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Researching on Baby Diaper Performance with 3D Absorbent Layer

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Abstract: Disposable diaper manufacturers have focused on absorbent zone layers as a way to ensure consumers achieve optimum comfort and minimize the environmental impact of products. The producers who want to achieve the desired performance values in the absorbent core layers have been investigated the amounts / mixing ratios of raw materials such as superabsorbent polymer (SAP) and wood pulp (pulp) or their distribution on the absorbent layer. When the absorbent core layers consisting of homogeneous SAP / pulp mixtures are examined in the current diapers, it is seen that the urine is concentrated in the middle section and this amount decreases towards the front and back parts of the diaper. It can be said that the SAP / pulp mixtures, which are sectionally evenly distributed in the absorbent zone layer, are used less in the front and rear sections, that is, the absorbent layer has a 3D structure. It can be said that the SAP/pulp mixtures, which are distributed sectionally on the absorbent layer, are absorbed more intensely in the middle region, so the amount in the front and back parts has less effect on the performance of the diaper. When the diaper machines currently in our company were examined, it was seen that it has not be possible to produce diapers with a 3D absorbent zone layer. In this study the effect of transferring some of the SAP/pulp mixtures homogeneously distributed in the absorbent layer from the back sections to the center of the core section on the diaper performance was investigated with the 3D mold system designed in our company. As result of the tested diapers, it was observed that the performance of the product increased or remained constant by moving the SAP / pulp mixes moved behind the absorbent layer to the center of the core layer. At the same time, it can be said that it is a cost-reducing work since raw materials that are not used in the front and back sections are saved.

Keywords: Baby Diaper, Core Distribution, Sectional Retention, 3D Absorbent Layer, SAP, Fluff Pulp

Introduction

Disposable absorbent hygiene products are designed to absorb and retain body fluids and faecal matter (Malarvizhi, 2015; Shanmugasundaram, 2010). Among these products that appeal to a wide range of users; diapers, sanitary pads, tampons, incontinence products, panties and mostly disposable wet wipes (Krafchik, 2016). The global market for hygiene products is growing significantly, especially with disposable products. Although absorbent hygiene products face the challenges of rising raw material prices due to the global economy and the limitation of bio-based resources, many consumers prefer these products (Kumar, 2014). While the world diaper market size was 50.5 billion dollars in 2019, it is expected to increase to 5.7% growth between 2020 and 2030. The growing adult population around the world, the high rate of urbanization and the number of working women are some of the main growth factors driving the diaper industry. The COVID-19 pandemic, which started around the world in late 2019, has also seriously affected the diapers market. The

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epidemic weakened the production capacities of diaper manufacturers due to the full or partial restrictions of most countries, causing the global diaper market to decline. Diapers with high absorbency have attracted great attention recently and took place in the diaper category with the largest market share in 2019. In addition, it is expected that high absorbent diapers will continue to dominate the market throughout the years 2020-2030. These diapers, which prevent leakage more than other diapers, are widely preferred because of the developments in Super absorbent polymer (SAP) technology. The growing demand for biodegradable, environmentally friendly diapers is another major driver for the worldwide diaper market. Disposable diapers only 2% of US landfill waste, meaning that most of them will not biodegrade for many years. Since conventional disposable diapers are non-biodegradable by nature, environmentally friendly biodegradable diapers are considered to be a will contribute contributor to the diaper market by attracting great interest recently. Biodegradable diapers are safe for babies' sensitive skin as they are not made from environmentally friendly petroleum-derived chemicals or skin irritants (Prescient & Strategic Intelligence, 2020).

When the diaper structure is analyzed simply; Urine is first rapidly absorbed from the soft porous nonwoven surface called the topsheet, and the liquid is transmitted downwards. In order to prevent wetness on the baby's skin, the urine absorbed by the upper surface should not exist from the upper surface to skin. Urine is then rapidly absorbed at the ADL (acquisition and distribution layer) and transmitted to the absorbent (core) layer. The polyester fibers in the ADL provide spread of the urine and transfer the liquid to the absorbent section evenly along the fiber lengths. The backsheet under the core layer of the diaper is typically produced from non-bioactive hydrophobic films that act as a microporous barrier. This layer is designed to have small pores, preventing water droplets from leaking the clothes (Counts et al., 2017).

Figure 1. Baby diaper

Absorbent core; It is the layer on which two different raw materials such as pulp (wood pulp) and SAP (super absorbent polymers) homogeneously distributed between two nonwoven surfaces are wrapped. Superabsorbent polymers in the core section hold about 30 times their own weight, and wood pulps hold about 1.5 times their weight. The purpose of pulp usage inside a diaper is to have very well urine distribution and a bit absorption.

