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Comparison of the Optimum Barrier Properties of PET/PE and BOPP/CPP Laminate Structures

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Abstract: In this study the barrier properties of two different laminate structures are investigated which are typically used in food packaging industry: PET/PE (Polyethylene Terephthalate/Polyethylene) and BOPP/CPP (Biaxially Oriented Polypropylene/Cast Polypropylene). The objective of this was to check if a structure based on BOPP could serve as a feasible alternative to the standard and traditional PET-based structure, while offering potential similar advantages in terms of barrier requirements. For this Water Vapor Transmission Rate and Oxygen Transmission Rate were measured using MOCON PERMATRAN-W® Model 3/34 G and MOCON OX-TRON 2/21 respectively. As we know BOPP (WVTR -1.5–5.9 g/m^2/24hrs for 100µm film) has a good barrier to water vapor as compared to PET (WVTR - 3.9–17g/ m^2/24hrs for 100µm film) and BOPP(OTR - 93–300 cc/m^2/24hrs for 100µm film) has low gas barrier as compared to PET (OTR - 1.8–7.7 cc/m^2/24hrs for 100µm film), thus a coating of EVOH (Ethylene-vinyl alcohol) is added to the BOPP film in order to improve the oxygen barrier properties of BOPP/CPP based laminate. The EVOH has polar hydroxyl groups present in vinyl alcohol which cause strong inter-and intramolecular bonding and which results in good gas barrier properties of EVOH. The final results of test performed on two laminates demonstrated that the BOPP/CPP laminate showed superior barrier properties compared to the PET/PE laminate which suggests that BOPP/CPP laminates can be used as an appropriate alternative to PET/PE structures for food packaging applications such as bakery items or snacks item. Further research could look into the suitability of each laminate structure for different food products based on the barrier requirements.

Keywords: *EVOH, BOPP/CPP, laminate, intramolecular, suitability*

Introduction:

The food packaging industry is constantly looking for new materials that can extend the shelf life of product, preserves the freshness, and help to achieve sustainability goals. Widely used laminate structures such as PET/PE have been used traditionally all around the world due to suitable barrier and mechanical properties. (Sarkar & Aparna, 2020). However, the increased consumer awareness, strict government regulation and self-motivation among the global packaging community has led to an increased emphasis on the sustainability and thus exploration of alternate materials which offers same properties with reduced environmental impact. Thus, BOPP/CPP laminate is emerging as a promising alternative to PET/PE based laminate that has comparable barrier properties with an additional advantage of material compatibility and environmental impact. (Tyagi, Salem, Hubbe, & Pal, 2021).

Barrier properties are critical in food packaging applications because they directly influence the shelf life and quality of the packaged product. Water vapor and oxygen are two primary factors that can deteriorate food products. Therefore, materials with low Water Vapor Transmission Rate (WVTR) and Oxygen Transmission Rate (OTR) are preferred for packaging (Mokwena & Tang, 2012). Traditional PET/PE laminates have been the industry standard for many food packaging applications. However, BOPP/CPP laminates are gaining attention for their potential to offer better barrier properties, thereby ensuring longer shelf life and fresher products (Lazić, Budinski-Simendić, Gvozdenović, & Simendić, 2010).

In addition to barrier properties, the choice of packaging materials is increasingly influenced by considerations of sustainability. As we know BOPP (WVTR -1.5–5.9 g/m^2/24hrs for 100µm film) has a good barrier to water vapor as compared to PET (WVTR - 3.9–17g/ m^2/24hrs for 100µm film) and BOPP (OTR - 93–300 cc/m^2/24hrs for 100µm film) has low gas barrier as compared to PET (OTR - 1.8–7.7 cc/m^2/24hrs for 100µm film) (Lu & Zheng, 2018). PET/PE laminates provide an effective solution but there are certain environmental problems associated with them because the structure is made up of films of two different materials which may affect their ability to recycle. (Tyagi, Salem, Hubbe, & Pal, 2021). In contrast, BOPP/CPP laminates can be considered as more environmentally friendly due to the compatibility of the material used in two layers, low carbon footprint and

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better recyclability. The shift towards more sustainable packaging solutions is driven by regulatory requirements, consumer demand for eco-friendly products, and corporate sustainability goals (Unwrapping the benefits of BOPP Films, n.d.).

