considering the light barrier properties since it's only a small part of the total package. But the fact is that the packages largest weakness against light could be in the caps especially for duplex board. This could be the case since the caps are made out of plastics which have a high light transmittance.

The commercial HDPE caps without pigment have a higher light transmittance compared to the paperboards used for packages since it is quite transparent. [29] Another important factor that must be taken into account is which parts of the packages that are exposed to light. The milk packages in a retail store could be packed in a way that makes the majority of the light exposure come from above where the caps are situated. The caps size in this case could therefore be even more critical. The cap's top area ratio against the package's top area could vary a lot which can easier be illustrated when looking at Figure 13 that shows some of the different packages with different plastic caps.

Figure 13. Different Tetra Pak packages and their caps. The variations of the caps sizes and shapes has a wide variety. http://upload.wikimedia.org/wikipedia/commons/thumb/7/7f/Tetra_Pak_package_portfolio_II.jpg/499px-Tetra_Pak_package_portfolio_II.jpg

2.3.1 Pigments effect on light transmission

A plastic cap is usually coloured with a pigment. Colouring a cap with different types of pigment is likely to change the transmission of light through the cap. [30] Milk packages often contains plastic openers or plastic caps. A pigment is a material that changes the colour of reflected or transmitted light as the result of wavelength-selective absorption. That means a pigment is designed to absorb most of the visible light spectrum except for a narrow interval. This interval of light is reflected and it is that colour that is perceived by the recipient. Different pigments absorb and reflect light at different wavelengths. [31] A colour will absorb light that is in the opposite of the "colour circle", Figure 14, and reflect light that is next to it in the circle. [31] Thereby the level of transmittance of light of certain wavelengths is dependent on what type of pigment that is used. In this particular study it is of importance to investigate which plastic caps that transmit light of wavelengths harmful to the product (see section 2.1.2).

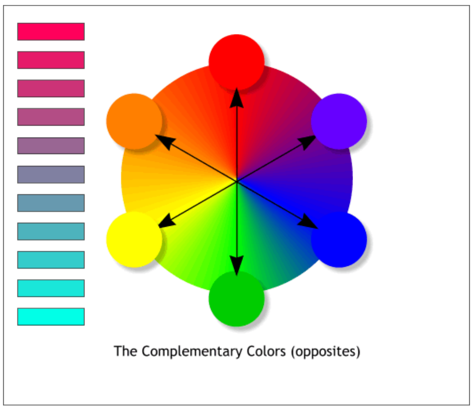


Figure 14. Shows the complementary colors. [31]

The transparency of a polymer film containing a pigment, can be expressed by the Lambert-Beer function which reads

$$T = 100 * \exp\left(-a * c * d\right) \quad (3)$$

, where T is the transparency in %, a is an absorbtion coefficient which describes the optical properties of the pigment, c is the concentration of the pigment in the polymer and d is the thickness of the layer. When choosing between different pigments, some aspects are important to consider: 1) The pigment cannot be used in concentrations so high that they alter the physical properties of the polymer to the extent that it becomes a problem for the plastic opener. It must also still be processable. 2) The absorption component should be as high as possible in order to be able to block light with as low thickness of the polymer layer as possible. 3) The pigment must give a colour that is aesthetically pleasing to the package´s consumer. [30]

Using a carbon black pigment is one of the best alternatives for blocking light. With this pigment it is possible to block about 99% of the light in the visible spectrum, by using a film with a thickness of 70-100 μm and a pigment concentration of only a few percent. The drawback of using carbon black is that it is very unattractive to consumers, especially in milk products. Therefore carbon black is not often used in dairy product packages. [30]

2.4 Dome spectrophotometer

In this section there will be a description of the dome spectrophotometer.

The dome spectrophotometer is a type of spectrophotometer that was constructed internally by Tetra Pak in order to measure light transmittance in three dimensions. The three-dimensional measurements are something that separates this method from other conventional transmittance measurements in conventional spectrophotometers. The method was particularly useful when measuring packaging material, since the transmission of entire three-dimensional structures, such as packaging bottoms, packaging tops and caps could be measured. It should be noted that the transmittance in flat samples also could be measured in the dome spectrophotometer.

The dome spectrophotometer was made out of a metallic half-sphere see Figure 15, shaped like a dome and hence the name dome spectrophotometer, with light diodes attached to it on the inside. These light diodes acted as light sources. Below the half-sphere, a receptor connected to an optical fibre was located. The metallic sphere could be lowered over the receptor in order to block light from the surroundings hitting the receptor. In order to perform measurements, a sample was placed above the receptor so that light coming from the diodes was blocked by the sample.

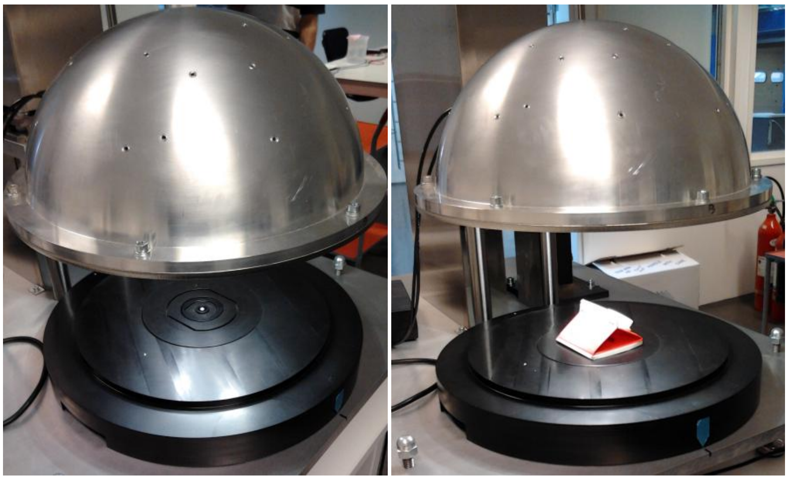


Figure 15. Shows the dome spectrophotometer. Left: No sample. Right: Sample placed above the receptor.

However, the light that successfully penetrated the sample would hit the receptor and become registered.

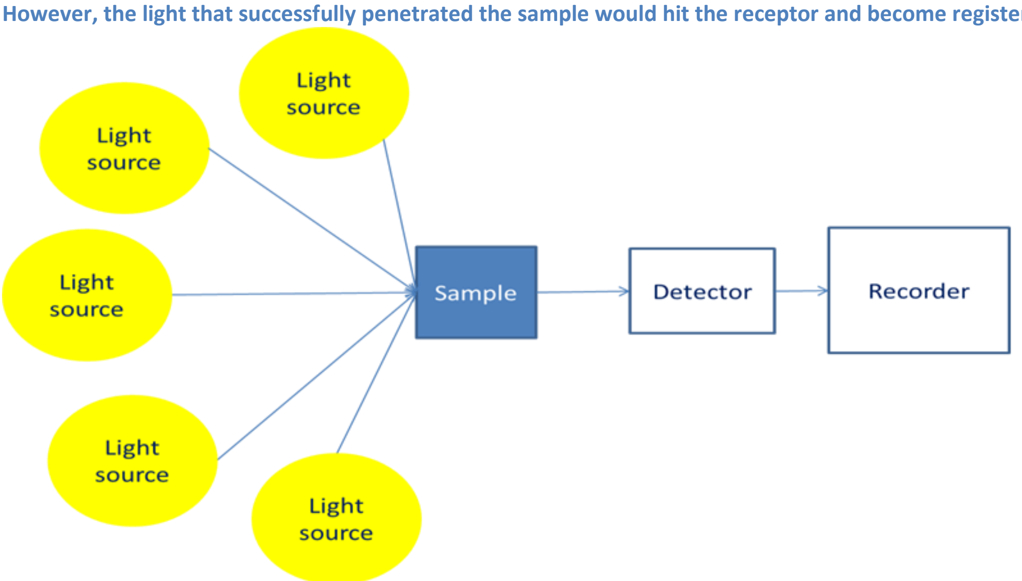


Figure 16Thereby the dome spectrophotometer could measure the fraction of light penetrating the sample and thereby the transmittance of the measured sample could be obtained, see Figure 16. The dome spectrophotometer was only able to measure the transmittance of a sample in the area were the light had a wavelength from 420-760 nm

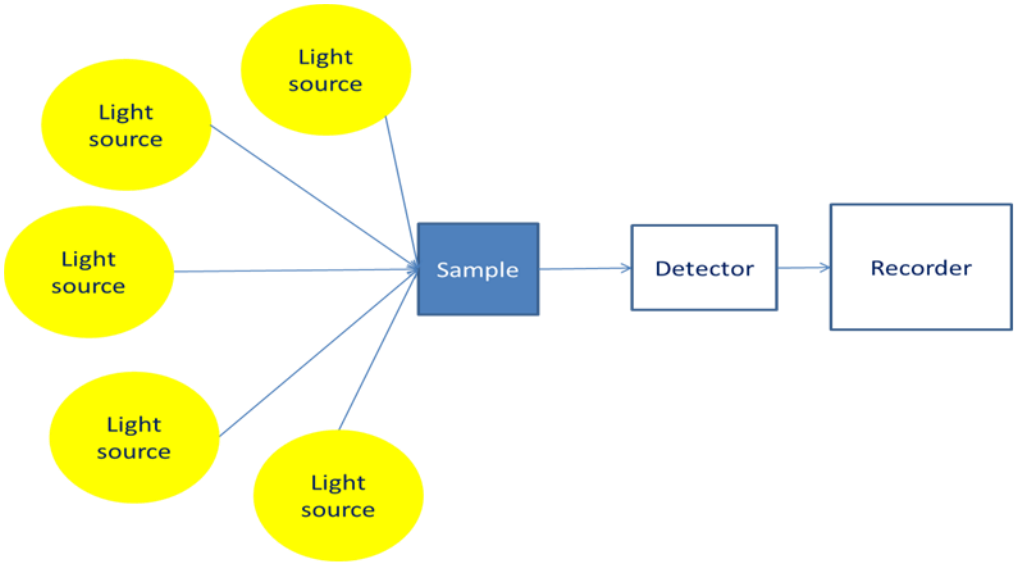


Figure 16. Shows the principle of the dome spectrophotometer. The light that successfully penetrates the sample, reaches the detector and is recorded

2.5 U-3010 spectrophotometer

A spectrophotometer of the model U-3010 with an integrating sphere produced by Hitachi from Japan was used when performing measurements on light barrier, Figure 17.

Figure 17. The U-3010 spectrophotometer used for measurements for flat samples.

The spectrophotometer used was a dual beam spectrophotometer, Figure 18, which consisted of a light source, a monochromator that selects specific wavelengths of the light into two beams, a sample holder, an integrating sphere (light collecting compartment) with a detector inside, and finally a recorder.

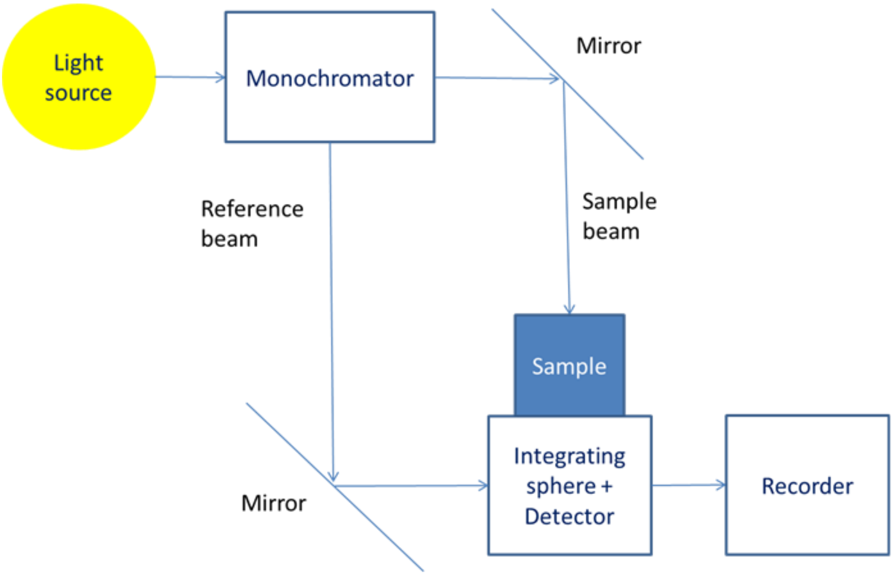


Figure 18. A simplified description of the function of the U-3010 spectrophotometer with an added integrating sphere.

3. Method and method development

The two main equipments used in order to measure the transmission of light through the different packaging material were two different types of spectrophotometers. Before performing the measurements some pretrials were performed in order to evaluate the two spectrophotometers and which of them were suitable for every type of experiment. The pretrials also showed that humidity and temperature needed to be regulated before performing light barrier measurements. Finally the "zero transmission" wavelength was decided to be used as a measurement of the light barrier of a paperboard.

3.1 Dome spectrophotometer

In this section there will be a general description of how the dome spectrophotometer was used. The method was somewhat modified when measuring different types of samples. These modifications will be described in other sections, describing measurements of specific samples in the dome spectrophotometer. For further understanding of the dome spectrophotometer the reader is referred to section 2.6.

First a "dark spectrum" had to be recorded. A dark spectrum was recorded by switching off the lights and registered in the software used. The dark spectrum was recorded so that noise would be eliminated. Before the measurements the dome spectrophotometer's lights had to be turned on for an hour in order to stabilize the light diodes temperature which otherwise would result in changes in light transmittance for different wavelengths caused by temperature differences. Before performing a measurement a "reference" had to be recorded by pressing a button on the computer screen. A reference was recorded so that if no sample was placed above the receptor (and thereby nothing would block the light hitting the receptor) the light from the diodes hitting the receptor would correspond to "100 % transmittance". Afterwards a sample was placed in a holder, so that the sample blocked the receptor. Different holders that were developed during the project were used when measuring different type of samples, in order to block stray light and to be able to position the samples. The metallic sphere with the diodes was then lowered above the receptor to block stray light from the surroundings. The measurements could then be started. Since all the light coming from the diodes corresponded to 100% transmittance, the receptor could register the fraction of light from the diodes penetrating the sample and hitting the receptor. For example if half of the amount of light of a certain wavelength from the diodes would penetrate the sample and hit the receptor, this would give 50% transmittance at this wavelength. The result would come up on the computer screen, displaying a graph with wavelength (nm) on the x-axis and transmittance (%) on the y-axis.

During the measurements it was noted that the reference transmittance would change with time. It was then decided to record a new reference at least every five minutes in order to avoid variations in the results due to change in the reference. Also, the precision of the dome spectrophotometer was tested in order to be able to get an idea if variations were due to actual differences between the samples or due to variations in the dome spectrophotometer. The relative standard deviation was calculated as a function of the transmittance. For transmittance that was very low (>0.01%) the relative standard deviation was very high and at higher transmittances the relative standard deviation was around 1%.

It was also noted that the height of a sample and its position relative to the receptor influenced the result to some extent. Therefore it was decided always to keep the size of the samples that were to be compared the same and always place the samples at the same position relative to the receptor.

3.2 U-3010 spectrophotometer

Samples from caps could also be measured in this machine by cutting off a flat sample from the top of the caps.

Before using the machine a warm up of the lamps was performed 30 minutes before the measurements, this since the lamps light radiation varies depending on the temperature. After the warm up a calibration was performed where the intensity of the light radiation for different wavelengths were determined. The sample being measured had to be placed adjacent to the integrating sphere otherwise the stray light would affect the results. Different holders for different types of samples were developed during the project in order to be able to able to block stray light and fit the sample.

The measurements took between 7-8 minutes each with the settings used. It was configured to measure light transmission for wavelengths between 200-850 nm, with a sample interval of 0.2 nm and report for every 1 nm.