Pulp consists of high density, homogeneous and uniform short fibers. Standard wood pulp liquid absorption capacity is about 10 cc/gr. However, when it is subjected to 5 KPa pressure, its liquid absorption capacity will be less than 2 cc. Pulp layers are usually derived from special trees grown in the North American continent. Liquid flows through the cavities of the fiber. The overall fiber length for wood pulp fibers used in diapers is approximately 2.6mm.

Super Absorbent Polymer or SAP, also known as Super Absorbent Material: It is used in fine-grained form (like table salt). It Increases the retention capacity in the diaper. This ensures thinner product with less wood pulp but higher performance. Sodium polyacrylate is the chemical material widely used as SAP. When the SAP contacts with water, sodium leaves itself by leaving carboxyl ions. These carboxyl ions are negatively charged, so they are sprayed together. It dissolves and absorbs water absorbed by sodium ions thanks to SAP polymer structure. With water, the polymer becomes gel. Gel is connected to each other with a three-dimensional structure by cross-linking, which causes high molecular density. Hydrogen inside the water (H-O-H) is retained by acrylate thanks to forces between polarity forces. The superabsorbent properties of SAP are provided by electrolytes in the fluid (urine contains 0.9% mineral electrolyte). Electrolytes reduce polarity. This ensures the superabsorbent capacity required for fluid retention. Therefore, diapers with SAP should never be tested with pure water, but the actual capacity can be seen with 0.9% saline solution. Mixture and distribution of these two important materials in the diaper is also very important

The mixture can be concentrated in a particular section of diaper instead of being evenly distributed, it is predicted that these two important raw materials can be used more efficiently. In other words, the absorbent layer of the diaper needs to be made in 3 dimensions. It is seen that the diapers of the well-known brands in the sector also confirm this prediction. With that improvement it also reduces usage of pulp (cellulose) and chemicals (SAP) which supports reducing disposable wastage and sustainable green world.

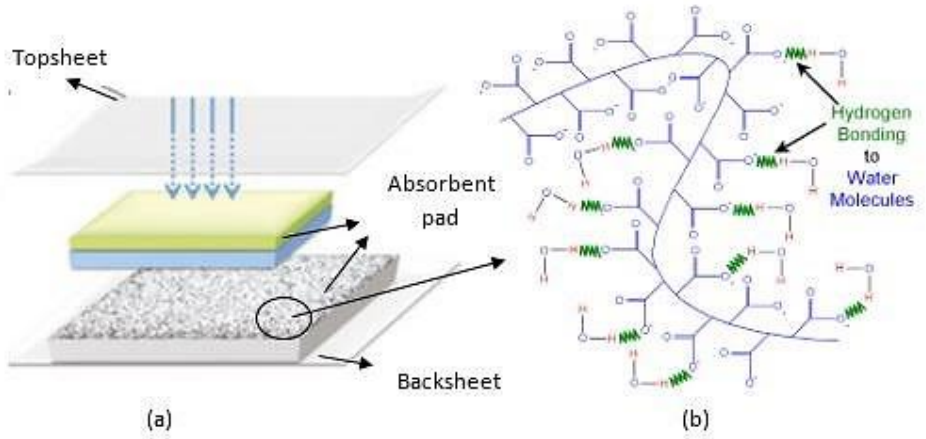

Figure 2. (a) Liquid absorption mechanism in disposable diapers; (b) attraction between water molecules and sodium polyacrylate monomer in the absorbent (Kotz, et al., 2014)

In this study, it is intended to achieve maximum benefit from SAP material by moving it to the middle zone. Towards that target, a new system developed to move collect most of SAP material at the middle zone of diaper. Performance values of diapers produced with new system were analyzed. Mixture and distribution of these two important raw materials in the diaper is also very important. The mixture can be concentrated in a particular section of diaper instead of being evenly distributed, it is predicted that these two important raw materials can be used more efficiently. In other words, the absorbent layer of the diaper needs to be made in 3D. It is seen that the diapers of the well-known brands in the market also confirm this prediction. With that improvement it also reduces usage of pulp (cellulose) and chemicals (SAP) which supports reducing disposable wastage and sustainable green world

Material and Method

Material

In the absorbent core generally utilise fiberized wood pulp, often termed "fluff pulp". With the use of pulp in the baby diaper, cellulose fibers help to easily transmit the liquid in the absorbent sectional and provide the integrity of the absorbent layer together with the SAPs, and also give softness and volume. Fluff pulp raw material properties used in the absorbent core section are given in Table 1.

