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Effect of Perforated Polyurethane Foam on Moisture Permeability for Car Seat Comfort

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Abstract
Polyurethane (PU) foams are the most essential part of a car seat cushion. PU foams are durable and easily moldable according to the shape of the car seat, but they are poorly permeable to moisture. This impermeability of PU foam causes wetness of the microclimate between the person and car seat and makes it uncomfortable. In this research PU foams with two different thicknesses and three different hole sizes were obtained from industry by the moulding process. The foams were tested for moisture permeability by the standard cup method to determine the effect of the size of the hole on the overall moisture permeability. The foams were further tested with 11 of the most common top layer fabrics to check the effect of the top fabric layer on the overall moisture permeability of the car seat. All the top layers were first tested by means of a sweating guarded hot plate (SGHP) to measure the water vapour resistance (Ret) and then 4 materials with the minimum Ret values were tested with the most permeable foam. The results shows that the perforation of PU foam causes a significant increase in moisture permeability, whereas the top layer with the minimum Ret value decreases the overall moisture permeability and a maximum of 40g/m2 of moisture per hour is obtained with the most permeable foam with the least Ret value of the top layer. This research is an initial work on replacing the car seat with perforated PU-foams.

Key words: *car seat, comfort, poly-urethane, moisture permeability.*

Introduction

Comfort is the basic and universal necessity of the human being. However, it is very complicated and challenging to define. Slater [1] defined comfort as a pleasant state of psychological, neurophysiological and physical harmony between the environment and the human being. According to him, comfort can be defined in the following ways [2]:

1. Absence of discomfort or unpleasant feeling
2. Physiological response of the wearer
3. Temperature regulation of the human body
4. Pleasant physical, physiological and psychological conditions and harmony between the human being and the surrounding environment

The normal internal body temperature of human beings is 37 °C (98.6 °F), with a tolerance of ± 0.5 °C under different climatic conditions. Any variation from a body temperature of 37 °C may create changes in the rate of heat production or the rate of heat loss to bring the body temperature back to 37 °C. Metabolic activity or the oxidation of foods causes the production of heat and can be partially adjusted by controlling the metabolic rate [2 - 4].

Comfort has become the main quality standard of cars. Comfort in a car is complicated process and includes different features like driving, behaviour, noise and ease of handling [5]. Thermal comfort is the most significant factor affecting passenger suitability. Car seats are one of the main features of vehicle comfort. Seats not only have a striking design or meet specific design standards for safety reasons, they must also have optimal parameters of comfort. Apart from ergonomic considerations, thermophysiological comfort is of significant importance. At present, the thermophysiological comfort of car seats can be acquired by a set of laboratory test apparatus. It is now probable to improve and calculate thermophysiological characteristics of car seats at the development stage by using a skin model and seat comfort tester [6, 7].

It was initially observed that a strong discomfort sensation arise due to the small quantity of water in the microclimate between the person and the car seat [8]. It has been confirmed in numerous researches that either moisture from sweating or additional moisture creates clothing contact sensations. The method for these calculations highlighted that a little amount of moisture is required to instigate a discomfort sensation [9, 12 - 17].

There are four factors of car seats with respect to the physiological point of view as follows:

- The preliminary heat flow ensuing from the first contact with the seat. Especially a feeling of warmth or cold in the first few minutes or even seconds after entering the car.
- The dry heat flow on lengthy journeys, i.e. the quantity of heat transferred by the seat
- The capability termed as “breathability” to transfer any sweat away from the body. In so-called “normal sitting situations” there is no distinguishable sweating; however, the human body constantly discharges moisture (insensible perspiration), which has to be carried away from the body.
- Contingent on heavy sweating (a vehicle in summer heat and stressful traffic situations), the ability to absorb perspiration without a damp feeling of the seat.