The machines precision was tested by measuring a paperboard sample 3 times. For values at 0.1% transmission the standard deviation is about 0.00025%. The standard deviation increases with higher transmission but the standard deviation is still too small to have an effect on the results. The standard deviation was still insignificant when performing measurements after putting the sample in and taking out of the spectrophotometer between the measurements. The machines precision makes it reliable.

3.3 Regulation of humidity and temperature of samples

It was noticed that the samples light transmittance for paperboard could vary after a period of time. This was theorized to maybe be the cause of the humidity changes and was therefore investigated. Changes in humidity affected the transmission and therefore introducing conditioning, the regulation of humidity and temperature, solved most of the problem with changing samples.

The conditioning of paperboard samples for the lab was performed by placing them in a room with a temperature of about 23 °C and 50% humidity for 3 hours, before measurements.

3.4 Zero transmission

When measuring the transmittance, it was not only of interest to obtain the absolute value of the transmittance at certain wavelengths. It was also of interest to see at which wavelengths there is none or very little transmission of light through a sample. This is because light of certain wavelengths can harm the product inside a package more than other wavelengths and therefore it is crucial to exclude almost all light of these wavelengths. Since the transmittance theoretically never can reach zero, it was of importance to establish a lower limit to where the transmission in practice could be rounded down to zero. This was the lower transmittance limit that was considered to be acceptable for a sample. The lower transmittance that was considered to be acceptable was 0.1 %. This limit was called the “zero transmission”.

For a paperboard a general appearance for the light transmission plotted against wavelength can be seen in Figure 19.

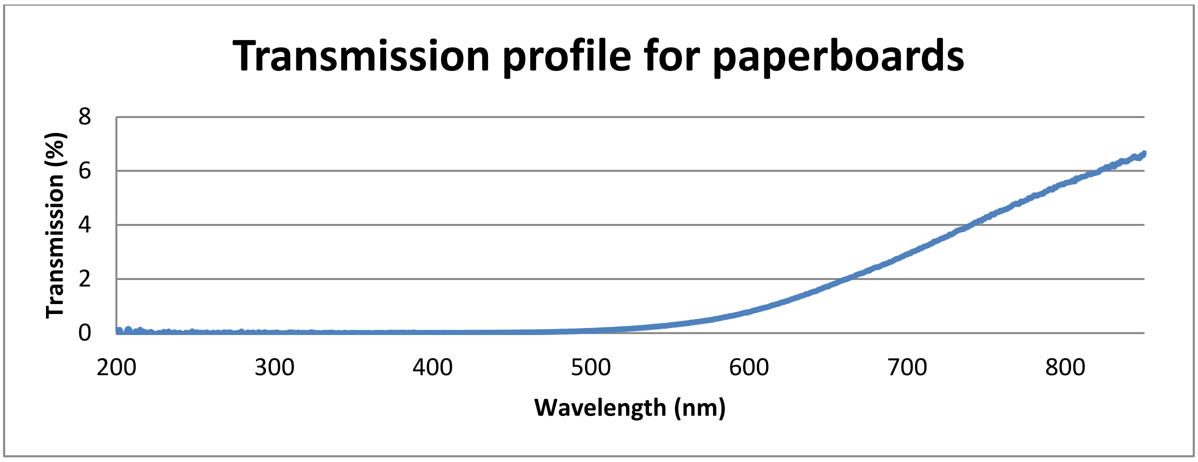


Figure 19. This graph shows the result of a paperboard measured in the U-3010 spectrophotometer. The wavelength of the light is shown on the x-axis and the light transmission is shown on the y-axis. The data close to 200 nm wavelength is affected by noise and should have been zero.

At a certain wavelength the light transmission is going to exceed 0.1%. The wavelength at which this occurred was called the "zero transmission wavelength". The zero transmission wavelength was what was used when determining the light barrier in paperboard. A *longer* zero transmission wavelength meant a *better* light barrier. The theoretical example in Figure 20 shows that the zero transmission wavelength is about 590 nm. Since the light transmission increases with wavelength, the light transmission is below 0.1% (below the maximum acceptable value) for all wavelengths below 590 nm. This would mean that in this theoretical example the paperboard would have an acceptable light transmission up to 590 nm. The scale is logarithmical in order to easily display at which wavelength the light transmission exceeds 0.1%.

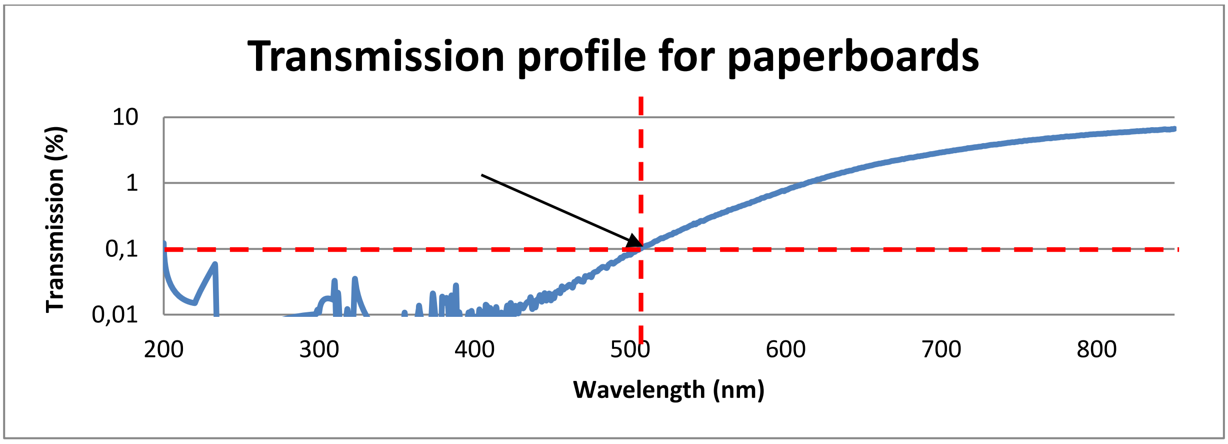


Figure 20. A general graph of the logarithmic light transmission plotted against wavelength for a paperboard. This graph shows the result of a paperboard measured in the U-3010 spectrophotometer. The wavelength of the light is shown on the x-axis and the light transmission is shown on the y-axis. The data close to 200 nm wavelength is affected by noise and should have been zero. The wavelength at which the transmission exceeds 0.1% is marked in the figure.

For plastic caps the light transmission plotted against wavelength the curve is much more irregular than for boards. See Figure 21. If the light transmission is below 0.1% at a certain wavelength there is no guarantee that shorter wavelengths give light transmission below 0.1%, as it is for paperboards. Therefore no specific “zero transmission wavelength” could be established for plastic caps. Instead all wavelength intervals where the light transmission is below 0.1% for the plastic caps were used instead.

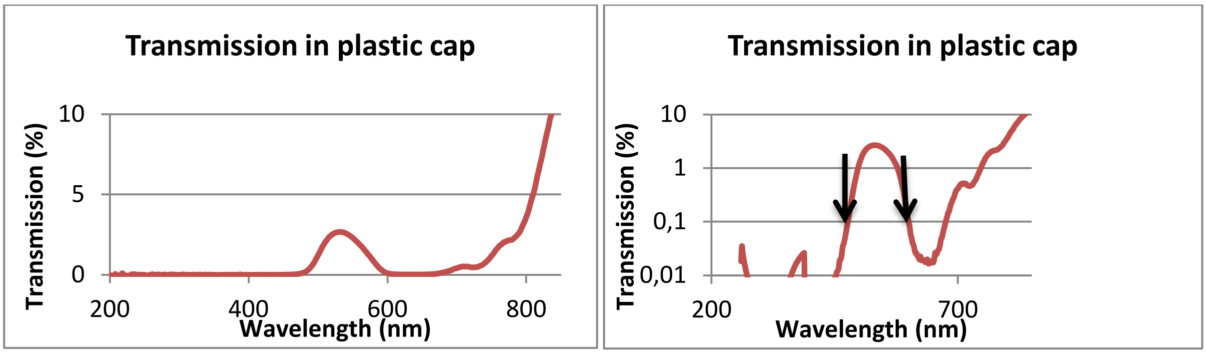


Figure 21. A general graph of the logarithmic light transmission plotted against wavelength for a plastic cap. The wavelengths at which the transmission exceeds 0.1% is marked in the figure.

3.5 Comparison between dome spectrophotometer and U-3010 spectrophotometer

The U-3010 spectrophotometer is more precise than the dome spectrophotometer but is more time consuming to use, Table 1. In this case when the important wavelengths are the ones that are below zero transmission (less than 0.1%) both the dome spectrophotometer and the U-3010 spectrophotometer are both good since the results are about the same since the standard deviations are very small at 0.1% transmission. Wavelengths below 400 nm have been verified to be below the zero transmission using the U-3010 spectrophotometer for paperboards. The minimum wavelength measureable for the dome spectrophotometer has therefore been set to 420 nm since wavelengths below that showed false higher transmission values.

Table 1. Comparison of U-3010 spectrophotometer and the dome spectrophotometer used.

	U-3010 spectrophotometer	Dome spectrophotometer
Results reliability	Is being used as a standard machine for transmission measurements. Is being calibrated regularly.	The results are similar as the results from the U-3010 spectrophotometer for when the zero transmission occurs.
Precision	The standard deviation with 3 replicates at an average of 0.1% transmission was at 0.00025%.	The standard deviation with 3 replicates at an average of 0.1% transmission was at 0.006%.
Time needed to perform a measurement	7-8 min.	About 10 sec.
Measureable wavelength interval	200-850 nm.	420-760 nm.
Pre treatment of flat samples, size	Need to prepare square samples that have sides that are about 2.5 x 2.5 cm.	Size can vary between 1-14 cm in radius for circular samples.
Manageability	Easy to handle. Few steps.	Easy to handle. Few steps.
Condition for measurements (3D)	Made to measure flat samples but can be made to measure non flat samples if a holder is made. Has to prevent stray light from entering.	Can measure both flat and non flat samples. Has to prevent stray light from entering beneath the sample.
Condition of samples after measurements	For flat samples traces from the holder used can be seen as both grey lines and compression and in worse case tearing of surface.	Intact.
Error tendency when using machine.	Every now and then abnormal spikes appear which has to be fixed by restarting the machine and starting the measurement again. The reason behind this problem is unclear. When placing a sample inside the spectrophotometer there is a risk of touching a part inside that misplaces it and affects the measurements.	Resetting the 100% transmission has to be performed about every 10 min after the pre heating. Otherwise the results may vary. But this step needs less than 5 sec.

It was decided that when measuring the light barrier properties of paperboard, the dome spectrophotometer would be used. The dome spectrophotometer was faster and did need to be cut into small pieces and didn't get scratches from sample holder after the measurements. It can also measure light barrier properties of three-dimensional structures, which was beneficial when performing light barrier measurements on folded package structures. Since paperboards light transmission increased with wavelength it was not important to be able to measure light transmission through the entire wavelength spectrum. If a paperboard had a zero transmission (transmission below 0.1%) at a certain wavelength, the transmission must also be below 0.1% at a lower wavelength. Therefore to be able to measure light transmission from 420-760 nm was quite enough. If a paperboard did not show any zero transmission at 420-760 nm, it could be complemented by measurement in the U-3010 spectrophotometer.

For the plastic caps, their irregular transmission throughout the wavelength spectrum made it important to obtain the transmission at all wavelengths. Therefore the U-3010 spectrophotometer was used.

3.6 Light barrier measurements of flat paperboards

The dome spectrophotometer was used when performing measurements on the light barrier properties for flat paperboard. The flat paperboards where obtained from different paperboard producers. Because of confidentiality reasons the names of the suppliers cannot be revealed. Instead the boards are named from A-J. From every different producer, boards with different thicknesses were obtained. All boards were duplex boards but some of them were coated with clay coating and others were not. The paperboards will be named by the following system: First the thickness, secondly a letter A-J (representing the paper producer). The transmission of all the boards from all different suppliers was measured in this experiment. Below is a table of all the producers and thicknesses.

Table 2. A list of all the paperboards used.

Producer	Thickness (mm)	Papertype
A	0.27, 0.32, 0.41	Duplex clay coated
B	0.26, 0.30, 0.41	Duplex clay coated
C	0.40, 0.42	Duplex clay coated
D	0.26	Duplex clay coated
E	0.25, 0.31, 0.38, 0.40	Duplex clay coated
F	0.39	Duplex
G	0.25, 0.30	Duplex clay coated
H	0.39	Duplex clay coated
I	0.40, 0.45	Duplex clay coated
J	0.39	Duplex

The light transmittance was measured for every paperboard sample in the dome spectrophotometer. A new holder was constructed for the flat paperboard samples. The new holder was shaped like a flat, black circle made of metal with a hole in it. The purpose of this holder was to weigh down the paper samples in order to keep them in place and avoid light coming in from the sides. The hole was there so light could hit the paper and penetrate into the receptor. The amount of light within the spectrum that penetrated the sample was recorded by the receptor. The computer then displayed the transmittance for wavelengths between 420-760 nm.

3.7 Thickness of the different paperboards

Since the paper density, thickness was known to vary, experiments to investigate the variations was performed. Therefore the thicknesses of all paperboards were measured. The zero transmission wavelengths of all paperboards were related to the thickness of the paperboard.

The thicknesses of the paperboards were measured with a micrometer from Lorentzen & Wetter that presented the result in micrometer with 4 numbers. The contact plate used for the measurements had a radius of about 1 cm.

3.8 Splitting of paperboards

In order to see how much each different layer within the paperboard contributed to the light barrier a test was performed where paperboards samples were split into their different main layers. The different paperboards were split into 3 layers where the thickness varied. The top layer (outer layer of a package) was white while the middle layer was brown and the bottom layer (inner layer of a package) was brown but darker than the middle layer. The transmission of the different layers was measured. Two methods were used for splitting, manual splitting and machine splitting.

3.8.1 Manual splitting

The different layers in a paperboard were difficult to separate by hand during normal condition due to the fact that the adhesion between the layers was too strong.

Samples of paperboard were therefore soaked in water in order to weaken the adhesion between the different layers of the paperboards. The treatment of the paperboard affects the mechanical properties as the drying conditions were different. This may influence the light barrier properties and was also investigated. The light barrier measurements were performed with the dome spectrophotometer.

The transmission values used was for wavelength 430 nm. This wavelength was chosen since the shorter wavelengths are the important ones when considering different wavelengths effect on milk. The measurement interval didn’t cover values lower than 420 nm well. The transmission value wasn’t zero for all the layers and therefore a comparison was possible. If a wavelength at about 650 nm was chosen it would give different results since the transmission behaviour for the different layers changes depending on the wavelength observed, which can be seen in Figure 22.

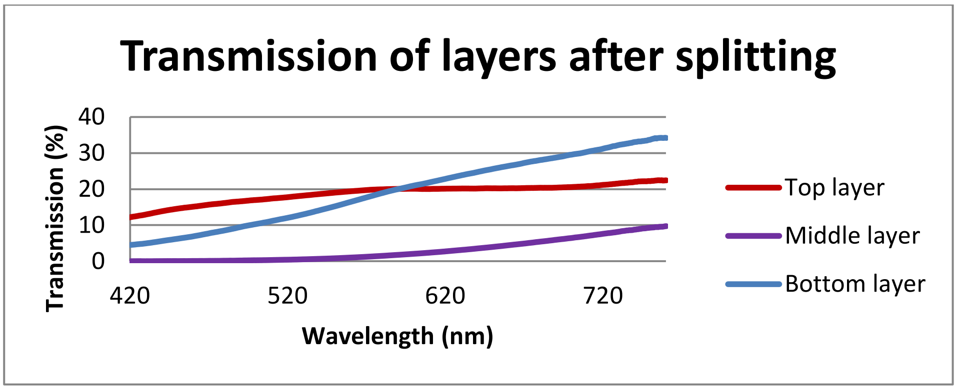


Figure 22. A general graph of the light transmission behaviour for the different layers in a duplex paperboard. The different layers were separated and measured in a dome spectrophotometer. . The top layer had a thickness of 0.127 mm and was bleached with addition of a clay coating, increasing its brightness. The middle layer had a thickness of 0.255 mm and was brown. The bottom layer had a thickness of 0.121 mm and was darker brown than the middle layer.