Table 1. Technical properties of fluff pulp fibres used in disposable diapers

Properties	Standart	Unit
Brightness (%)	ISO 2470	87
Basis Weight (g/m2)	T-410 0M-02	675 g/m2
Fiber Length (mm)	T-271 0M-02	3,1
Mullen (kPa)	T-807 0M-03	900
Density (g/cc)	T-411 0M-05	0,64
Moisture (%)	T-412 0M-02	8
Ash Content (%)	T-211 0M-02	0.1
SCAN Absorbency Capacity (g/g)	SCAN-C 33:80	11,4
SCAN Absorbency Time(s)	SCAN-C 33:80	3,2

While the diaper is free, 1 g of cellulose fiber has a water absorption capacity of 10 cc, while its absorption capacity decreases to 2 cc under pressure. That's why SAPs that hold liquid even under pressure were needed. SAP raw material properties used in the absorbent core section are given in Table 2.

Table 2. Properties of SAPs required for use in disposable diapers

Properties	Standard	Unit
Moisture content (w--t%)	WSP 230.3	~2%
Centrifuge retention capacity (g/g)	WSP 241.3	~ 33,5 g/g
Absorbency under pressure at 0.7 psi (g/g)	WSP 242.3	~ 22 g/g
Permeability dependent absorption under pressure (g/g)	WSP 243.3	~ 11g/g
Particle size distribution on >850µm (%)	WSP 220.3	max 1%
Particle size distribution on >150µm (%)	WSP 220.3	max ~15%
Flow rate (g/s)	WSP 250.3	~ 12 g/s
Apparent Bulk density (g/l)	WSP 250.3	650 - 750

3D mold modifications are designed in the machine to carry the amounts of SAP and Pulp used in the back sections of the absorbent layer to the middle section. The high vacuum amount under the mold enables the SAP and Pulp to be transported by sticking to the mold. It is possible to prevent this amount of vacuum on the mold by blocking the pores of the mold. In order to prevent homogeneous distribution of SAP and Pulp on existing molds, product trials have been made with non-permanent modifications.

These designs prevented an even (non-sectional) distribution of the homogeneous SAP/pulp mixture in the absorbent section. For this reason, the absorbent core layers of the diapers produced with 3 different molds were divided into 5 sections and examined.

Method

Sample productions were carried out at the Fameccanica diaper line at a production speed of 450 m/min and an output speed of 1000 pads/min. In the study, the core mix ratios were determined as 11/9 grams. During the production of diapers, 1% tension was applied. Core section is bonded with hot melt adhesive applied in the temperature between 150-170 °C.

Table 3. Sample Productions

Code	Content
C	Current Production
S1	1st mold production
S2	2 nd mold production
S3	3 rd mold production