The purpose of this study is to compare the barrier properties of PET/PE and BOPP/CPP laminates by measuring their Water Vapor Transmission Rate (WVTR) and Oxygen Transmission Rate (OTR). The barrier properties of a laminate are result of the sum total of the barrier properties of individual layer. Thus, the PET/PE laminate have cumulative result of PET (Polethylene Terephathalate) and PE (Polyethylene) and similarly BOPP/CPP will have properties which combine the result of BOPP (Biaxially Oriented Polypropylene) and CPP (Cast Polypropylene). Here we have used MOCON PERMATRAN-W® Model 3/34 G for measuring WVTR and the MOCON OX-TRON 2/21 for measuring OTR in order to provide a comprehensive analysis that illustrates the potential of BOPP/CPP as a sustainable alternative to PET/PE due to same material used in both the layers. Our findings could support food packaging industry in material selection, thus contributing to improved product protection incorporating sustainability practices.

It is critical to understand the advantages and limitations of laminate structure in order to optimize any packaging. This research evaluates the barrier performance of both the structure and also highlights the importance of materials which are made up of compatible materials. In order to proceed with the main objective of this paper, it is important to understand the components that affects the barrier properties of packaging materials. Therefore, we did an extensive literature review on the subject, which is detailed below.

Barrier Properties in Food Packaging

The reason barrier properties are critical in food packaging is that they directly affect the shelf life of food products and thus, the quality. The packaging materials preserves the product, maintain its shelf life and prevent spoilage by preventing the transmission of moisture and gases. In this review we will explores the existing literature related to the factors which comprise the barrier properties of packaging materials, focusing on the Water Vapor Transmission Rate (WVTR) and the Oxygen Transmission Rate (OTR) (Vasile & Baican, 2021).

Importance of Shelf Life in Food Packaging

Shelf life represents the period during which a packaged product remains suitable for human consumption, a fundamental concept in food packaging. The shelf life of food items depends on the barrier properties of packaging material, which help to protect the product against environmental factors that are the main cause of deterioration. Food products such as coffee, snacks and bakery items are extremely sensitive to moisture and oxygen, thus, packaging with high barrier properties is required to maintain their freshness and extend shelf life. Within the package the surrounding environment such as amount of moisture content and gas exchange plays an important role in preserving the quality of product (Robertson, 2009).

Oxygen Transmission Rate (OTR)

In order to design a successful packaging, the knowledge of the gas transmission/oxygen transmission properties of packaging materials is crucial. The OTR (Oxygen Transmission Rate) measures the amount of oxygen that can permeate or pass through a given area of laminate or film under specified conditions. Lower the value of OTR, better are the barrier properties, which is important for the products which require protection against moisture and oxygen in order to reduce oxidation of food product (Larsen & Liland, 2013).

Water Vapor Transmission Rate (WVTR)

WVTR (Water Vapor Transmission Rate) is also another critical attribute related to barrier property of a laminate or film which affects the shelf life or quality of food products. WVTR measures the amount of water vapor passing through a packaging material under specified conditions. The lower values of WVTR indicates that the moisture barrier property of laminate is good and thus, this laminate can be used for water vapor-sensitive or moisture-sensitive products (Pan, Bora, Gee, & Dauskardt, 2023).

Environmental Considerations

Another important aspect which has become increasingly important in selection of packaging materials in current times is sustainability. There are wide varieties of laminate structure which can provide optimum barrier properties but choosing a material combination which is sustainable whether it is in terms of material compatibility, reduced carbon foot print or greenhouse gas emission is important. For example, PET/PE laminates have been commonly used in industry and is effective as well, but their environmental impact is cause of concern (Banerjee & Ray, 2022). The main reason to worry is that production and disposal of laminates with PET/PE structure led to significant carbon emissions as well as waste management challenges owing to the different materials used in two layers. On contrary, a laminate with a BOPP/CPP structure can be more environmentally friendly, owing to their lower carbon footprint and has better recyclability.

Methodology

The purpose of this study is to compare the barrier properties most commonly used laminate in food packaging, that is PET/PE (Polyethylene Terephthalate/Polyethylene) and comparing the same with another laminate which is BOPP/CPP (Biaxially oriented Polypropylene/Cast Polypropylene) laminates used in food packaging. The methodology comprises accurate measurement and analysis of Water Vapor Transmission Rate (WVTR) and Oxygen Transmission Rate (OTR).