3.8.2 Machine splitting

Another way to separate the layers in a paperboard is by physically slicing them apart with a sharp blade. In this case a machine with a rolling blade was used. To be able to split them apart the position of the blade had to be adjusted manually. The thickness of the different layers varies which would mean a lot of samples had to be used for preparations in order to get the right thickness of the layers. This method does not change the mechanical properties of the layers and keeps them almost intact which is more preferred compared to grinding. Grinding is another alternative method used to separate layers in paperboard but it destroys the other layers.

3.9 Introducing creases onto paperboard

Making creases on paperboards was done in order to make it easier to fold into a package and also to make it fold in a correct way. It was done by using two molds, one “male” and one “female” that were pressed together which left an imprint on the paperboard. A machine that pressed together the moulds was used.

A machine, MTS 858 Table top System, was used when making creases on paperboard, Figure 23.

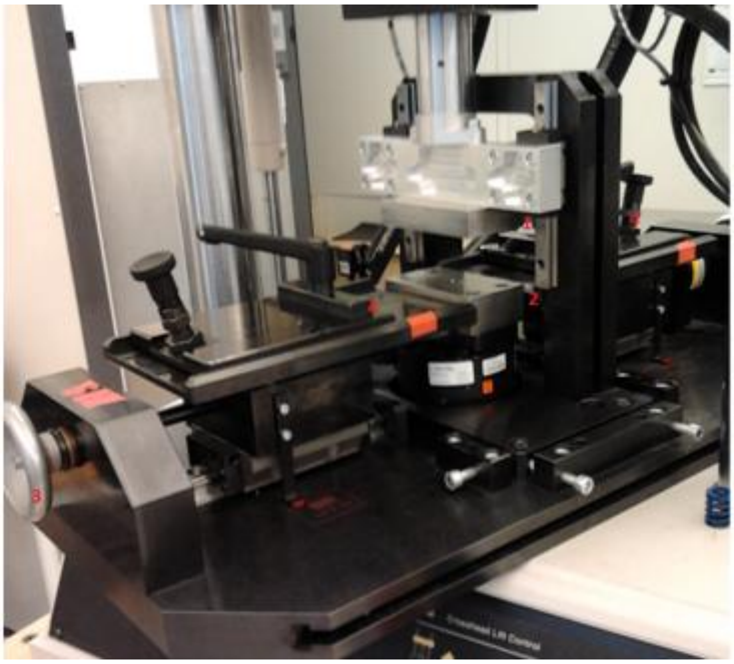


Figure 23. MTS 858 Table top System used for applying creases on paperboard.

The creasing mould used was designed for the bottom part of a Tetra Brik Square 1000 ml which can be seen in Figure 24.

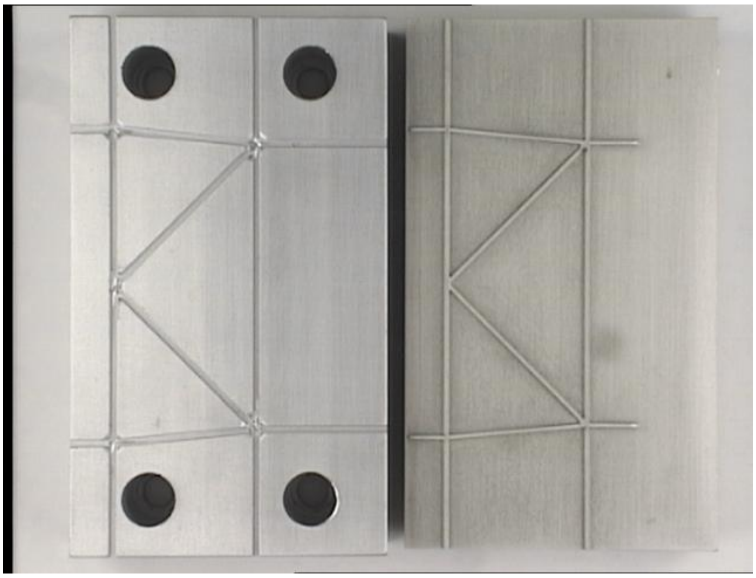


Figure 24. A creasing mould with a pattern for creating creases for the bottom part of a Tetra Brik Square 1000 ml. Female part on the left and male part on the right.

Before using the machine warm up for about 1 hour of the machine were performed. The preheating purpose was to eliminate the fluctuation of the temperature of the equipment and in particular the hydraulic oil used. This was the case since material's density changes with temperature which would affect the adjustment of the distances later on, which is an important parameter when creasing. Preparations by centring the molds and calibrating the distance were made. After inserting the values for the creasing depths in the software used to control the machine it was ready for use.

The carton samples used during the creasing were clasped with two clamps at each end horizontally. This was done in order to simulate the forces exerted on the carton in the production. The horizontal forces have an effect on the formation of cracks and force needed to obtain a certain creasing depth. The horizontal force was adjusted to one Newton per millimetre. In this case the paper width used was 110 mm which means the force was adjusted to 110 N.

The samples used were placed between the molds with the machine direction (fibre direction) along the short lines. This was due to that it was the way it was creased in the industry with the rolling creasing. It is more resistant to cracks when the creases are not applied along the fibres.

3.10 Effect of creasing on flat paperboard

Creases are applied on paperboard made for packages in order to locally weaken the bending stiffness. The weakened part is easier to fold and also controls where the folding occurs. When creases are applied on a paperboard several things could happen like compression, formation of cracks and movement of material to mention a few. The combined effects to the light barrier will be investigated.

An experiment had been performed where the density and transmission for paperboards had been measured. But no obvious effect of the density related to the transmission at 710 nm was observed.

A test was carried out to see how creasing affects flat paper samples. The different creasing depths made were about 0.10, 0.15 and 0.20 mm.

The horizontal force that exists in the industrial production of creases was simulated by hanging 10 kg (98.2 N) at one end of the clips attached to the paper. It had to be done this way since the measurement device for the horizontal force connected to the adjuster was broken and had to be temporarily replaced somehow.

3.10.1 Creasing effect on crack formation

When creases are applied on a paperboard formation of cracks could occur depending on the creasing depth and paperboard used. Experiments where different paperboard and different depths are used were performed.

Creasing was performed twice on the same paper, one creasing pattern on each side. This type of creasing enabled folding of new types of package bottoms. These samples however did not fit in the dome and therefore the light barrier measurements were not performed.

One time creasing was performed at beginning for each sample, 194x110 mm. By experimenting and trying out creasing two times by doing it on each end of the paper a different bottom part to the ones used by other packages could be made.

The difference between the bottom part used compared to the Tetra Brik is that it isn't separated in the middle, Figure 25. The flaps are also turned to the other side. The bottom part was different but it made it easier to measure on since it represented a bottom part better than by just using half a bottom part, Figure 26.

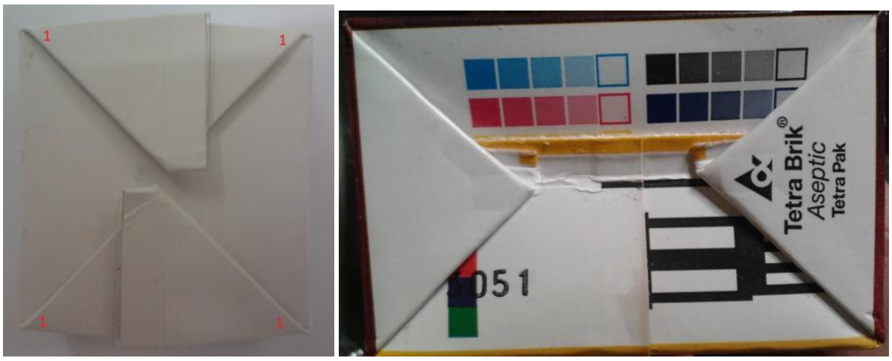


Figure 25. The folded bottom parts used during the experiments to the left. To the right is the bottom part of a Tetra Brik 1 litre.

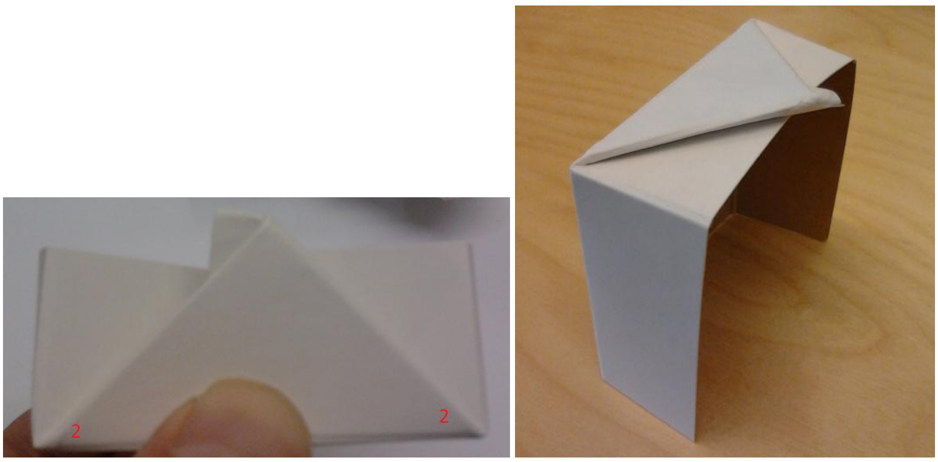


Figure 26. The original way to fold the package for a Tetra Brik.

It had been noticed that the crack formation varied with the paperboard used. It was therefore interesting to see if a pattern could be distinguished. The actual creasing depth and force used for the different samples were compared to the formation of cracks.

24 samples from 8 different paperboards were chosen when analyzing the crack formation tendency. Creasing depth chosen was about 0.1, 0.15 and 0.2.

3.10.2 Creasing effect on light barrier properties

In this section there will be a description of the method used when investigating how creasing affects light barrier properties in paperboard.

In order to investigate if and/or how introduction of creases into flat paperboard samples affected the light barrier properties, flat paperboard samples were creased to different depths ,0.10, 0.15, 0.20 mm, and the light transmission was measured before and after creasing. Afterwards the results were analyzed to see if there were differences in light barrier properties before and after the creasing. The paperboards that were tested were board from 8 different suppliers and only paper used for 1 litre packages. This was because the only creasing tool available was used for creasing paperboard used for 1 litre packages. 1 litre packages are usually made of paperboard with a thickness of around 0.4 mm. The paperboards that were used were 0.41 mm A, 0.41 mm B, 0.40 mm C, 0.38 mm E, 0.39 mm F, 0.39 mm H, 0.40 mm I and 0.39 mm J.

Three replicas of each of the 8 different types of paperboard was used for each creasing depth, leading to eight paperboard types, three replicas of each paperboard type, three different creasing depths. In total 72 samples. In order to see the effect throughout the entire paperboard and not just on the place where the crease was applied, the transmittance of thirteen different points on the paperboard was measured before and after creasing. The holder used for the flat paperboard samples were used.

First of all three samples of every paper type were cut out in 11x17.5 cm. Afterwards they were marked with thirteen points in a pattern that can be shown in Figure 27. The transmittances for all of these thirteen points on all the uncreased paperboards were then measured in the dome spectrophotometer. This led to eight types of paperboards, three replicas of each paperboard, thirteen points of each replica and three different creasing depths. In total 936 light transmittance measurements of the uncreased paperboard.

Afterwards all the paperboards were creased into the three different depths and all the light transmittance measurements in the dome spectrophotometer were repeated on the same points of all the samples that were previously measured.

Finally for all creasing depths the light transmittance before and after creasing was compared to see how the creasing affected the light barrier.

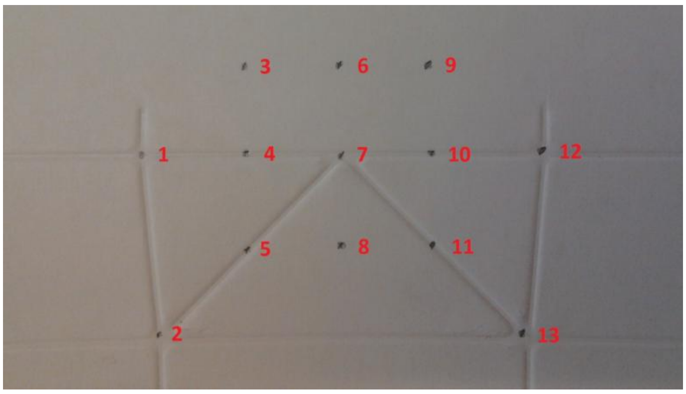


Figure 27. Measurement points in dome spectrophotometer for a creased paperboard.

3.11 Measurements of paperboard folded into bottom parts of a package

Double creased samples were folded into bottom parts of a package and measured in the dome spectrophotometer. This was done in order to see if a difference could be seen in the light barrier properties between the different creasing depths used on three dimensional bottom parts.

The double creased samples had been prepared by cutting out 256x110 mm paperboard pieces. The folded bottom parts were 6 x 6 x 2 cm.

3.11.1 Transmission for folded paperboard into bottom parts of a package with dome spectrophotometer

The light barrier for the three dimensional structures were analyzed for different samples from different producers in the dome spectrophotometer.

3.11.2 Comparison of flat paperboard and folded paperboard

This test was performed in order to see if folding of paperboard affected the light barrier. The dome spectrophotometer was used in order to measure the light transmission of the flat paperboard samples. Afterwards the flat paperboard samples were folded into package bottom parts. The transmission of these packages was measured in the dome spectrophotometer. Afterwards the transmission of the flat and folded paperboards was compared to see if there was a difference in light transmission.

3.11.3 Creasing depth vs. transmission for folded paperboard with dome spectrophotometer

The light barrier properties of samples with different creasing depths on the different bottom packages made were measured in the dome spectrophotometer. This was done in order to see if any effects could be observed.

3.12 Light exposure effect on transmission in paperboard

Experiments where paperboard samples were exposed to light were performed in order to see the effects of light exposure.

Three samples were used where half of each sample was protected with aluminium foil, Figure 28. The other half was exposed to sunlight. It was done this way to easier compare the effect of light exposure. The sizes of the samples were 5 x 10 cm. The samples were put by a window. Conditionings of the samples were performed every time before the light barrier measurements in the dome spectrophotometer. During the conditioning the samples were placed in the shadow below a table. Both the protected and the unprotected part of the samples were measured.

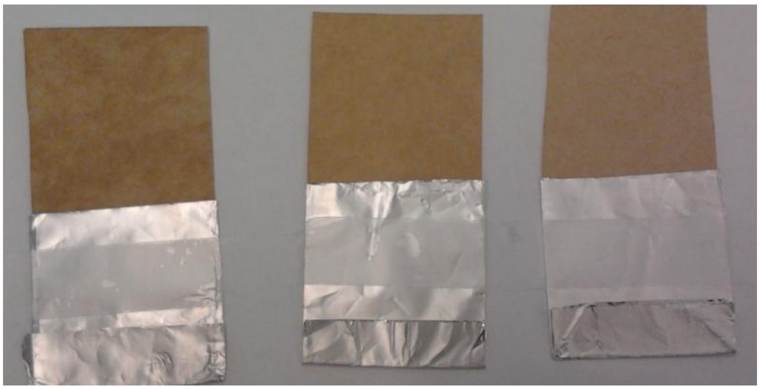


Figure 28. Three samples from different producers 0.27 mm A, 0.42 mm C and 0.25 mm D. Half of the sample had been wrapped in aluminium foil to protect it while the other half were exposed.

3.13 Effect of printing on light barrier

Measurements were carried out in order to investigate what effects the printing had on the light barrier. This was tested for flat samples and top part of packages. The dome spectrophotometer was used for tests.