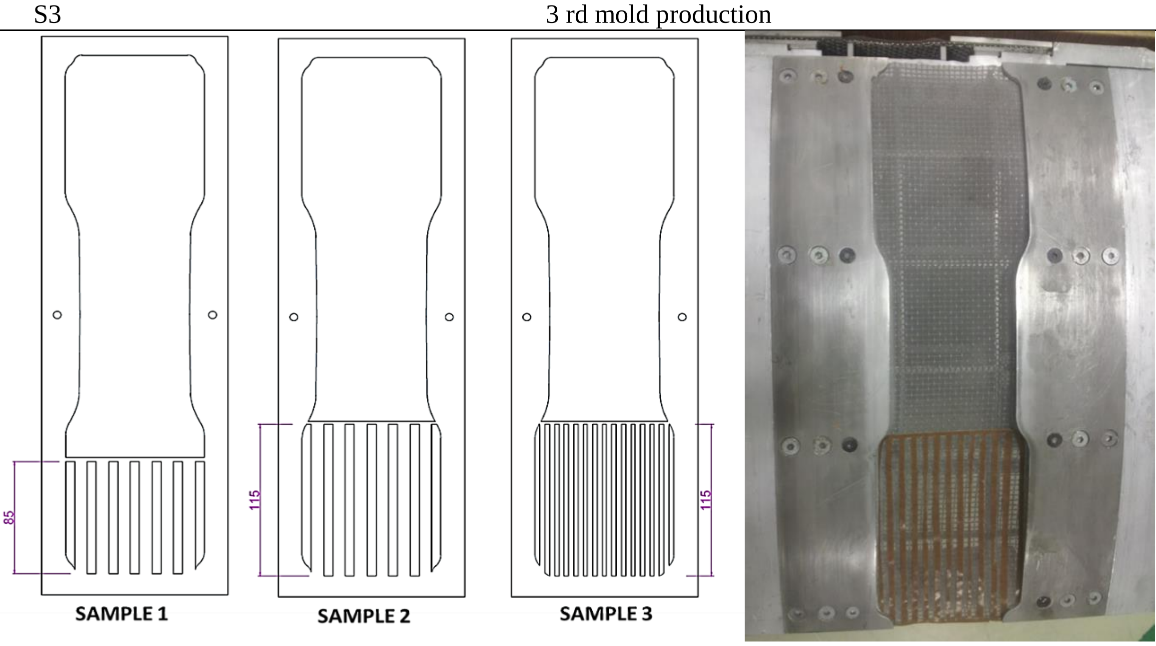

Figure 3. Technical drawing of baby diaper absorbent layer mold modified with sticking shim (metal plate) in 3 different ways

For the absorbent core section mold with a length of 425 mm, shim metal sheets with lengths of 85 and 115 mm were designed. In the first sample, the shim metal designed for the posterior section formed 20% of the mold. In the second sample, the shim metal designed for the rear area formed 27% of the mold. In the third sample, the shim metal designed for the rear area formed 27% of the mold. At the same time, in the 3rd sample, by using 50% thinner shim sheets than the 1st and 2nd molds, the closed areas were increased 42% more.

Table 4. Applied tests

Test Type	Tests and Standards
Physical	Determination of Diaper Dry Weight [g/m²] NWSP 130.1. R0 (15)
Liquid Absorption Properties	Rewet (Repeated Fluid Release) [g] DEGUSA S. SUSE.205-4.1
	Absorption Time (Repeated Fluid Release Time) [s]
	Maximum Absorption [g] DEGUSA S. SUSE.202-4.1
	Maximum Retention [g] DEGUSA S. SUSE.202-4.1
	Leakage (PAKTEN PR-46)
	Sectional Retention Method [g] DEGUSA S.SUSE- AWT.-203e

For dry diaper weight determination; Due to the differences that may arise from that may arise in the absorbent section from the SAP-pulp raw material, 5 samples for each product were tested on a Precisa brand NWSP 130.1. R0 (15) precision balance under normal atmospheric conditions. For the determination of leakage; the specific weight placed on the diaper and the solution was poured on the filter paper, and it was visually tested on 5 diapers for each sample, according to PAKTEN PR-46 standards. In the maximum absorption capacity test; after the diapers were kept in pure water solution with 0.9% NaCl for 30 minutes without applying any pressure, the amount of liquid absorbed by the diaper was calculated by weighing and subtracting from the weight of the first diaper. Determination of maximum holding capacity; After the maximum absorbent capacity test, the first diaper weight was subtracted from the weight after the diapers were kept in a centrifuge at 2800 rpm for 45 seconds. For maximum absorption and maximum holding capacity tests, 3 diapers were tested according to DEGUSA S. SUSE.202-4.1 standards. In the Rewet (Repeated Fluid Release Amount) test; After pouring 0.9% NaCl solution into the diaper placed in a hook designed according to the baby's anatomy, the amount of liquid left by the hygienic product under 11 kg weight was calculated by testing 3 diapers for each sample according to DEGUSA S. SUSE.205-4.1 standards. In the absorption time (Repeated Liquid Release Time) test; The duration of the amount of liquid left by the diaper used for the rewet test under 11 kg weight was calculated. 3 diapers tested according to DEGUSA S. SUSE.205-4.1 standards

Retention of Diapers by Section

For SAP determination; The diaper is weighed and five sections of equal size are drawn on to the diaper. The sections are then cut out along the marked dividing lines using scissors. The sections are then weighed, sealed in teabags, and immersed in the test solution. After a defined immersion time the teabags are hung up in order to remove the non-absorbed liquid. In order to determine the retention, the teabags are centrifuged. Then the individual diaper sections (without teabag) are weighed. 0.9% NaCl weight solution was used in the tests

A triple determination is carried out in each case. The test method is given below

a. The dry diaper is weighed (WT).
b. The diaper is spread out tautly on a table. Five sections are drawn on (see Figure 4). The length of the sections is determined by the minimum width of the absorbent core. The section width is determined by the length of the absorbent core divided by five (section 1 is located in the area of the tape).
c. The individual sections are then cut out along the marked dividing lines using scissors.
d. The sections are weighed G, (weighed accuracy: 0.1g) and heat-sealed in teabags.
e. The teabags are placed in the photographic dish, which is filled with test liquid, and gently submerged to ensure complete wetting. The test solution has to be changed after each set of diapers (3) tested
f. After 30 minutes the teabags are hung up with pegs for 5 minutes in order to allow the excess fluid to drip off the teabag.
g. The teabags are weighed (Gn1-5) in order to determine the absorption per section.
h. In order to determine the retention, the teabags are centrifuged for 45 seconds in the 2,800-rpm centrifuge
ı. For final weighing of the individual diaper sections Gg1-5, the teabags are removed (weighing accuracy: 0.1 g)