Materials and Sample Preparation

Materials:

1) PET / PE Laminate – Structure: 12µ PET / 25µ PE
2) BOPP / CPP Laminate - Structure: 18µ Hb Hr BOPP / 25µ CPP

Sample Preparation:

First, samples from both laminate structures i.e. PET / PE and BOPP / CPP were cut into standard size of 10 cm x 10 cm, suitable for testing with the our selected MOCON instruments.

After that samples were conditioned for 24 hours at 23°C temperature and 50% relative humidity in order to ensure that the environmental conditions are consistent before conducting the test.

Measurement of Water Vapor Transmission Rate (WVTR)

In order to measure the Water Vapor Transmission Rate (WVTR) of the above laminate samples we have used the instrument the MOCON PERMATRAN-W® Model 3/34 G. The said instrument is designed to measure the rate at which water vapor pass through the packaging material. Fig.1. illustrates the process of WVTR.

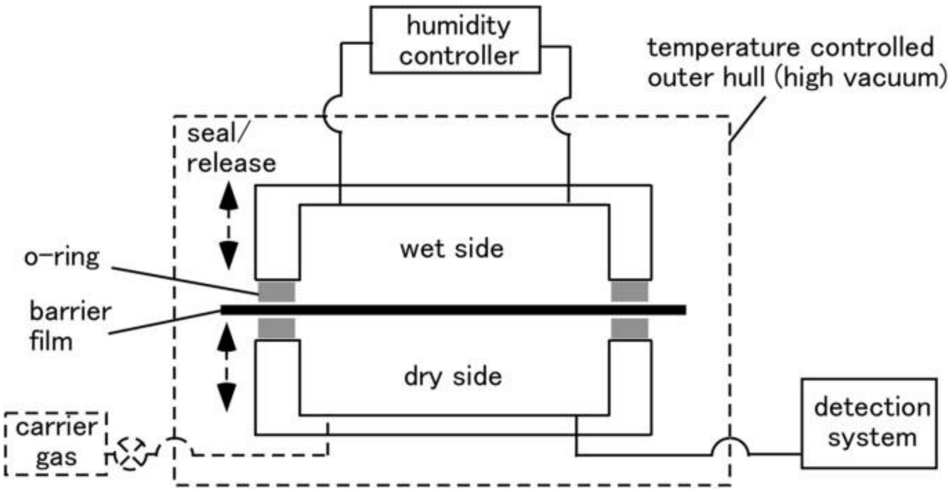

Fig. 1. Water Vapor Transmission Rate Process Schematic (WVTR) (Nakano et al., 2016)

Procedure

Each sample was placed in the test chamber of the MOCON PERMATRAN-W® Model 3/34 G. The test was conducted under controlled conditions (37.8°C temperature and 90% relative humidity). The instrument measured the amount of water vapor passing through the sample over a 24-hour period.

Calibration: The WVTR tester was calibrated as per the guidelines of manufacturer in order to ensure reliable and accurate measurements.

Data Analysis: The result or value of WVTR was calculated based on the amount of water vapor that permeated or passed through the sample and is expressed in g/m²/24 hours. Table 1 represents the comparative valued of WVTR of two laminate structures.

Table 1. Comparison of Water Vapour Transmission Rate

Water Vapour Transmission Rate		
Reading	12µ PET / 25µ PE	18µ Hb Hr BOPP / 25µ CPP
W1	13.84	6.89
W2	14.12	6.82
W3	13.94	6.75
W4	14.02	7.10