In this experiment, four different types of flat samples from packages with different printing colours were measured. First the transmission of a non printed part (white) of the sample was measured and afterwards the transmission of an area from the same sample printed with colour was measured. See Figure 29. The results were then compared.

The four different types of packages that were used were the following:

- Proviva Blåbär, 1 litre package from Elopak with blue as the dominating colour
- Proviva Skogsbär, 1 litre package from Elopak multicoloured with green red and blue
- Proviva Mango, 1 litre package from Elopak with yellow as the dominating colour
- Milbona mellanmjölk, 1 litre package from Elopak with green as the dominating colour

Figure 29. Shows the different flat samples with different printing colours.

3.14 Light transmission of plastic caps

When measuring light transmittance in the plastic caps, both the dome spectrophotometer and the U-3010 spectrophotometer were used. The caps that were measured were 15 different plastic caps each with different colours. The colours of the caps that were tested were the following:

Beige, black, blue, brown, dark blue, dark green, light brown, light green, orange, purple, red, vanilla, white, yellow and one blue available in the market, see Figure 30. The concentrations of the pigments of the caps were unknown.

Figure 30. The plastic caps used for the experiments. 14 plastic caps from Tetra Pak were available while the blue plastic cap in the bottom right corner was found in the market.

3.14.1 Light barrier measurements of plastic caps with U-3010 spectrophotometer

The transmittance of the 15 different caps was measured in the U-3010 spectrophotometer. Only one replica of each cap was measured. This was due to the fact that one cap took approximately eight minutes to measure in the U-3010 spectrophotometer but had high accuracy.

A holder for the caps had to be constructed in order to fit the caps into the U-3010 spectrophotometer. Afterwards every individual cap was measured in the U-3010 spectrophotometer as described in section 1.2. The transmittance of every cap at wavelengths between 200-850 nm was obtained, with 1 nm interval.

4. Results and discussion

The different paperboards have been named with a thickness and a letter. The thickness is for the paperboards thickness while the letter represents a specific producer.

4.1 Light barrier measurements of flat paperboard

All the paperboards from producer A, F, H, I, J and 0.30 mm B, 0.42 mm C, 0.31 mm E, 0.38 mm E and 0.40 mm E all have a zero transmission for wavelengths above 500 nm, see Figure 31. This means that the transmission is below 0.1% for at least all wavelengths smaller than 500 nm which is much lower than the 8% limit set by International Dairy Federation for chilled stored milk packages. The paperboards protect against light induced off flavours with Riboflavin since these off-flavours only occurs with light up to about 480 nm.

The paperboards 0.26 mm B, 040 mm C, 0.26 mm D and 0.25 mm E have a zero transmission wavelength below 500 nm and the paperboards from producer G have below 0.1% transmission for wavelengths up to 400 nm.

None of the paperboards have a zero transmission wavelength of 650 nm and above. Since light of 650-700 nm causes off-flavour reactions with chlorins and phorphyrins the paperboards may not give enough protection against light that causes off-flavours with chlorins and porphyrins. Since there is no international recommendation for light transmission in paper based packaging material at these wavelengths and chlorins and phorphyrins are present in very small concentrations in milk, full protection (transmission below 0.1%) against wavelengths of 650-700 nm may not be necessary.

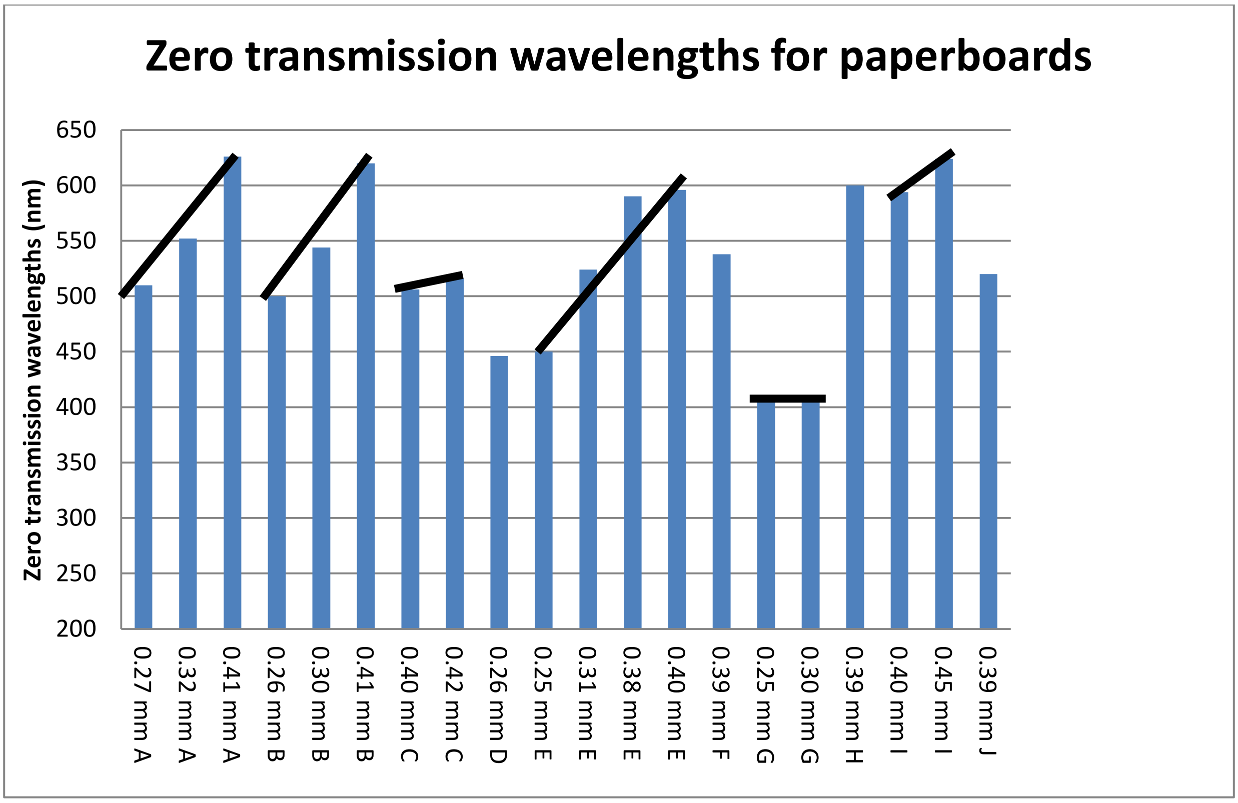


Figure 31. Comparison of the zero transmission wavelength for all the different paperboards. The measurements were performed with U-3010 spectrophotometer for wavelengths between 200-850 nm. The black lines were added to easier see the relation between thickness and zero transmission wavelengths.

4.2 Thickness effect on light barrier

Figure 32 shows the zero transmission wavelength as a function of thickness for all producers. The higher the zero transmission wavelength, the better the light barrier. As can be seen in Figure 32, as the thickness increases for a specific producer the zero transmission wavelength increases. For the same producer the thicker the board the better the light barrier. When comparing paperboards from different producers, thinner paperboards may have better light barrier properties than thicker paperboards from another producer. For example when comparing the thickest paperboard from producer A (about 0.41 mm) with the thickest paperboard from producer C (also about 0.41mm), A has a much better light barrier even though they have the same thickness. Since the only factor that is varied within paperboards from the same producer is the thickness while other factors vary between producers, such as chemical composition etc, it is reasonable to believe that light barrier improves with thickness but it is not the only factor that affects the light barrier. Other factors may be how the paperboard is processed, its chemical composition, the amount of light absorbing compounds such as lignin etc.

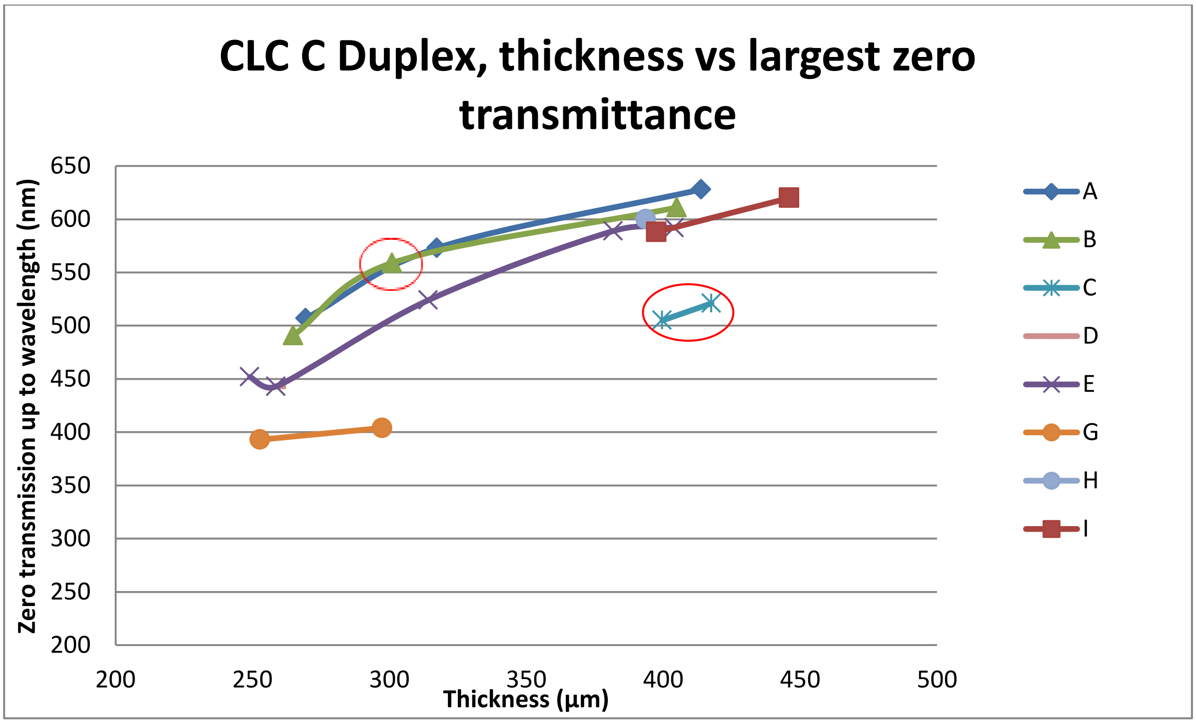
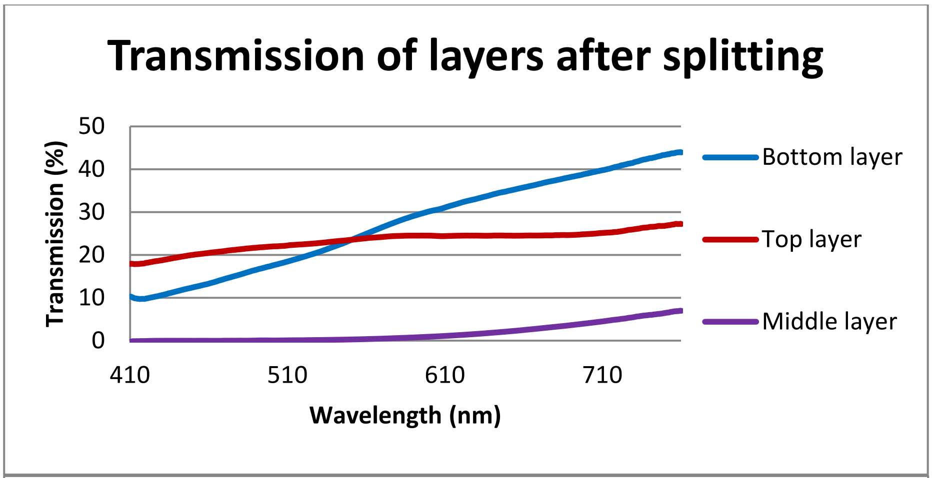


Figure 32. The largest zero transmission wavelength plotted against thickness. The paperboards were measured with U-3010 spectrophotometer which measured transmission for wavelengths between 200-850 nm. Since the profile of paperboards transmission doesn't show any peaks (see Figure 20) the zero transmission could be used as a value for barrier property. When the zero transmission wavelength increases it means the barrier improves. The different shapes symbolize the different suppliers. All values for the different thickness from the same paperboard supplier have been connected with a line in order to easier see how the different suppliers vary with each other. Supplier F and J was not included in this graph since they varied with the others by not having a clay coating.

4.3 Splitting of paperboards

4.3.1 Manual splitting

The profile of the different layers is shown in Figure 33. The middle layers barrier was the best among the three layers that the samples were split into. Even though the bottom layer and top layer had about the same thickness their transmission profiles varied. The intersection for the top and bottom layer was shifted depending on the producer.



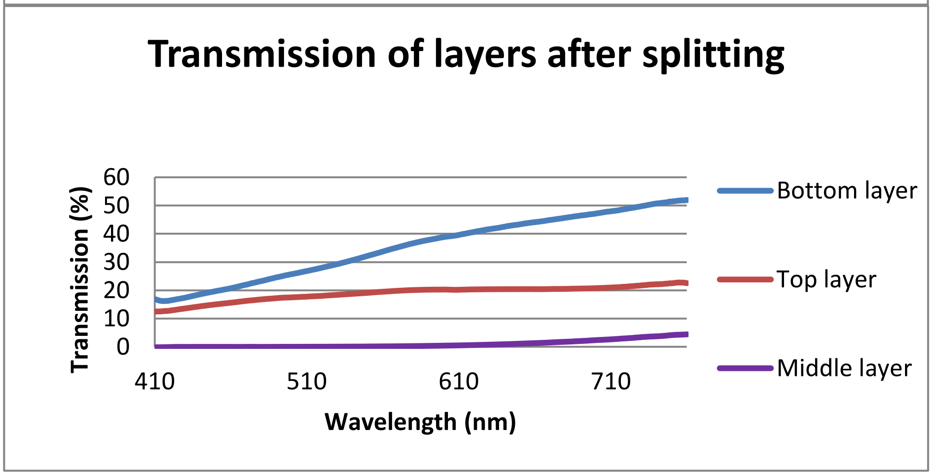


Figure 33.Graphs of the light transmission behaviour for the different layers in a duplex paperboard from producer H with 0.39 mm thickness and producers A with 0.41 mm thickness is plotted here. The different layers were separated and measured in a dome spectrophotometer. . The top layer had a thickness of 0.127 mm and was bleached with addition of a clay coating, increasing its brightness. The middle layer had a thickness of 0.255 mm and was brown. The bottom layer had a thickness of 0.121 mm and was darker brown than the middle layer.

The measurements of the thickness of the different layers for a paperboard varied for the different paperboards and producers, Figure 34. A relation between thickness of the different layers and the paperboards thickness was observed. Top and bottom layers were rather constant while middle layers thickness increased when the total paperboards thickness increased. The total thickness of the different layers showed a value higher than the original paperboard thickness. This was most probably due to the layers being uneven to begin with and when the thickness was measured it was the largest thickness over an area that was measured.