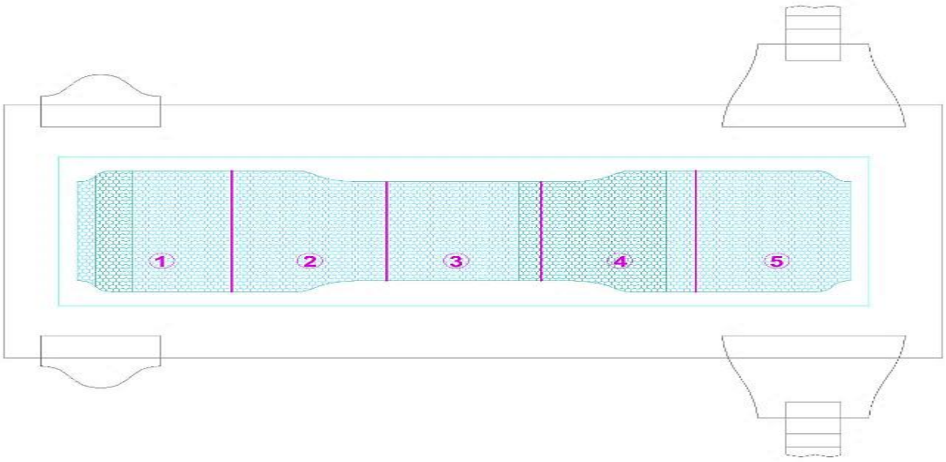

Figure 4. Technical drawing of baby diaper absorbent layer mold modified with sticking shim (metal plate) in 3 different ways

Evaluation

A1-5 = Gn1-5 – Gtr1-5 [g]
R1-5 = Gg1-5 – Gtr1-5 [g]

mSAP = ((mAbs. Mat x (RetAbs. Mat – RetFI)) / (RetSAP – RetFI) [g]

If the retention of the fluff pulp cannot be determined, an average retention of 1.5g/g is included in the formula.

A1-5: Absorption (diaper sections 1 - 5) [g]
R1-5: Retention (dipaer section 1-5) [g]
Gn1-5: Weight of the wet sections (1-5) [g]
Gtr1-5: Weight of the dry sections (1-5) [g]
m SAP: quantity of superabsorber [g]
m FI: quantity of fluff pulp [g]
m Abs.Mat.: quantity of absorptive material [g]

Ret SAP: superabsorber retention [g/g]
Ret FI: fluff pulp retention [g/g]
Ret Abs.Mat.: absorptive material retention [g/g]
(= retention of the hygiene article [g] / quantity of absorptive material [g]) (Evonik, 2007).