Thermophysiological comfort is based on the fundamentals of energy conservation. ***Figure 1*** shows all the energy created has to be dissipated in precisely the same amount from the body [18]. The mathematical formula mentioned under this principle is:

$$M - P_{ex} = H_{res} + H_c + H_e + \Delta S/\Delta t \quad (1)$$

The energy of production is given by M, and in the case of cars the range of M is between 150 and 300 watts. P_{ex} is the exterior physical work, which in a car is primarily due to steering and shifting

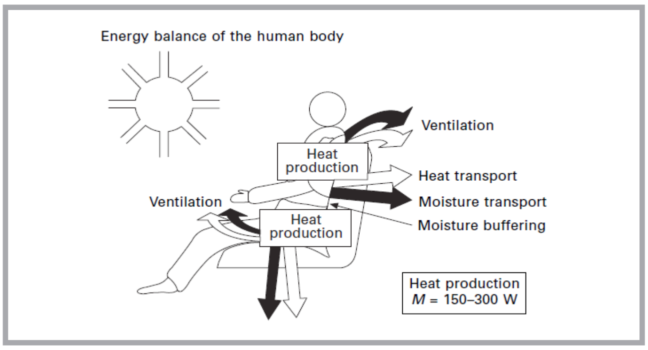

Figure 1. *Energy balance between the heat produced and dissipated as a prerequisite for good thermal comfort [18].*

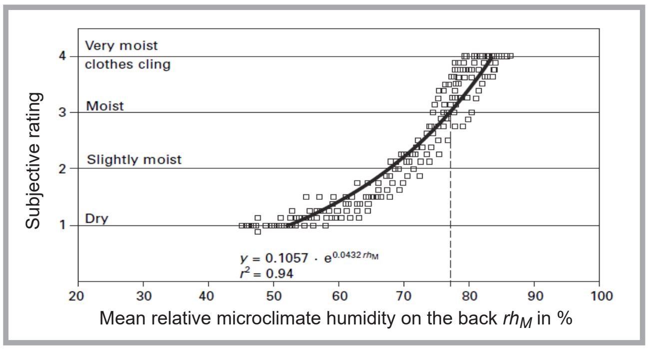

Figure 2. *Subjective moisture sensation of human test subjects as a function of relative humidity in the microclimate between the skin and seat [18].*

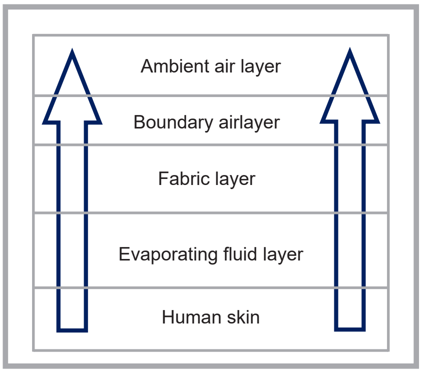

Figure 3. *Transportation of moisture vapor through different layers [3].*

gears, being much smaller than M. H_{res} is the respiratory heat loss due to breathing, which is approximately 10% of the metabolic rate M. H_c is the dry heat flux encompassing conduction, radiation, and convection. H_c is heavily dependent on the car seat, the passenger's clothing and cabin climate. The same applies for H_e; which is caused by perspiration.

If more energy is produced than discharged, then the body suffers from hyperthermia. However, too much heat loss causes hypothermia. Both these conditions lead to alteration of the body's energy content ΔS with time Δt. ΔS can be either positive (hyperthermia) or negative (hypothermia) and is zero for a steady state.

This steady state ($\Delta S = 0$) is necessary and has to be the goal of a car seat producer to acquire energy balance. M, P_{ex} and H_{res} cannot be affected by the car seat, however, H_c and H_e can be affected.

Water vapour transportation

The moisture sensation of a person is very significant for observation of the overall seat comfort. ***Figure 2*** reveals that a seated passenger can distinguish microclimate humidity between the skin and seat [18]

For achieving a dry microclimate, the breathability of the seat to transfer sweat produced away from the body is critical. The human body continually discharges moisture, called insensible sweating. The human body loses 30 grams of moisture per hour. As car seats cover a large area of the body, the seat has to accommodate a large part of perspiration produced and thus a substantial quantity of moisture per hour. In order to maintain thermoregulation, the human body does not only produce insensible sweating but also sensible perspiration to cool down the core temperature of the human body through the evaporation of sweat. Up to one liter/hour of moisture can be produced during sports activity or hot surroundings.

For sensible perspiration, moisture is actively produced by sweat glands inside the human skin. However, the desired cooling effect can be acquired only from the evaporation of this moisture. This is a direct requisite of the vehicle seat, which has to permit this evaporation. Besides thermoregulation, the human body sweats further due to mental stress. This stress driven sweating may be produced during car driving in tough traffic circumstances. Thus it is important that the seat delivers high vapour transport to permit the evaporation of perspiration for the majority of seating situations. The seats must have low water vapour resistance (i.e. high breathability). All the parts of the seats must be water vapour permeable as one single impermeable layer can obstruct transportation of water vapours.