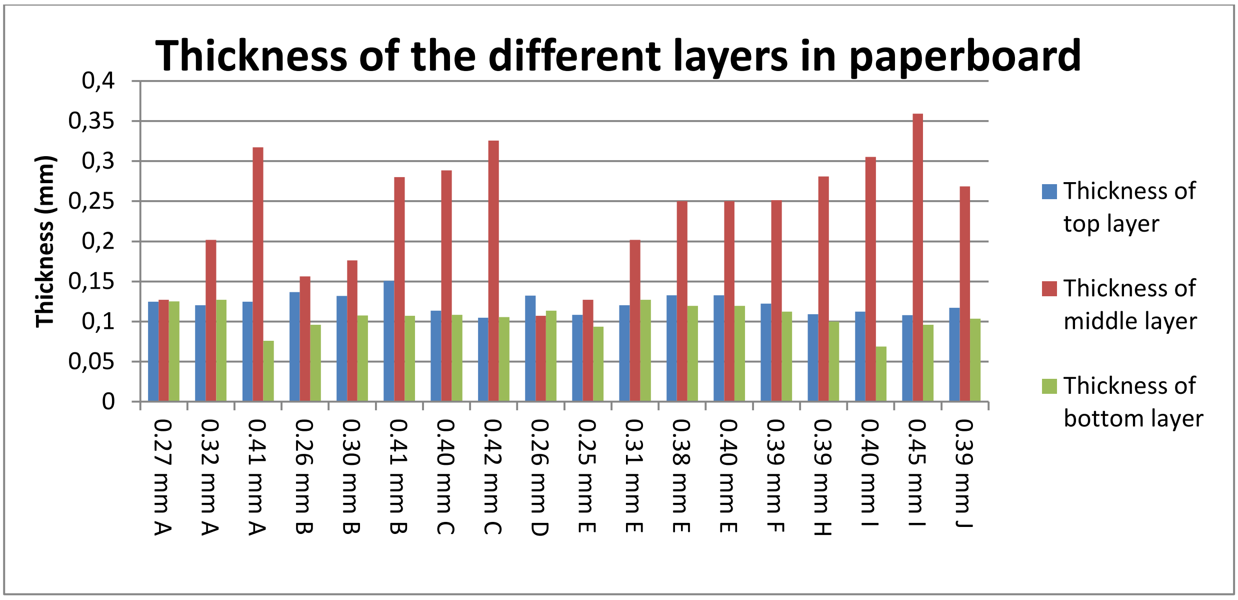


Figure 34. The graph shows the thickness of the different layers in paperboard after splitting for the different producers. Data from producer G is missing since the splitting wasn't successful.

The middle layers importance increases with increased total thickness which can be seen when comparing the transmittance from the same producer with different thicknesses, Figure 35. The importance also depends on the composition of the layer because a composition with better light barrier will give larger effect with increased thickness. This is the case since the top and bottom layers thickness are almost constant when the total thickness varies.

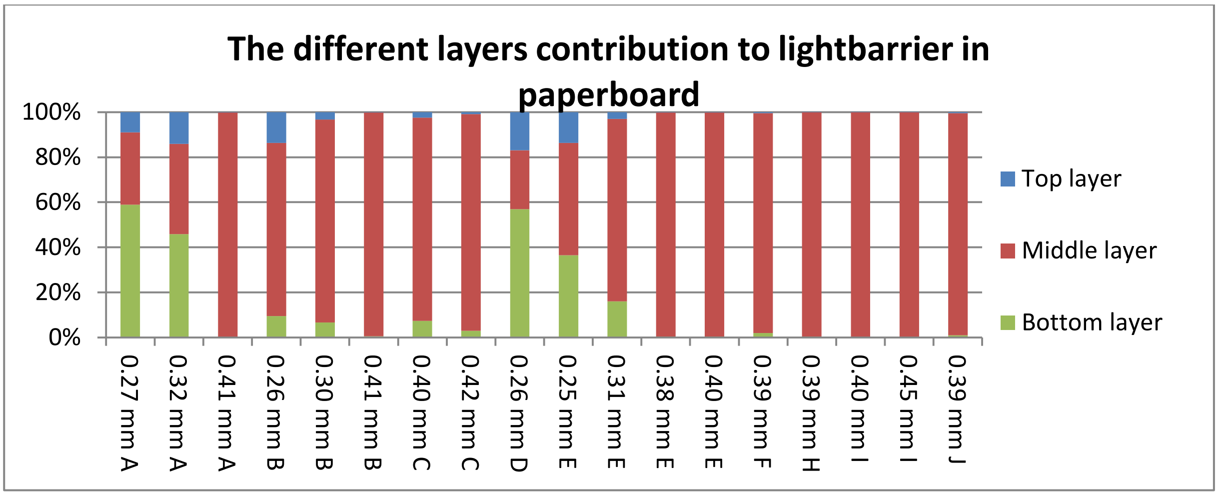


Figure 35. The duplex clay coated paperboards layers were split into three parts. The top layer consisted of the white part that consisted of bleached paperboard with a clay coating. The middle layer was brown. The bottom layer was also brown but darker than the middle layer. The transmission of the different layers was measured in the dome spectrophotometer. All three layers from the different samples have been included in this graph. The transmission values at 430 nm were used to make this graph. The contribution of each layer was calculated by taking the inverse transmission of the layer divided by the sum of the inverse transmission of all layers. Data from producer G is missing since the splitting wasn't successful.

If all the layers had the same thickness (0.1 mm), the light barrier would be located in the middle and bottom layer, Figure 36. The top layers influence was small which can be explained by Figure 33 since it has a worse light barrier for most paperboards at wavelengths above 430 nm.

The normalization formula used to make this calculation was:

Equation 4

$$\text{Transmission at 0.1 mm} = (transmission\ of\ layer)^{\frac{0.1\ mm}{thickness\ of\ layer}}$$

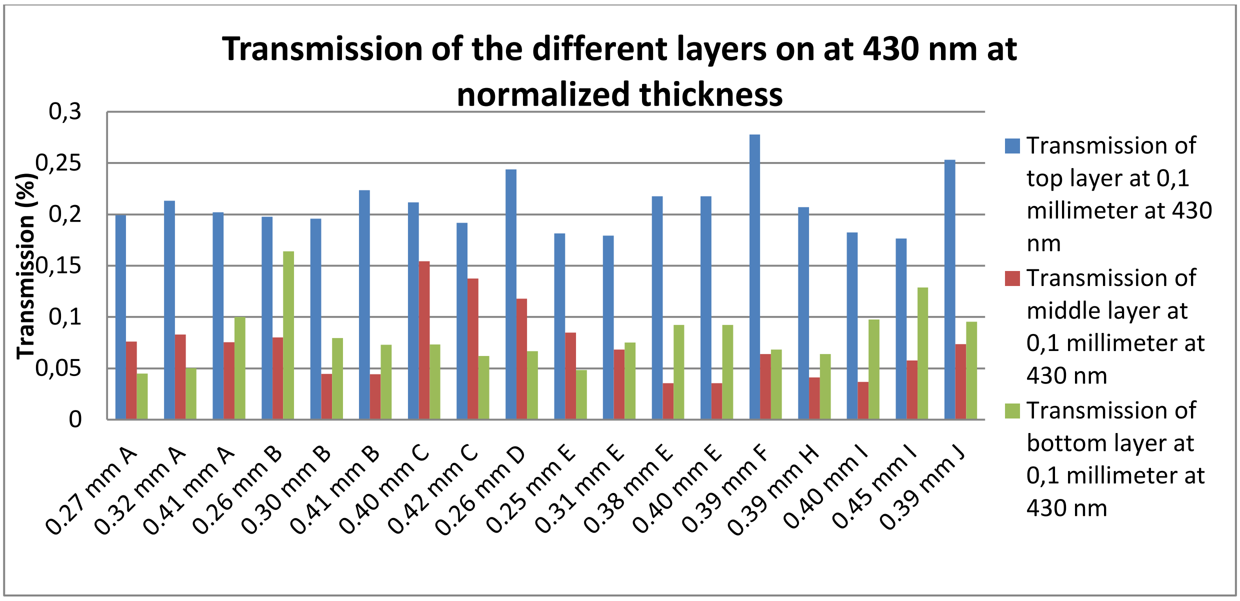


Figure 36. The transmissions for the different layers have been calculated by using Equation 4. Data from producer G is missing since the splitting wasn't successful.

4.3.2 Machine splitting

For paperboards with thickness around 0.4 mm and above, the light barrier was located 95-100% in middle layer, Figure 37. This was the case since the thickness of the middle layer was thicker than the other layers.

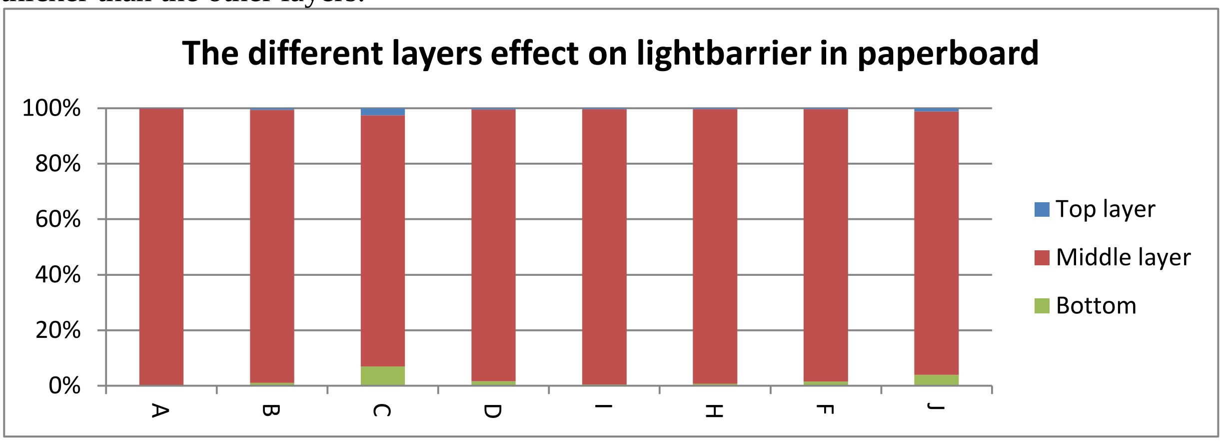


Figure 37. The relative effect of the different layers. The transmission value used is from wavelength 430 nm. The paperboards thickness was an average of about 0.4 mm.Machine splitting

4.4 Effect of creasing on flat paperboard

4.4.1 Creasing depth vs. creasing force

Increased creasing depth lead to increased force needed, one graph is shown in Figure 38. The other graphs can be found in Appendix part "Creasing depth vs. Creasing force".

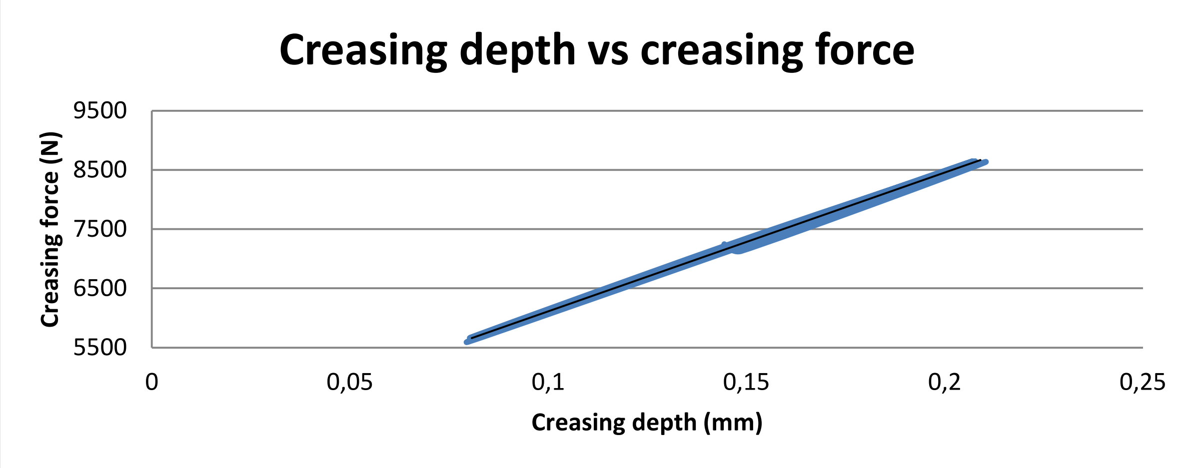


Figure 38. The paperboard used in this graph was 0.38 mm E. The MTS machine used showed the creasing force used for different creasing depths which was used to make this graph. Measurements were performed for three different creasing depths with three replicates at each.

But the force needed to reach a certain depth was different for the different paperboards, Appendix part "Creasing depth vs. creasing force". Paperboard C needed the least force while paperboard I needed the highest creasing force per millimetre creasing depth, Figure 39. The creasing force needed was 50% more for paperboard from producer I compared to producer C.

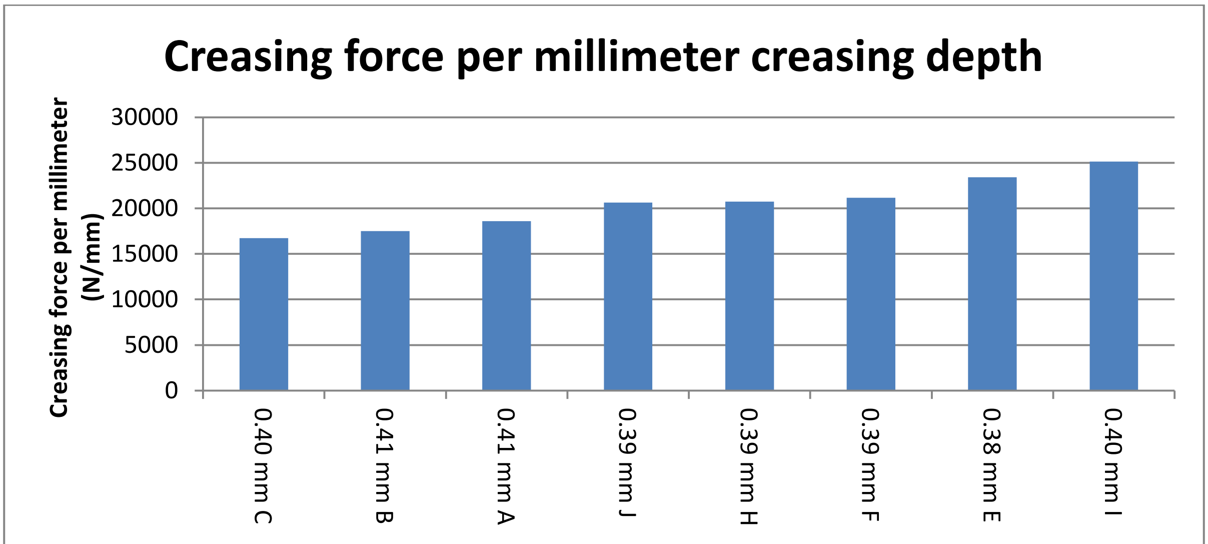


Figure 39. Eight different paperboards with thickness of about 0.4 mm were used during this experiment. The values were obtained by plotting the creasing depth against creasing force. On the y-axis is the creasing force needed per millimetre which was obtained by inserting the linear equation in similar graphs as Figure 38 and afterwards using the linear constant.

4.4.2 Creasing effect on crack formation

The cracks appeared on the locations which were probably exposed to the largest amount of force. Depending on the folding the cracks are or are not exposed.

The cracks that appeared were located at the corners inside the pattern, Figure 40**Error! Reference source not found.**. The cracks appeared at those specific places since those places were exposed to the largest forces during the creasing when applying all the creases at once.

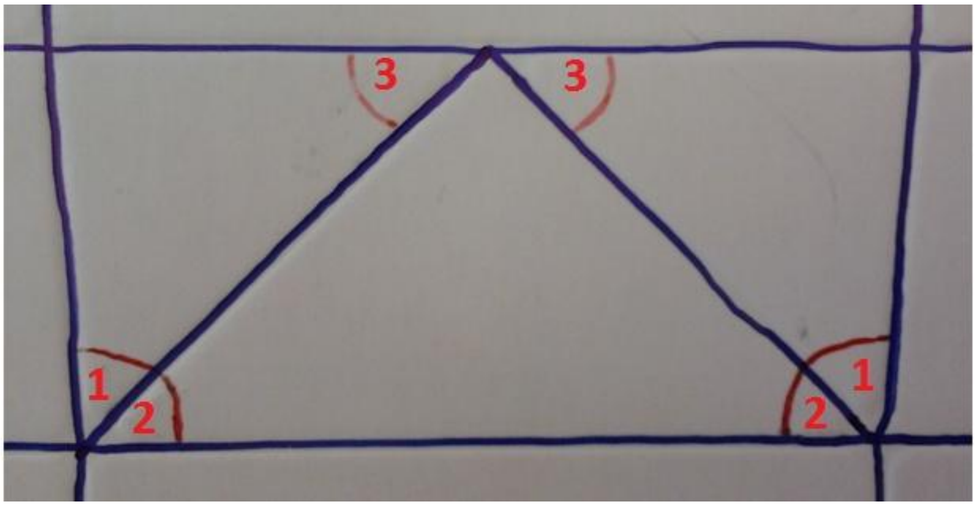


Figure 40. Creasing pattern marked with blue pen while the area marked with quarter circle marks the sites where the cracks usually appeared.