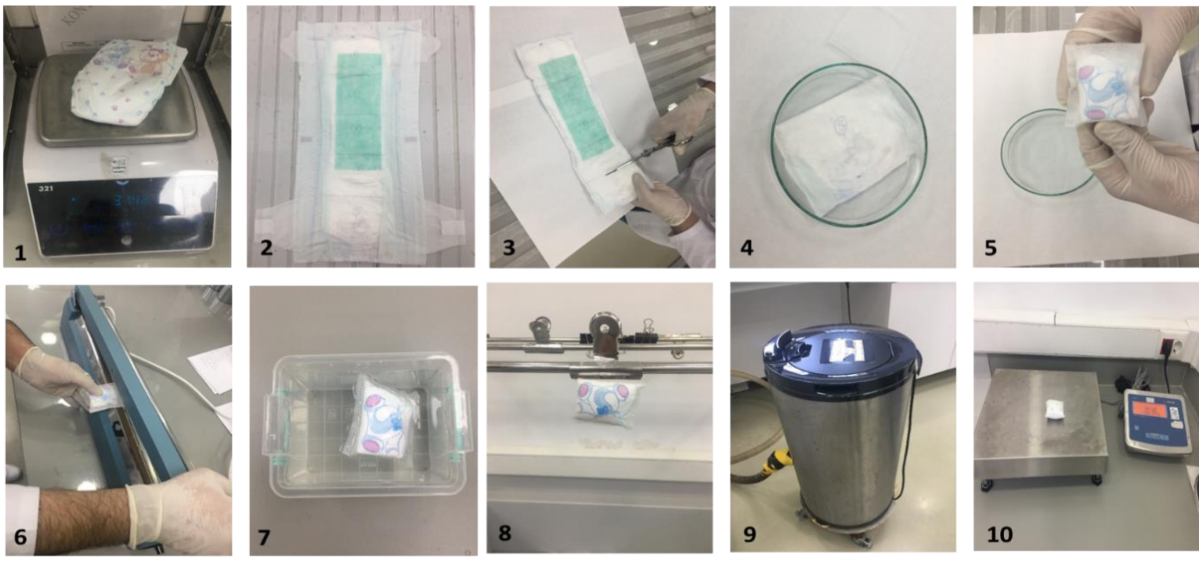

Figure 5. Retention of diapers by section test steps

Results and Discussion

In this study, the distributions of SAP & pulp amounts of diapers produced with 3 different molding techniques were investigated.

Determination of Sectional Absorbent Core Fluid Retention

Before transferring the studies to concentrate the amount of SAP & pulp used on the front and back of the absorbent layer to the middle parts by mold modification on the machine, the sectional distributions of SAP & pulp in 3 different competitor diapers in the market was examined.

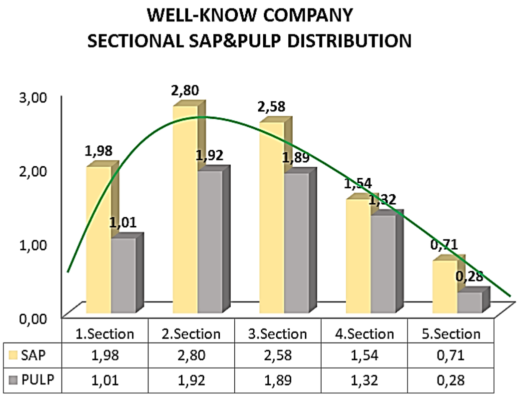

Figure 6. Comparison of well-known company's sectional SAP&Pulp Distribution. (Yellow columns are SAP & grey columns are PULP amount)

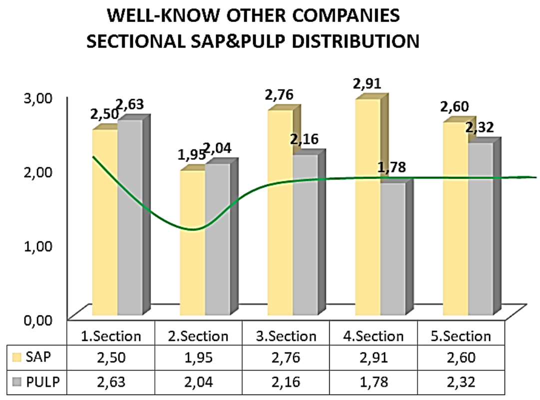

Figure 7. Comparison of well-known other companies sectional SAP&Pulp Distribution. (Yellow columns are SAP & grey columns are PULP amount)

When the product of the company (Figure 6), which as proven itself in the international arena, is examined; Parabolic increases in SAP & Pulp amounts are seen towards the 2nd and 3rd middle sections. Less SAP and Pulp content were detected in the 4th and 5th sections of the back part of the diaper. This 3D core structure, made with large investments in the machine, shows the desired curve of the work. However, considering the superior cost policy of the company manufacturer, the same performance is aimed with the molds produced by our company at lower costs. When examined in Figure 7, similar curves of competitor diapers without 3D core structure can be seen.

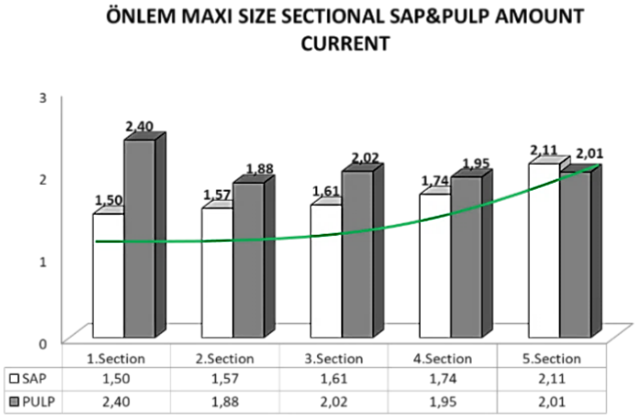

Figure 8. Current baby diaper

The sectional SAP & pulp distributions of the existing Önlem brand diapers were analysing before starting the trial production with the mold. While the amount of SAP & Pulp was higher in the posterior parts, it was observed that this amount decreased in the middle parts.