In the case of fabrics, moisture vapour transmission is managed by the inter yarn or inter fibre gaps. Vapours are diffused through air gaps between fibrous materials. It can be observed from figure 3 that the resistance to moisture vapour diffusion comes in different layers during the diffusion of moisture vapours through textile materials. These different layers are

1. The evaporating fluid layer (which is full of water saturated vapor),
2. The confined air layer (sandwiched between the skin and fabric),
3. The boundary air layer,
4. The ambient air layer.

Moisture vapour is transmitted through fibrous materials by the following mechanisms:

1. Diffusion of water vapour through the air gaps between fibres,
2. Absorption, transmission and desorption of water vapour by fibres,
3. Adsorption and migration of water vapour along the surface of fibre,
4. Water vapour transportation by forced convection [3].

Investigation of scientific literature revealed the keen interest of researchers to solve the issue of reliable determination of the vapour permeability properties of textile materials [11, 12].

Upright cup method (*Figure 4*)

In this method, the fabric sample is positioned and sealed above a cup, 2/3rd of which is filled with water, and then it is placed in a wind tunnel in a standard atmosphere on a weighing balance and the variation in mass of the fabric at a time interval is calculated [10].

Sweating guarded hot plate

This method is also called a skin model and is utilized for evaluating the thermo-physiological comfort of clothing and work as per ISO 11092 standard [7]. This method simulates the transportation of moisture through textiles and clothing assemblies when they are worn next to the human body. Evaluation of the water vapour resistance of the fabric is made from the evaporative heat loss in the steady state condition by this method. The temperature of the guarded hot plate is maintained at 35 °C and the standard atmospheric condition for testing (65% R.H. and 20 °C) is utilised.

The water vapour resistance (R_{et}) of the fabric is calculated as follows:

$$R_{et} = \frac{A(P_m - P_a)}{H - \Delta H_c} - R_{et0}(\frac{m^2 Pa}{W}) \qquad (2)$$

where, A is the test area, P_m the saturation water vapour partial pressure at the surface of the measuring unit, P_a the water vapour partial pressure of air in the test chamber, H the amount of heat supplied to the measuring unit, ΔH_c is the correction factor, and R_{et0} is the apparatus constant [3].

The evaluation of moisture vapour transmission through fabric is slow and sensitive but a very effective process. Different standard methods utilised for evaluating moisture vapour transmission properties of textile substrates are as follows:

1. The evaporative dish method or control dish method (BS 7209),
2. The upright cup method or gore cup method (ASTM E 96-66),
3. The inverted cup method and the desiccant inverted cup method (ASTM F 2298),
4. The dynamic moisture permeable cell (ASTM F 2298),
5. The sweating guarded hot plate method, skin model (ISO 11092).

Experimental part

There are two common thicknesses of car seat PU foams which are used according to the seat requirement. Each foam, with 3 different hole sizes, was obtained from industry, made by the molding process. The foams were not drilled or cut from the top or bottom in the laboratory so that the real surface property of the foams should be kept, as the molded surface is very different from that of cut foams.