When folded, only the cracks at number one were exposed but they were located above triple layer of carton when folded in the way it was done during this experiment. This means that the effects of the crack marked as number one in the Figure 40 are probably not measurable with the dome spectrophotometer after the carton has been folded. When folded in the original way only the cracks marked as number two would be exposed. But since these also are located above triple layer of carton the light barrier effect of the cracks would be not be measureable when folded.

It was also noticed during folding and attaching double sided tape that the paper from producer I and J had quite different surface compared to the other paperboards. This was the case since the tape had problems sticking to the bottom layer (brown side) of the paperboard.

As the creasing depth increased the crack formation tendency did as well, Figure 41.

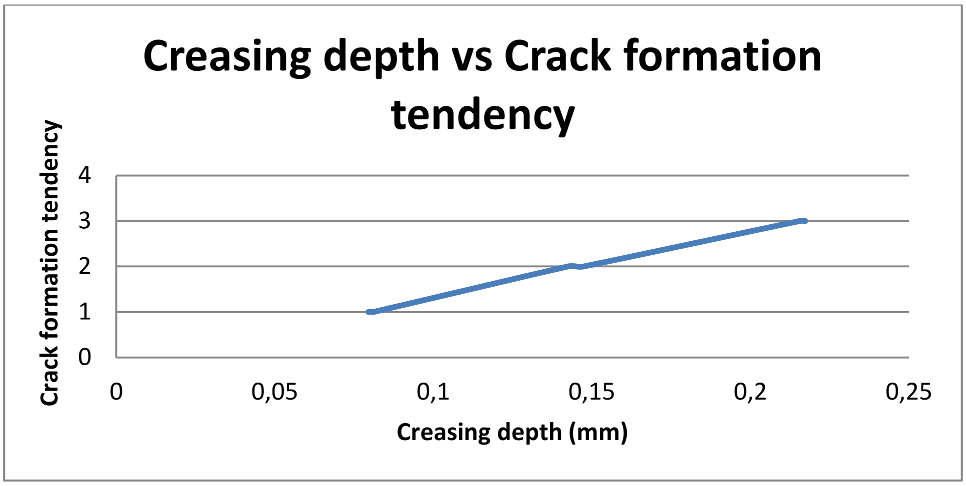


Figure 41. The crack formation tendency was scored between 0-4 where 0 is no cracks and 4 is large crack penetrating through the whole paperboard. The paperboard used for this graph were 0.41 mm A.

The crack formation was different for different producers for certain creasing depths, Figure 42. Paperboard from producer A was the most prone to crack formation while paperboard from J was least.

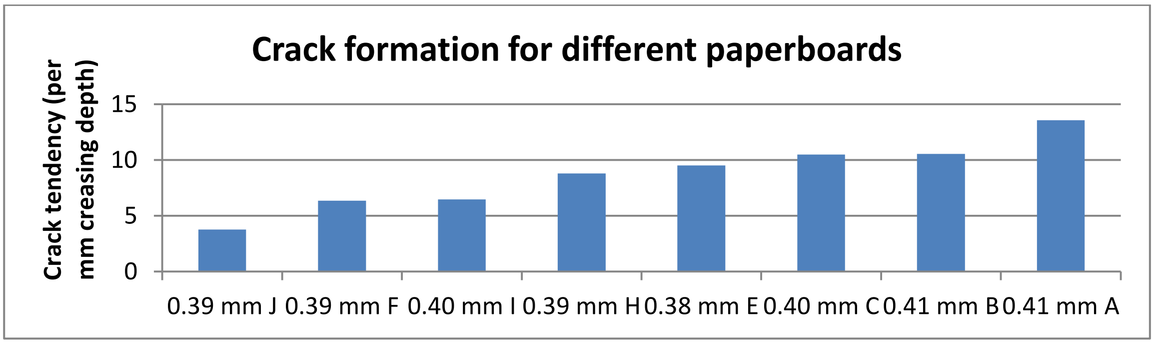


Figure 42. The crack tendency values for the different producers were obtained by giving the different cracks a score from 0-4 for the different samples. No cracks were given 0, barely visible cracks 1, visible surface cracks 2 and large surface cracks larger than 1 cm were given 3. The crack score was then divided by the creasing depth.

4.4.3 Creasing effect on light barrier properties

Observations showed that creasing a 0.4 mm thick paperboard with creasing depth between 0.2-0.3 mm improved the light barrier, Figure 43. Effects on the light barrier can still be seen for 0.1 mm creasing depth but the effects are not as clear as for creasing depths 0.2-0.3 mm. The improved light barrier may be due to the compression that occurs. When doing a more thorough analysis it showed that the measurement point number seven showed highest effect.

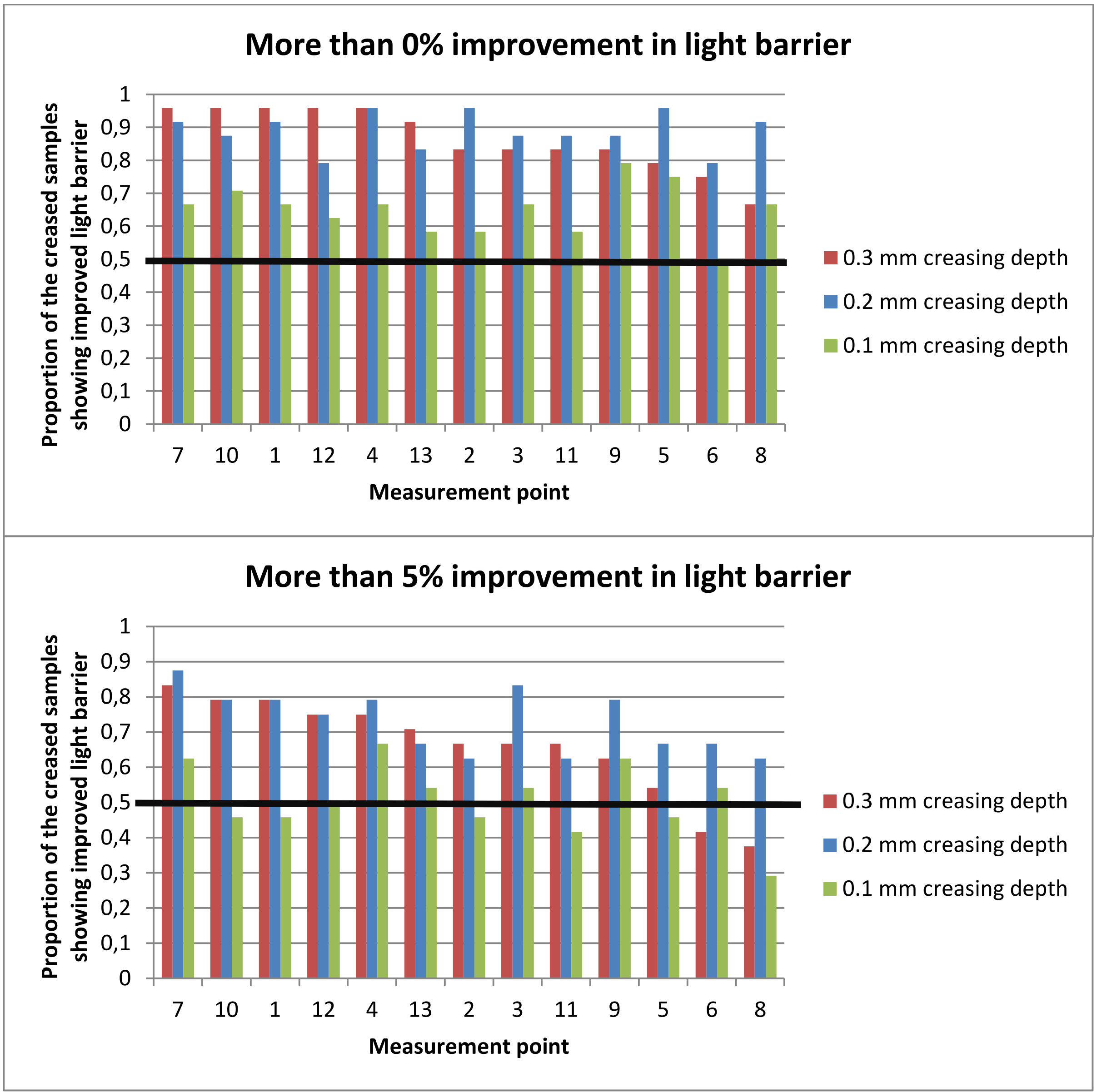


Figure 43. Creasing effect on the light barrier for different creasing depths is shown here. The black line marks when more than 50% of the samples shows improved light barrier. 2 different graphs for improvement in light barrier for 0% and 5% is shown here.

It was interesting to see that the points, 1, 4, 7, 10 and 12 at the first horizontal line, Figure 44, showed a higher effect compared to the other measurement points which made it less of a coincidence.

The creasing depths used for the samples didn't result in cracks penetrating the samples. If penetrating cracks appeared it would result in weakened light barrier.

Improving the light barrier by compressing the whole paperboard is not an alternative since the bending stiffness would be weakened.

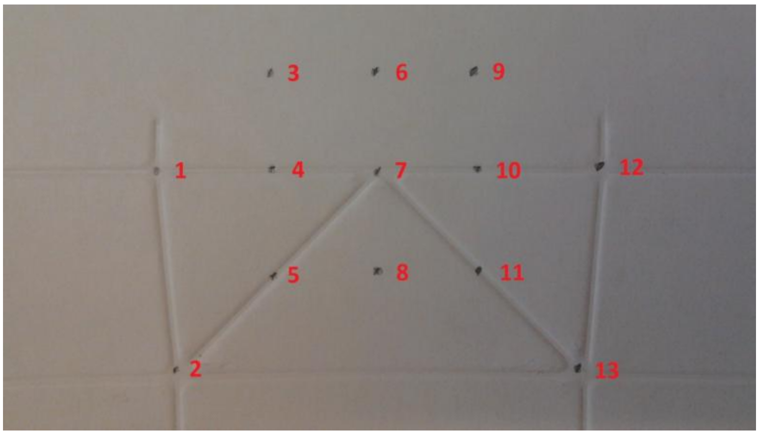


Figure 44. Used here again to make it easier for the reader to analyze. The picture shows the measurement points.

4.5 Measurements of folded paperboard into bottom parts of a package with dome spectrophotometer

4.5.1 Comparison of dome spectrophotometer results for flat paperboard and folded paperboard

A systematic difference could be observed when comparing the 3D package compared to the flat samples, Figure 45. The 3D package showed a decrease in transmittance which in turn resulted in larger zero transmission wavelengths. But the increase was only 0.3-5.0% which is very small. The decrease was due to the thicker layer paperboard on the packages and also cause of the different geometry.

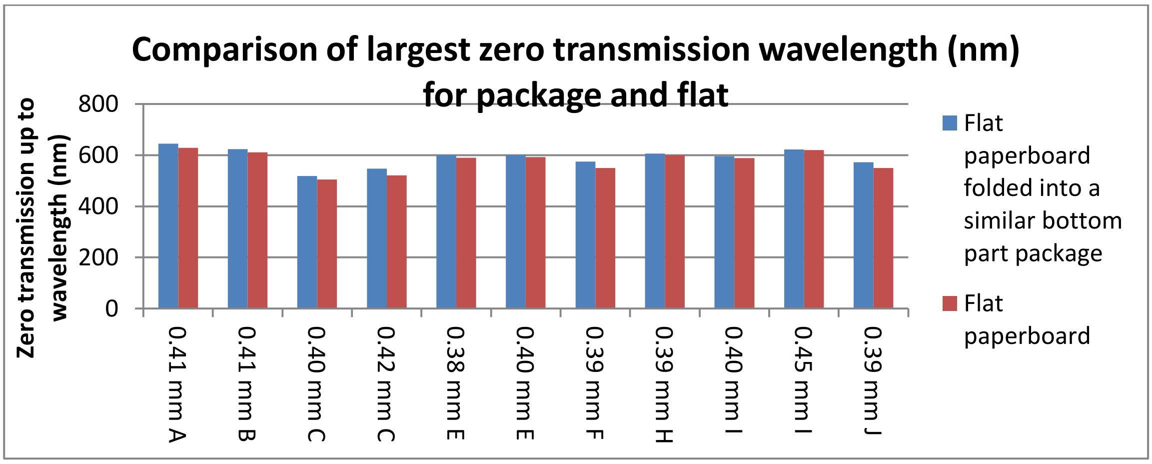


Figure 45. Measurements was performed in the dome spectrophotometer. The largest zero transmission wavelength is compared for both flat paperboard and flat paperboard folded into a similar bottom part package.

4.5.2 *Creasing depth vs transmission for folded paperboard with dome spectrophotometer*

No systematic difference in light barrier could be seen among the different creasing depths used on the different folded bottom parts, Figure 46.

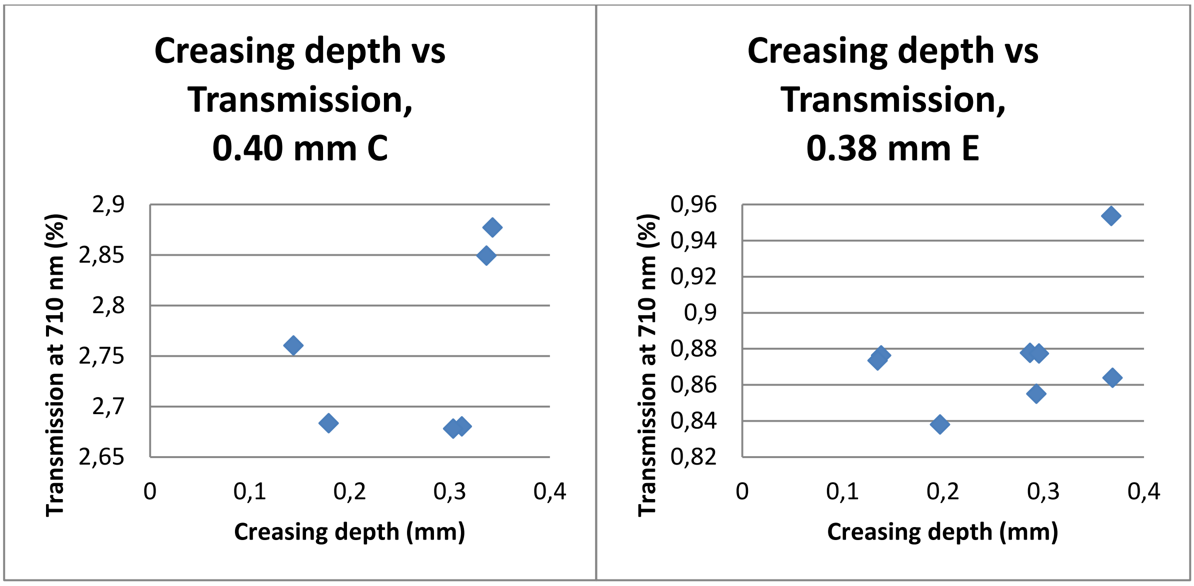


Figure 46. Creasing depth against transmission at wavelength 710 nm has been plotted in these graphs.

4.6 *Light exposure effect of light barrier in paperboard*

The colour on the paperboard samples used became lighter after light exposure, Figure 47. The colour changed from brown to slightly yellowish brown.