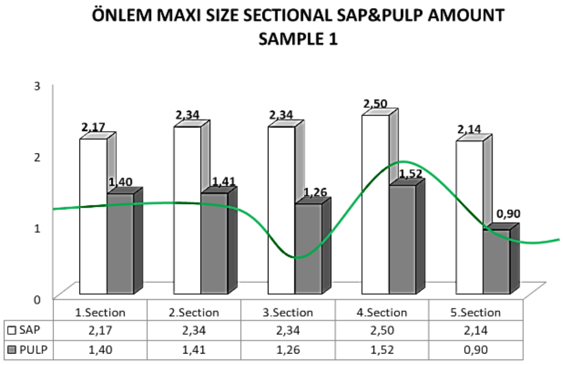

Figure 9. Sample 1

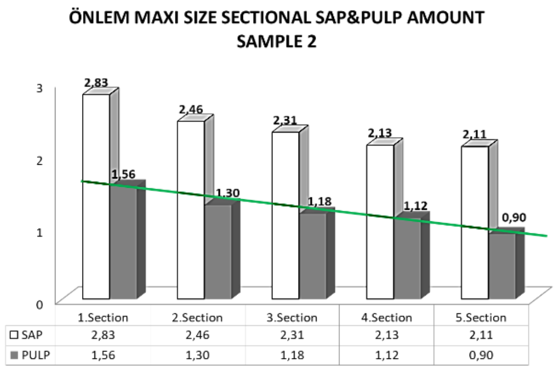

Figure 10. Sample 2

In the first sample (Fig. 9) we closed back side of diaper with shim. When 1, sample analyzed shows that the diapers have an uneven SAP & Pulp distribution from the front to the back. This situation was far from expectations. For the 2nd sample (Figure 10), the die length was increased by 35% compared to the 1st trial, and the back part was closed a little more. The amount of SAP and Pulp decreased towards the back of the diaper, but they were not high enough in those regions, although they should have been concentrated in regions 2 and 3. This formwork system was close to expectations, but not exactly as desired.

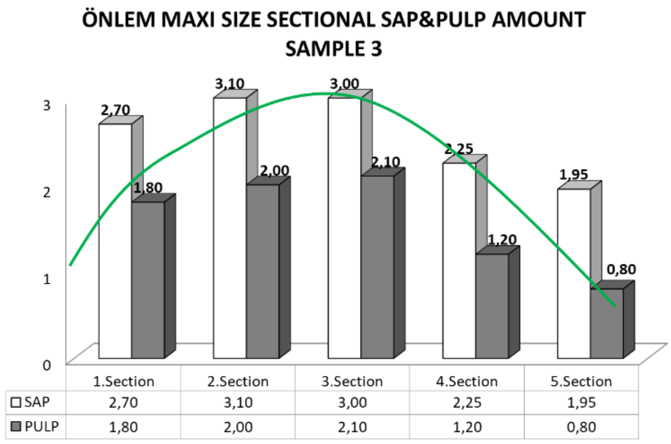

Figure 11. Sample 3

In the last trial, sheets with thinner and less spacing compared to the 1st and 2nd trials (50% thinner) were used. As a result of this study, it was ensured that the product amount was collected in the middle section. It is seen in the graph that the desired absorbent section structure is obtained.

Absorbent Core Liquid Absorption Time Comparison

The performance comparison of the liquid absorption times with the ideal core mold with the competitor companies and the current product was made.

Table 5. Liquid absorption time comparison

		3D CORE TRIAL	CURRENT PRODUCT	WELL-KNOWN COMPANY 1	WELL-KNOWN COMPANY 2	WELL-KNOWN COMPANY 3
	Unit	AVG	AVG	AVG	AVG	AVG
Diaper Weight	g	30,6	30,6	25,7	32,5	29,7
1st Liquid Absorption Time	sec	27	42	40	48	52
2nd Liquid Absorption Time	sec	59	68	47	115	129
3rd Liquid Absorption Time	sec	71	81	108	119	215

Lower data for liquid absorption time means that it absorbs liquid in a shorter time, so it can be understandable that its performance is better and the liquid trapped in a shorter time will not leave wetness on baby skin. As a further output of this study, we found that the 3rd liquid absorption time in the diaper improved up to 12% compared to our current product. As seen in Table 5, the 3rd suction time was shortened by allowing the product amount to accumulate more in the middle section

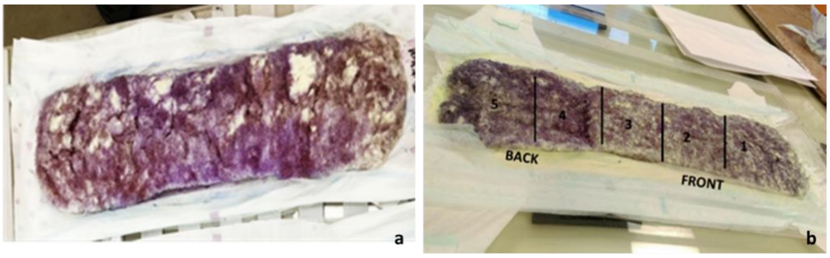

Figure 12. Image of absorbent core that acquisition liquid a) current b) sample 3