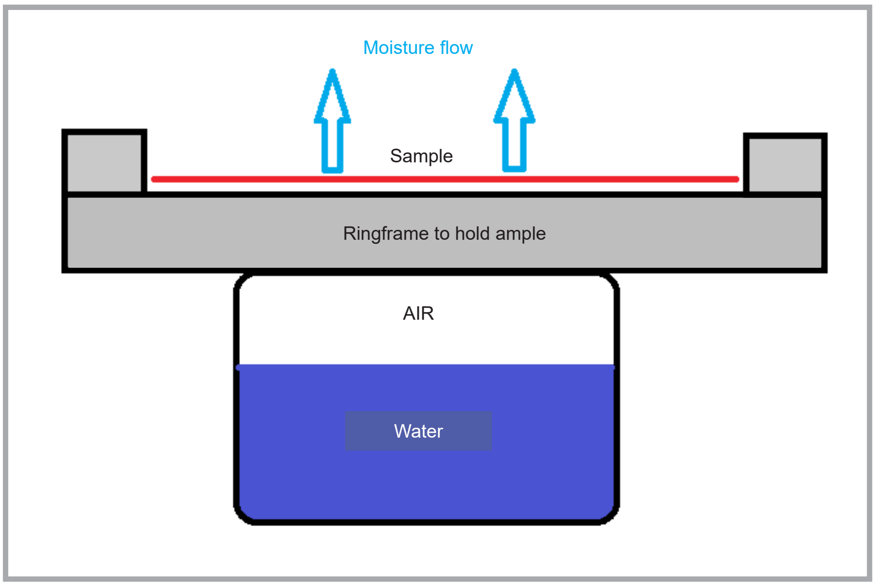

Figure 4. *Upright cup method [3].*

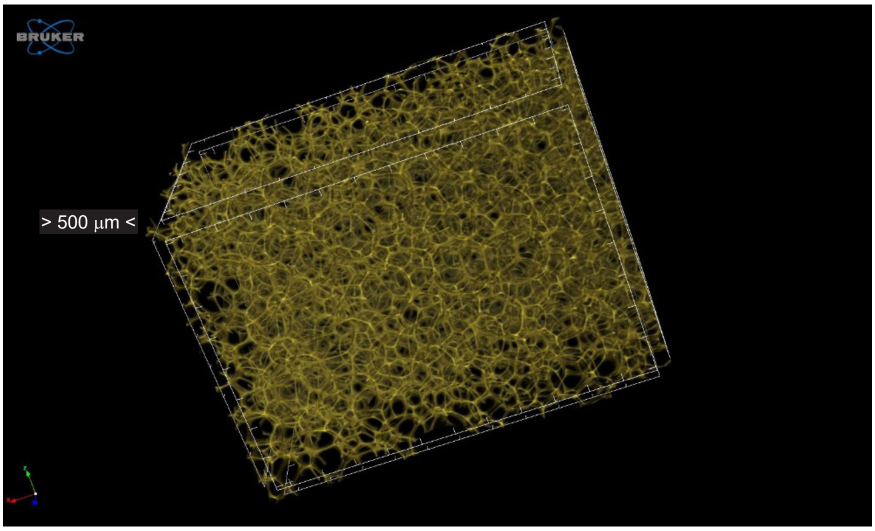

Figure 5. *X-ray micro tomographic image of PU-foam.*

Table 1. *Properties of PU foam used for the experiment.*

	Foam thickness, mm	Number of holes, -	Hole diameter, mm	Total area of foam sample, mm2	Area of holes, mm2	Area of solid foam, mm2
A	60	0	0	16505	0	16505
A1		7	10		550	15955
A2			15		1236	15268
A3			20		2198	14307
B	85	0	0	16505	0	16505
B1		7	10		550	15955
B2			15		1236	15268
B3			20		2198	14307

The original foam was first observed under X-ray micro tomography, which is very beneficial to observe the internal structure of the material. ***Figure 5*** clearly shows that the air gaps inside the PU foam are not connected from the top to the bottom of the foam material. and hence nthis material can never be breathable to air or moisture.

It is shown in ***Figure 5*** that the PU foam does not have open channel pores, which means that moisture cannot be transmitted from the top to the bottom surface. Consequently it was decided to replace the PU-foam with perforated foams to enhance the moisture permeability.

The original foams and perforated foam properties are shown in ***Table 1***.

Figure 6 shows a real picture of the perforated foams.