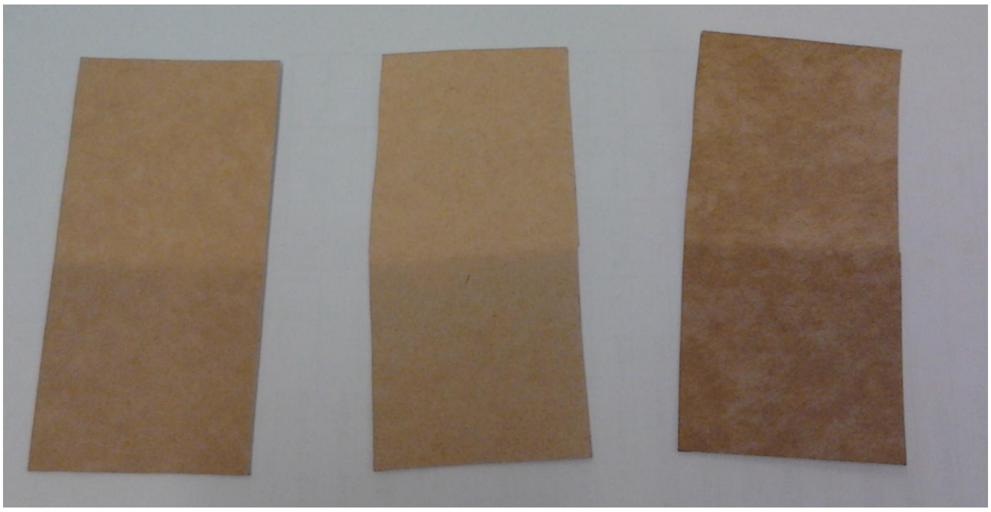


Figure 47. Three different paperboard samples were exposed to light. The samples were from left 0.42 mm C, 0.25 mm D and 0.27 mm A. This was the samples appearance after 75 days of light exposure. The bottom part was protected with aluminium foil while the upper part was exposed.

How a paperboards transmission profile changed after being exposed to sunlight by a window for 75 days is shown in Figure 48. The largest changes are located in the lower wavelengths when comparing percentage change in transmission. The transmission at wavelength 510 nm increased with about 110% while the transmission at wavelength 710 nm increased with about 25%. But the changes are larger for the larger wavelengths when comparing the difference in transmission since. The profile looks almost the same except that it has been shifted to the left.

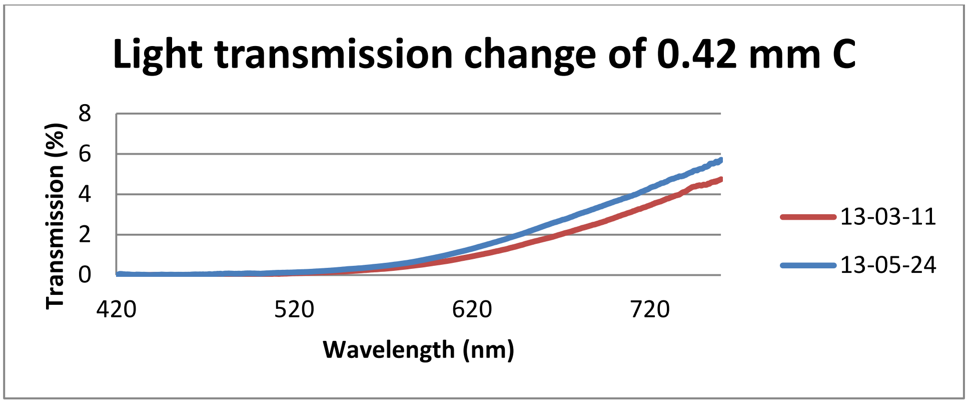


Figure 48. In this graph the transmittance for wavelengths between 420-760 nm of paperboard sample 0.42 mm C was plotted. The measurements were performed on the part of the sample that was exposed to sunlight by a window. The result from 11th February and 24th May was plotted. Only the result from this sample was chosen since the other samples also showed similar results.

For better visualization the wavelength used for the transmission was at 710 nm. This was the case since the difference is larger for the larger wavelengths but going all the way to 760 nm where the data is less stable was not preferable. During the first few days the light barrier showed an improvement, Figure 49. The periodical peaks may be due to the humidity changes during the light exposure. This is the case since the samples had been conditioned at about 50% humidity and afterwards been placed at a place with about 20% humidity. It takes longer time for humidity to go down compared to up. But how fast it changed wasn't studied.

After a couple of days the light barrier weakened and kept weakening beyond the starting point. This can be seen in Figure 49 by noting that the light transmission increased with time, when the paperboard was placed in the sunlight. The reference also changed slightly probably because the concentration of light it was exposed to during the conditioning was enough to affect the paper even though they were placed in the shadow. The reference showed the same pattern as the start of the light exposed part where the light barrier improved. During the 75 days the reference may have been exposed to the same concentration as 1-2 days of the light exposed part.

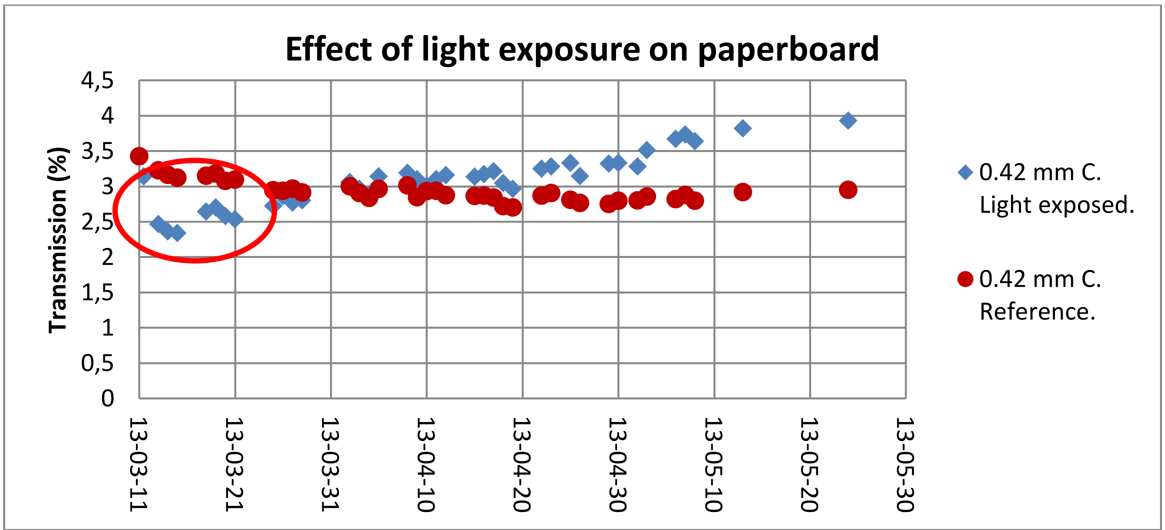


Figure 49. The graph shows how sample 0.42 mm C transmittance at wavelength 710 nm changed after being exposed to sunlight by a window. Only this sample was plotted since the other samples also showed similar profiles except that the two lines crossed each other earlier. The transmittance is plotted on the y-axis while the different dates are plotted on the x-axis. Half of the sample was protected (red circle shapes in the graph) with and aluminium foil while the other half were exposed (blue diamond shapes in the graph). The light transmission over a period of 75 days was plotted. The first couple of days showed a decrease in transmittance. After those days the transmittance increased.

The light concentration the samples were exposed to increase rather constantly over a longer period, Figure 50. A higher increase of light concentration can be observed in April. The concentration of light the samples were exposed to is less than the values in the graph since the measurements represent the value outside on a clear day. The samples were placed indoors by a window. The concentration of light the samples were exposed to was therefore lower since the window blocks some of the light.

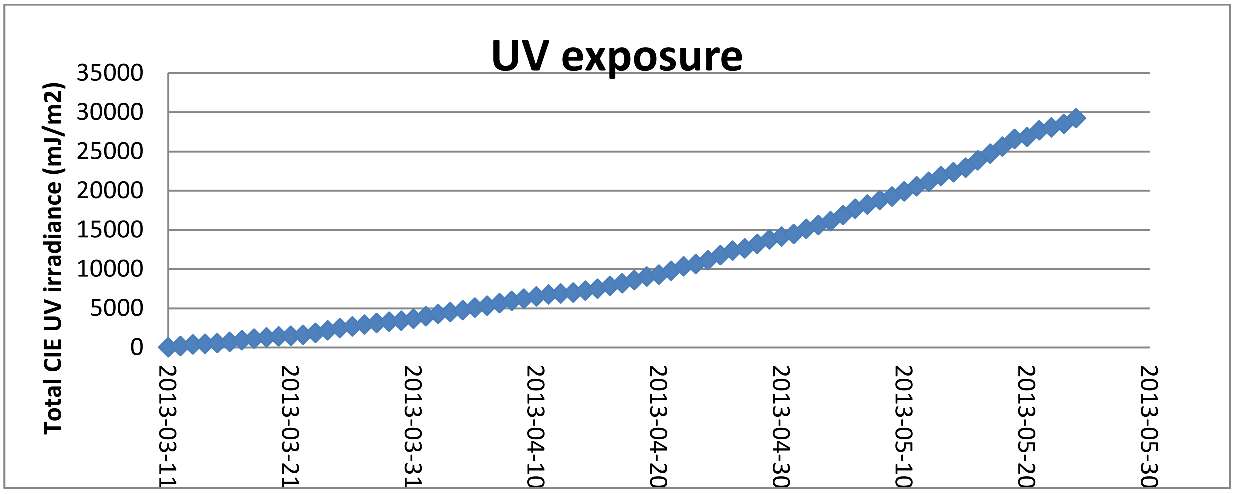


Figure 50. The concentration of UV light that the location where the paper samples were placed over has been plotted here. The measurements were performed over 75 days. The data was obtained from SMHI, http://strang.smhi.se/extraction/index.php

By using the data for total light concentration and the transmission another graph was made, Figure 51. The profile of the graphs appears to be logarithmic.

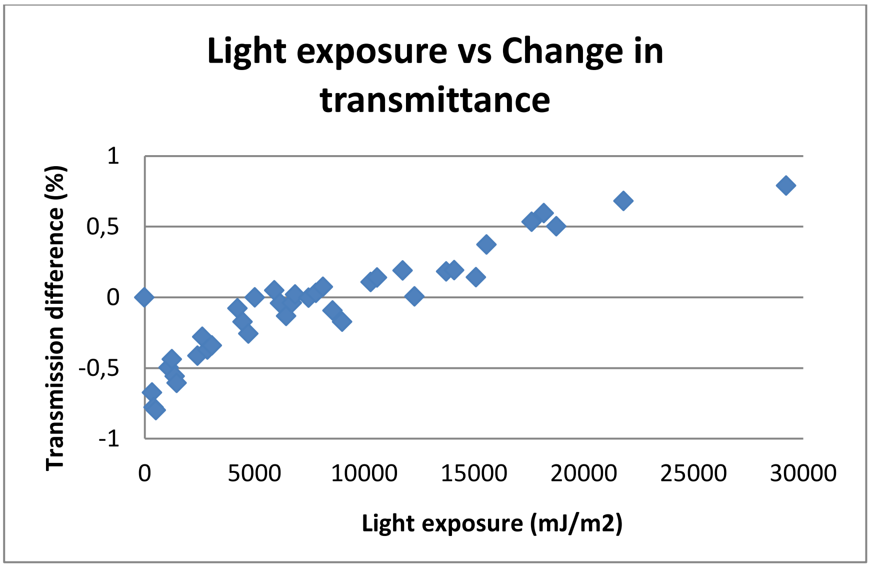


Figure 51. How the light exposure over 75 days affected the paperboard sample 0.42 mm C have been plotted here. On the y-axis is the change ($T-T_0$) in transmission. The x-axis is the accumulated total light concentration outside on a clear day.

These findings show that long term light exposure causes paperboard to deteriorate its light barrier and give rise to yellowing. This is probably because the lignin in the paperboards undergoes photochemical reactions triggered by UV-light. These reactions are known to cause browning/yellowing of paper. These light induced reactions breaks down lignin. Since lignin is a light absorbing compound it is reasonable to believe that breakdown of lignin reduces light absorption in paperboard and thereby weakens the light barrier. From these findings it could be a good idea to store paperboard in dark areas if maintaining its light barrier is necessary. Paper based packages that are stored outside, for example in open markets, are highly exposed to sunlight and should therefore be kept in darker areas to avoid light barrier deterioration.

4.7 Measurements of printing effect on flat samples

The results of measuring the effect on light transmission of different printing colours on flat samples can be seen below. See Figure 52. The printing on packages has a positive effect on light barrier of bleached packages. The printing colours on the different packages are not standardized colours and neither are they completely homogenous. This makes comparison between different printing colours difficult. However the result clearly shows that when applying printing colour on none printed surface, it can significantly decrease light transmission (improve light barrier). The effect printing colour has, depends on the colour used and the wavelength of the light. This is because objects of certain colours absorb and reflect certain light depending on the wavelength of the incoming light.

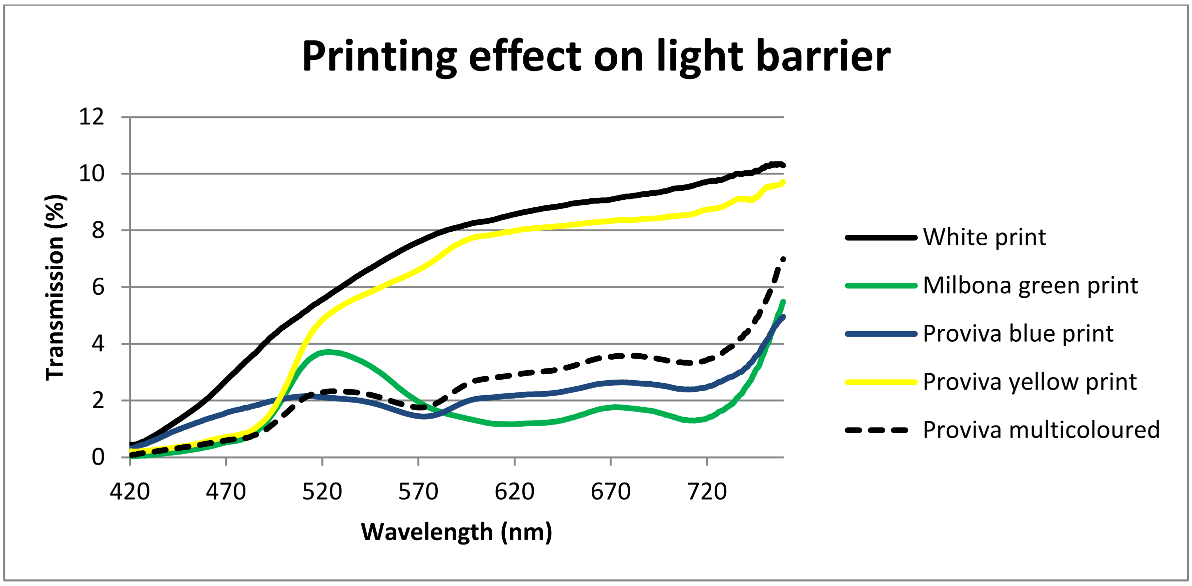


Figure 52. In this graph the transmission of printed and none printed part of Proviva blåbär, mango and skogsbär package is shown. The packages were made from a triplex board that consists of a top layer that is white (bleached) a middle part that is slightly yellow (termomechanical pulp) and a white bottom layer (bleached). Measurements were performed in the dome spectrophotometer for wavelengths between 420-760 nm.

4.8 Light barrier measurements of plastic caps

Figure 53and Figure 54 show the transmission at the wavelengths between 200 and 850 nm for several plastic caps that had a peak in the area of 400-600 nm that needs to be blocked by extra light barriers with the exception of the blue plastic cap available in the market. They help to add barrier above 600-750 nm. The graphs are displayed both with the transmission as a logarithmic and as a non-logarithmic scale. The logarithmic graph was made to be able to see the whole picture while also being able to distinguish where the transmission is below 0.1% for the whole spectrum.