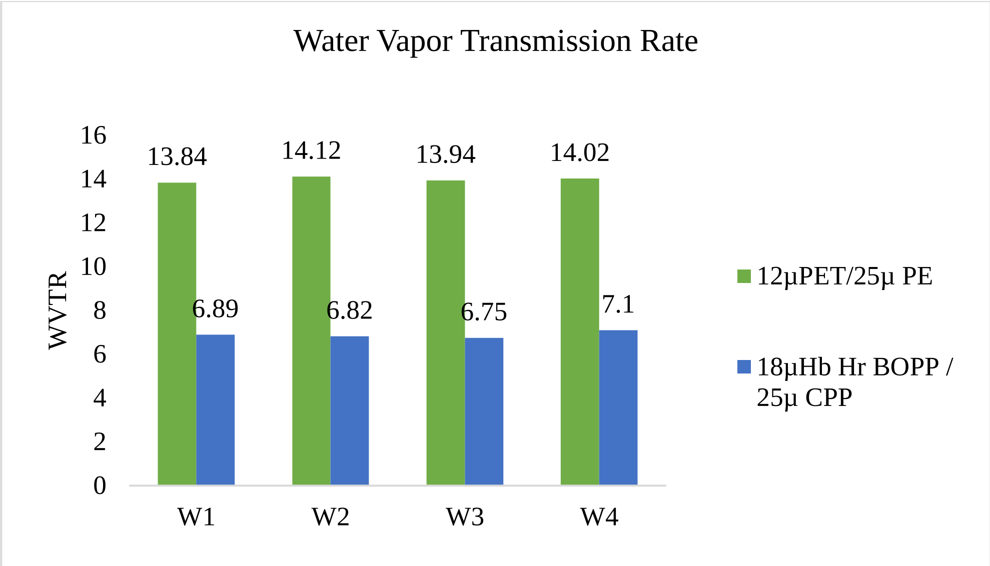

Fig 2. Comparative analysis of Water Vapour Transmission Rate

Measurement of Oxygen Transmission Rate (OTR)

In order to measure Oxygen Transmission Rate (OTR) of the laminate samples we have used the instrument MOCON OX-TRAN® Model 2/21. The said device measures the rate at which oxygen pass through packaging materials under controlled conditions i.e. (23°C temperature and 0% relative humidity). Fig. 2 presents the schematic process of OTR.

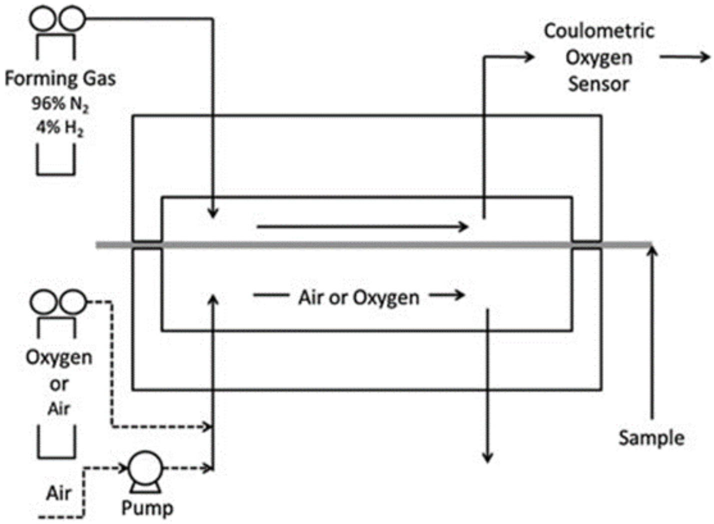

Fig. 3. Oxygen Transmission Rate (OTR) Process Schematic (Abdellatief & Welt, 2012)

In this test on one side the prepared samples were subjected to a controlled oxygen atmosphere, and the other side was exposed to a nitrogen carrier gas. The said instrument measures the amount of oxygen which permeated through the laminate sample in a time period of 24-hour.

Calibration: The OTR tester was calibrated as per the guidelines of manufacturer in order to ensure reliable and accurate measurements.

Data Analysis: The result or value of OTR was calculated based on the amount of oxygen that permeated through the sample and is expressed in cc/m²/24 hours. Table 2 represents the comparative valued of OTR of two laminate structures.

Table 2. Comparison of Oxygen Transmission Rate

Oxygen Transmission Rate		
Reading	12μPET/25μ White PE	18μHB HR BOPP/25μ White CPP
O1	109.8	84.6
O2	112.6	90.5
O3	110.7	85.7
O4	110.5	87.8