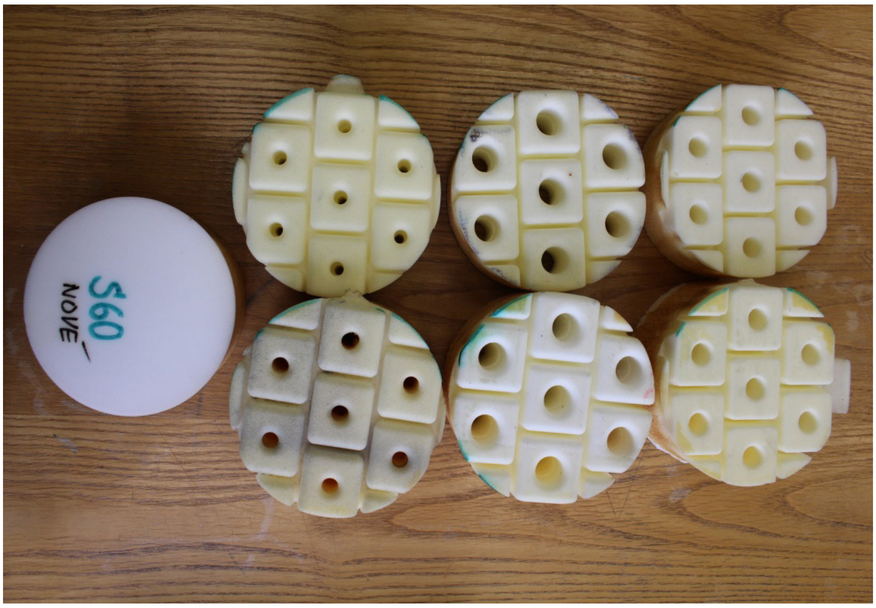

***Figure 6.** PU foam samples.*

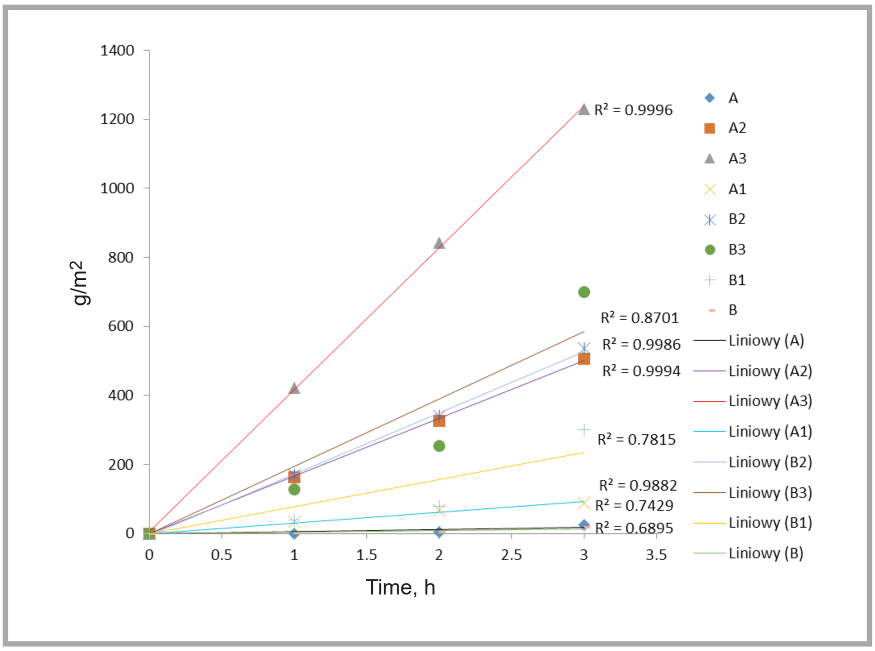

***Figure 7.** Moisture permeability through PU-foam.*

***Table 2.** Properties of top layer of car seat cover.*

No.	Fleece			3D Spacer			Face Fabric			
	Mass per unit area, g/m²	Thickness, mm	Material composition	Mass per unit area, g/m²	Thickness, mm	Material composition	Technology	Warp direction details	Weft direction details	Material composition
26989	100	2	100% PES	250	3	100% PES	warp knitted	14 wale/cm	29 course/cm	100% PES
25976	230	5	70% PES, 30%WO					13 wale/cm	24 course/cm	
25979				335	5	100% PES				
26728							woven	33 end/cm	18 pick/cm	
26977	100	2	100% PES	250	3			32 end/cm		
26200	230	5	70% PES, 30%WO	335	5		warp knitted	15 wale/cm	25 course/cm	
26195	100	2	100% PES	250	3					
25962							woven	34 end/cm	18 pick/cm	
25967	230	5	70% PES, 30%WO	335	5			36 end/cm	16 pick/cm	
29086							warp knitted	14 wale/cm	28 course/cm	
29084							woven	36 end/cm	16 pick/cm	

All the foams were tested with the upright cup method (ASTM E 96-66) for water vapour permeability. Any other technique of moisture permeability measurement was not possible as the foams were thick, and it was not possible to use such thick samples. Testing was performed in a climate chamber with controlled conditions to avoid condensation of moisture in the sample. The testing was performed for 3 hours and measurements obtained after every hour.

Eleven of the most common top layer fabrics were obtained from the car industry and tested first for water vapour resistance (R_{et}) on a sweating guarded hot plate (SGHP). The 4 samples with the minimum Ret value were selected to test moisture permeability as a combined layer with perforated foams (***Table 2***).

Results and discussion

All the PU foams were tested for moisture permeability with the upright cup method (ASTM E 96-66) as well as for water vapour permeability; the test was performed for 3 hours and measurements obtained after every hour.