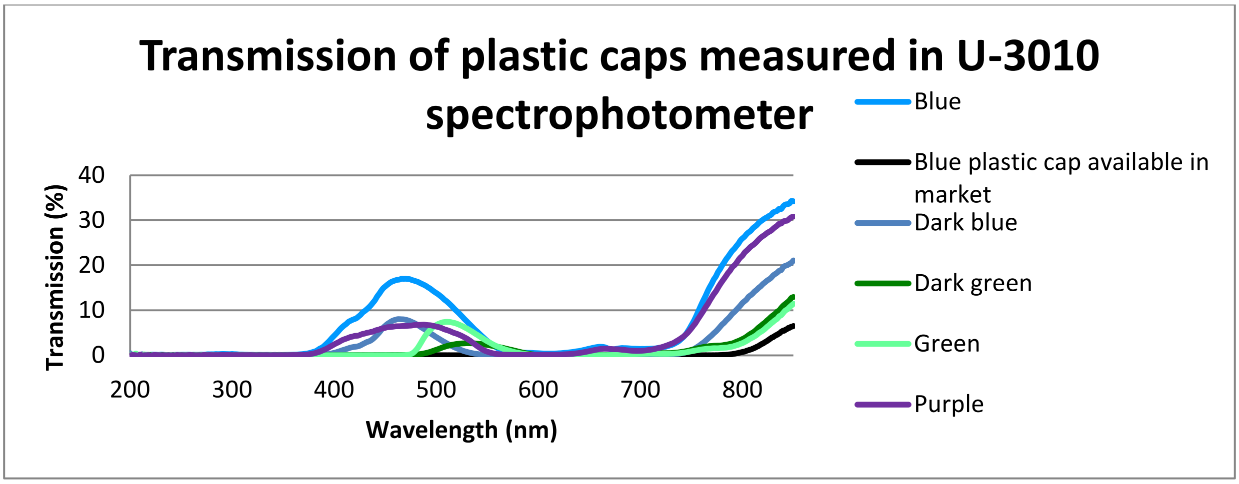


Figure 53. The graph shows the transmission plotted against wavelength between 200-850 nm for 6 plastic caps. Measurements were performed with U-3010 spectrophotometer.

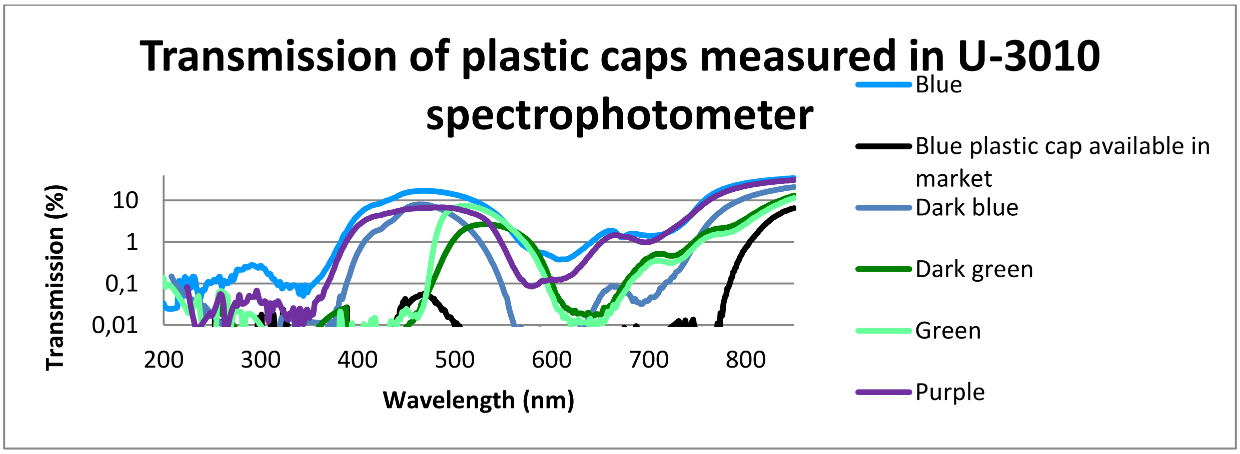


Figure 54. The graph shows the logarithmic transmission plotted against wavelength between 200-850 nm for 6 plastic caps. Measurements were performed with U-3010 spectrophotometer.

The Figure 55 and Figure 56 show the transmission at the wavelengths between 200 and 850 nm for several plastic caps that have a weak barrier above 600 nm and even earlier for some colours with the exception of dark brown. Adding more pigment of these colours is not an effective way to extend the barrier range with mocha as an exception. It just improves the colour

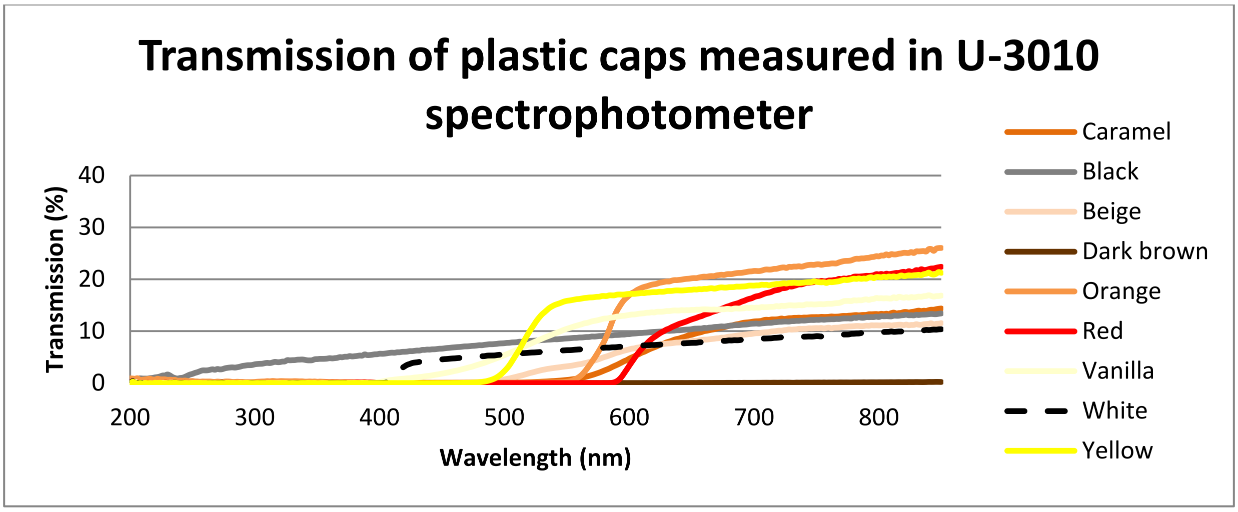


Figure 55. The graph shows the transmission plotted against wavelength between 200-850 nm for 9 plastic caps. Measurements were performed with U-3010 spectrophotometer.

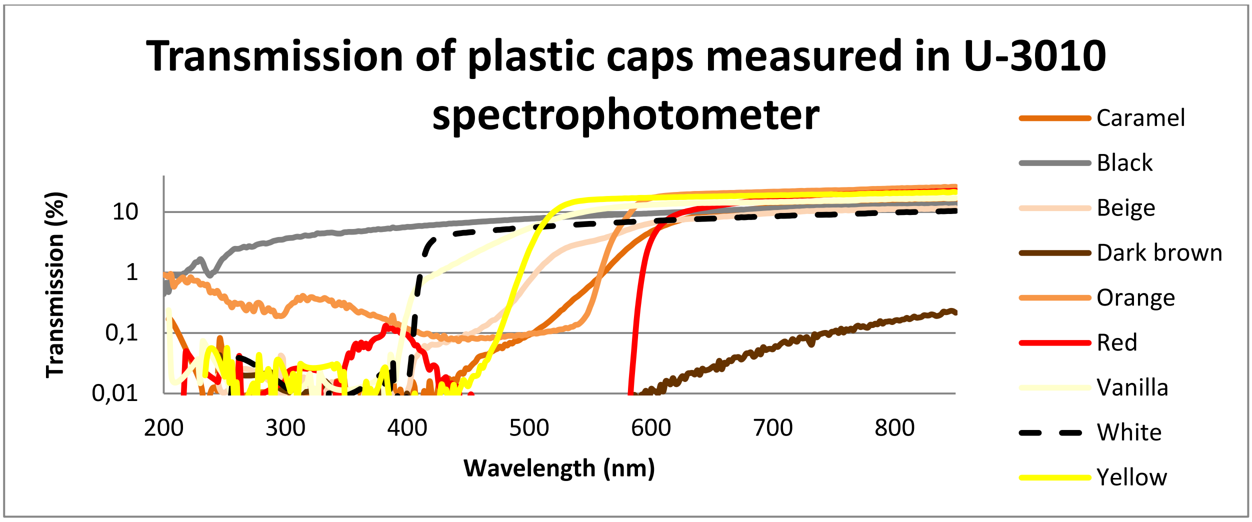


Figure 56. The graph shows the logarithmic transmission plotted against wavelength between 200-850 nm for 9 plastic caps. Measurements were performed with U-3010 spectrophotometer.

Table 3 shows, for every single cap, at which wavelengths the transmission is below the zero transmittance.

Since Riboflavin triggers off-flavour reactions at wavelengths from 220-375 nm and 410-475 nm and chlorins and phorphyrins at wavelengths from 650-700 nm it is of importance to see if transmission of these wavelengths is below the zero transmission limit. Table 3 below shows whether or not the transmission of the caps fall below 0.1 % transmission for wavelengths that excite Riboflavin and chlorins/porphyrins.

Table 3. Shows if the plastic cap gives a transmission below 0.1 % for wavelengths that excite Riboflavin, chlorins and porphyrins. All plastic caps were about 0.75 mm in thickness except the blue plastic cap available in the market that was about 0.59 mm in thickness.

Plastic cap measured in U-3010 spectrophotometer	Zero transmission (below 0.1%) wavelengths (nm)	Zero transmission for all wavelengths that excite Riboflavin (220-375, 410-475 nm) within the area 200-850 nm	Zero transmission for wavelengths that excite chlorin and porphyrin (650-700 nm) within the area 200-850 nm
Beige	200-452	No	No
Black	None	No	No
Blue	200-214, 234-244, 322-354	No	No
Dark brown	208-746	Yes	Yes
Dark blue	214-388, 550-716	No	Yes
Dark Green	200-476, 602-674	Yes	No
Light brown	208-502	Yes	No
Light Green	216-472, 596-580	No	No
Orange	410-508	No	No
Purple	200-368, 574-586	No	No
Red	214-380, 396-586	Yes	No
Vanilla	200-396	No	No
White	200-404	No	No
Yellow	200-474	No	No
Blue cap available in market	200-783	Yes	Yes

As can be seen in Figure 53 to Figure 56 the transmission at all wavelengths in the spectrum varies depending on the pigment the cap is coloured with. This is because objects of certain colours absorb and reflect light depending on the wavelength of the incoming light. The black and the brown pigment give the most uniform transmission. This means that these colours give no or very few peaks in the wavelength spectrum i.e the light transmission does not vary too much with wavelength. The reason to this is that black and brown absorbs wavelength throughout the entire electromagnetic spectrum, unlike other colours which only absorbs a narrow interval of the electromagnetic spectrum. The light transmission at a certain wavelength does not only depend on the colour the pigment has, it also depends on the concentration of the pigment. Black and brown pigments give the advantage that lower amounts of pigments are required in order to decrease light transmission to below 0.1 % because these colours give a uniform transmission without high peaks. Colours that give high peaks may require higher amounts of pigment in order to reduce light transmission to below 0.1%. Higher concentrations of pigments increases costs and too high concentrations may alter the physical properties of the cap. There is however the disadvantage that consumer may not find brown or black caps on milk packages attractive.

In this experiment, the only caps that have a transmission below 0.1% at all wavelengths that induce off-flavour reactions in milk are the brown cap. The results between the caps are hard to compare since the pigment concentrations were unknown.

5. Conclusions

Paperboards from different producers vary in light barrier properties which are due to the raw material and the processing. Paperboards from producer A, F, H, I, J and 0.30 mm B, 0.42 mm C, 0.31 mm E, 0.38 mm E and 0.40 mm E all had below 0.1% transmission for light that induce off flavour reactions in milk with Riboflavin. This means that there are paperboards available in the market that ensures protection against light that trigger off-flavour reactions with Riboflavin at room temperature. No paperboards had below 0.1% transmission against light that triggers off-flavour reactions with chlorins and phorphyrins (650-700 nm). But the light transmission limit for those wavelengths is higher than for wavelengths that induce off flavour reactions with Riboflavin since the concentrations of chlorins and porphyrins are much lower. More studies are needed in order to establish the light transmission limit between 650-700 nm.

Paperboards from producer A had the best light barrier properties both regarding paperboards used for 1 litre packages (thickness of around 0.40 mm) and portion packs (thickness of around 0.30 mm). This is because producer A had the paperboards with the largest zero transmission wavelength of the corresponding thickness.

The light barrier for paperboards improved with increased thickness. Thickness is not the only factor that matters regarding the light barrier of paperboards. Other factors, such as composition of the paperboard also influence the light barrier but exactly how could be further investigated if necessary.

The thickness of the different layers in paperboard varied between the producers. The thickness of the middle layer was the largest for paperboard with thickness larger than 0.38 mm. When comparing the relative thickness and mass it is shown that they are closely related. At wavelength 430 nm it is shown that the light barrier properties are located 90 to almost 100% in the middle layer for paperboard with thickness about 0.4 mm which are paperboards used for 1 litre packages.

Transforming a flat paperboard into a three dimensional package first by creasing and then folding didn’t weaken the light barrier since the cracks that appeared (if they appeared) was located at positions above extra layer of paperboard. Applied printing colour of a paperboard resulted in a decreased light transmission throughout the entire wavelength spectrum. As long as the light barrier of the paperboard is sufficient, the final package will also have a light barrier that is sufficient.

Long term sunlight exposure deteriorates the light barrier of a paperboard. From these findings it could be a good idea to store paperboard in dark areas if maintaining its light barrier is necessary. Paper based packages that are stored outside, for example in open markets, are highly exposed to sunlight and should therefore be kept in darker areas to avoid light barrier deterioration.

Plastic coloured caps affect the light transmission at different wavelengths depending on the pigment used due to selective absorption and reflection of light. The brown cap and the blue one available in market had a light transmission below 0.1% for all wavelengths that causes off-flavour reactions with Riboflavin, chlorins and phorphyrins. This means that there are plastic caps available in market that ensures protection against off flavour reactions which may be used in non-foil milk packages at ambient storage.

6. Further research

Regarding the paperboards further investigations on the how the chemical composition of the paperboards need to be performed. Especially investigations on how the content of the light absorbing compound lignin affects the light barrier. Such research could give information that could be used to modify the composition of the paperboard in order to improve its light barrier.

None of the tested boards gave a transmission below 0.1% for wavelengths that causes off-flavours with chlorins and porphyrins, 650-700 nm. Since naturally occurring chlorins and phorphyrins are present in such small concentrations in milk, investigations need to be performed if these compounds have a significant effect on inducing off-flavour reactions and at which light concentration.

In this study the paperboards were only folded into bottom parts of packages. Since the bottom part is the part of a package that is exposed to the least amount of light, studies on how folding into other parts of packages need to be made.

When investigating how long term exposure of sunlight affected the light barrier of a paperboard, only the brown bottom layer of the paperboard was investigated. Since the white top layer (outside layer) is the part of the board that is exposed to light in a package, studies should be performed where the white top part is exposed to light as well.

Only investigations on how different types of pigments affected the light barrier were performed in this study. The concentration of the pigments was unknown. Therefore research where the pigment concentration in plastic caps is related to the light barrier properties should be investigated. Also combining different colours of pigments in plastic caps could be performed.

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