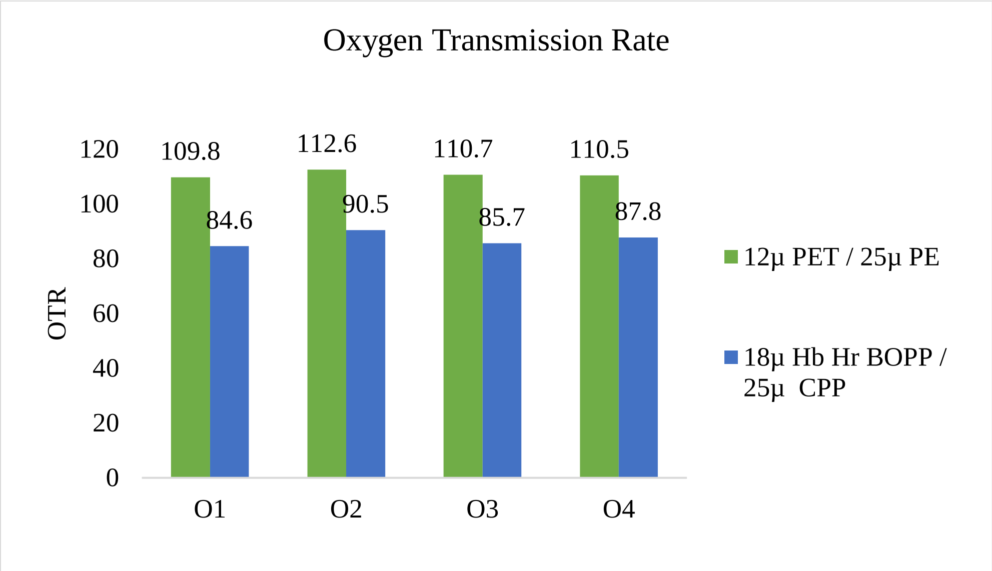

Fig 4. Comparative Analysis of Oxygen Transmission Rate

Experimental Controls

Following controls were implemented in order to ensure that the reliability and reproducibility of the results was maintained:

Environmental Control: The test was conducted in a controlled environment for both the parameters under constant temperature (WVTR – 37.8 °C, OTR -23°C) and relative humidity (WVTR – 90%, OTR – 0%).

Sample Consistency: In order to minimize variability, the same batch of laminates is used to prepare the samples.

Instrument Calibration: In order to maintain accuracy throughout the process, the instruments were calibrated as per manufacturers guidelines before each set of measurements.

Limitations

The study provides good insights into the barrier properties of PET/PE and BOPP/CPP laminates however, it is limited by the specific conditions under which the test was performed. Variations in sample handling, measurement techniques and environmental conditions could possibly affect the results.

Conclusion

Through this study we have conducted a detailed analysis of the barrier properties of two different packaging material structures: First is PET / PE based two-layer packaging material having a structure of 12μ PET / 25μ PE and high barrier, high resistant BOPP / CPP based structure (18μ Hb Hr BOPP / 25μ CPP). The primary goal was to gauge and compare the water vapor transmission rate (WVTR), and oxygen transmission rate (OTR) of two materials in order to determine the suitability for various packaging applications.

The results show that 18μ Hb Hr BOPP / 25μ CPP displays superior barrier properties compared to 12μ PET / 25μ PE. As from the above table, the values of WVTR for the 12μ PET / 25μ PE structure were 13.84 g/m²/24hrs (W1) and 14.12 g/m²/24hrs (W2), whereas the 18μ Hb Hr BOPP / 25μ CPP structure exhibited significantly lower values of WVTR of 6.89 g/m²/24hrs (W1) and 6.82 g/m²/24hrs (W2).

In a similar way, the value of OTR for the 12μ PET / 25μ PE were 109.8 cc/m²/24hrs (O1) and 112.6 cc/m²/24hrs (O2), were higher than the 18μ Hb Hr BOPP / 25μ CPP which has values of 84.6 cc/m²/24hrs (O1) and 90.5

cc/m²/24hrs (O_2). In BOPP based laminate structure, in order to improve the oxygen or gas barrier of BOPP film, a special coating of EVOH is used. Besides this in order to improve the surface energy of laminate, BOPP is corona treated. This will improve the print quality of laminate and we will get the results similar to PET. As we know CPP has limited seal strength thus a copolymer is used to improve the sealing properties of CPP. These results above suggest that the 18µ Hb Hr BOPP /25µ CPP offers better protection than 12µ PET / 25µ PE against both moisture and oxygen, which are one of the important factors for maintaining the shelf life and quality of pre-packaged products.

Finally, it can be concluded from above data that 18µ Hb Hr BOPP / 25µ CPP provides better barrier properties as compared to the other laminate structure i.e.12µ PET / 25µ White PE. This makes it a more suitable alternate for packaging applications that require low WVTR and OTR. This study highlights that while selecting an appropriate packaging material is extremely important to ensure quality and longevity of packaged product, we should look for options which are more sustainable and environment friendly.

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