It is observed from ***Figure 7*** that non-perforated foams A and B are almost impermeable to moisture and the bigger size of the porosity causes higher breathability of the foam. Foams A3 and B3 have the maximum air area (area of the holes) in the sample and shows a significant increase in moisture permeability. The A3 sample shows more permeability than the B3, which is due to the thickness difference of the sample, and the moisture permeability is dependent on the thickness of the sample.

Table 3. *Air and moisture permeability of car seat's top layers.*

No.	R_{et}, m^2Pa/W	Air permeability DIN EN ISO 9237 in l/min/100 cm²
26989	14.2318	500
25976	12.4050	275
25979	16.1789	263
26728	16.9876	195
26977	14.7294	150
26200	17.9185	140
26195	15.3477	98
25962	15.4576	98
25967	21.9974	98
29086	31.2510	93
29084	29.0179	75

As the results of the perforated foams were very reasonable regarding moisture permeability, hence different top layer combinations were used to test the overall permeability of the car seat sandwich structure. All the top layers were tested first for air permeability by ISO standard 9237, as shown in ***Table 3***, to determine that of the top layers. The air permeability and moisture permeability are not comparable when the material is thick, and there is a possibility of axial airflow. As a consequence, the top layers were also tested for moisture vapour resistance by standard ISO 11092. Four of the samples were chosen according to low resistance to moisture and better air permeability, and later sandwiched with the perforated foam.

As shown in ***Table 3***, the four top samples were sandwiched with the highest permeable foam A3 and again tested for moisture permeability with the upright cup method (ASTM E 96-66) for water vapour permeability.

Figure 8 shows the overall permeability of the car seat cover with foam A3, and it can be seen that there is nearly 20 - 30 g of moisture transfer each hour, which is almost equal to the average human perspiration during driving. The top layer with 3D spacer fabric and wool showed better transportation of moisture. In this research the most common top layers are taken from industry to simply investigate the effect of perforated PU-foam.

Conclusion

The breathability of a car seat is a serious issue and in this research a unique concept of perforated molded PU-foams was used instead of classical foams. The results shows that perforation plays a significant role in the moisture transfer. An average human perspires 20 - 40 g per hour while driving but classical foams are impermeable and cause discomfort for the driver, whereas perforated foam and a top layer work together efficiently to transfer nearly 40 g/hour of moisture. The top layers of the fabric also play an important role, and it was observed that the layers with 3d spacer fabric and wool percentage have better transportation of moisture from the PU-foam below. The top layer will be studied further in future research as different layers sandwiched together with flame or chemical adhesion, which further reduces breathability; whereas in this research some of the most common top layers were taken to simply investigate the overall performance with the perforated foams. The perforated foams can be a future replacement for classical foams. The different design of grooves and shapes of holes can also be introduced to increase the porosity of the foams. This is a novel and initial work and further research will be done regarding the lifetime of the perforated foams.

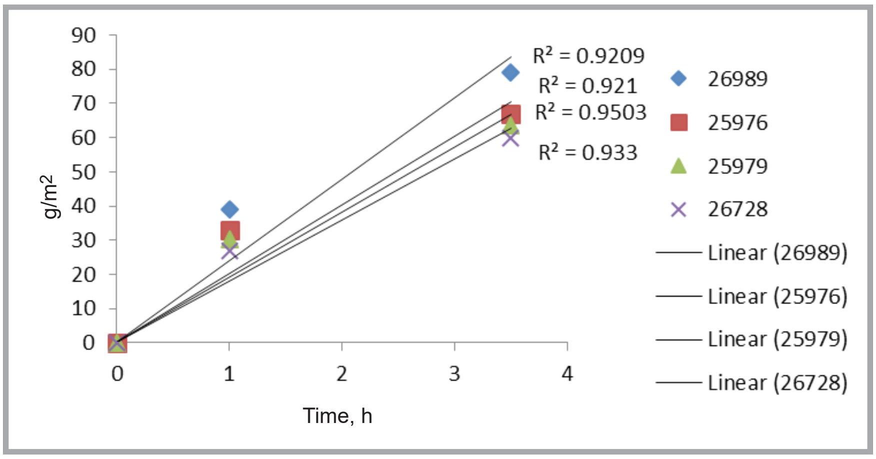

Figure 8. *Water vapor permeability of sandwich car seat cushion.*

Acknowledgement

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