Rewet Amount (gr) and Time (sec)

It is desirable that the diapers absorb the liquid quickly and not give it back even under pressure, so that the baby's skin does not feel wet and there are no leakage problems. In this context, it is expected that the cellulose/SAP mixture in the absorbent layer will absorb the liquid quickly and not transfer the liquid back even under pressure. In do to determine these values, absorption time and rewet tests are performed.

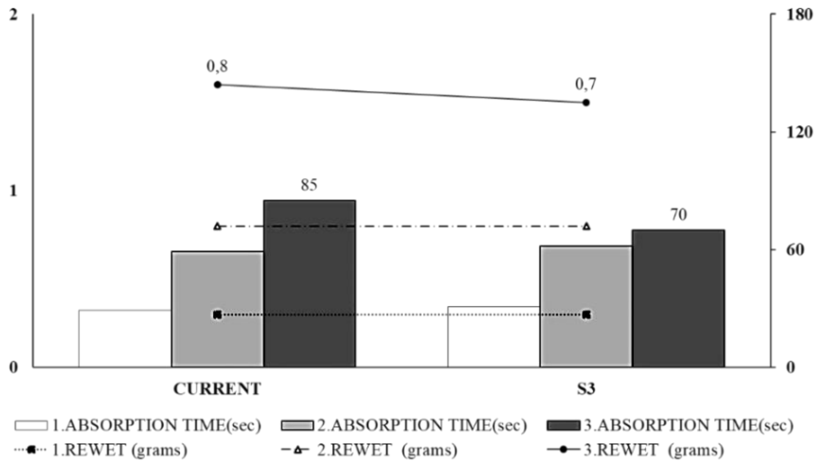

Figure 13. Rewet and absorbtion time

When the 3rd rewet, values are examined, it is seen that the S3 sample developed with the new mold has lower rewetting values than the existing sample. The main reason for this can be explained as the trapping of the liquid in the desired area with the newly designed mold, unlike the existing mold system. When the 3rd absorption times are examined, it is seen that the fastest absorption time is in the S3 sample. While it is desired to complete the liquid absorption time for diapers as soon as possible, it has been determined that the current sample has a higher absorption time. It can be said that the main reason for this is the SAP & pulp mixture, which is intensely present in the 2nd and 3rd sections of the developed product, as opposed to the mixture that is evenly distributed to the regions in the existing product.

Maximum Absorption and Maximum Retention (grams)

In the maximum absorption and maximum retention tests, 0.9% saline solution is used to simulate urine. With this test, it is observed how much the diapers absorb and how much urine they hold. Accordingly, although there is no significant difference for the two different samples tested, it is seen that it absorbs and retains similar amounts of saline solution.

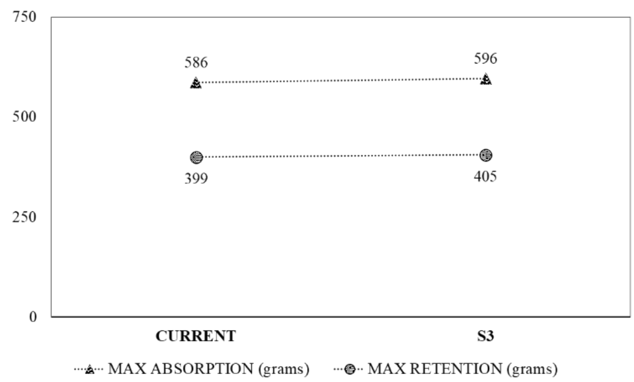

Figure 14. Maximum absorption and maximum retention (grams)

Conclusion

In this study, it was aimed to increase the SAP &pulp density in different parts of the diaper instead of distributing the SAP &pulp amounts in the absorbent section of the diapers equally. Before this study, it was found that the amount of SAP & Pulp increased towards the back of the diaper. With raising the concentration of SAP and pulp in the middle section, as the saturation ratio and liquid absorption capacity will increase, the skin of the baby will remain drier. For this, firstly, the absorbent parts of the cloth were divided into 5 different regions and marked. Afterwards, it was aimed to increase the amount of SAP & Pulp on the 2nd and 3rd regions where urine is intense. At this point, three different molds were designed and regional density was realized for the distribution of SAP &pulp amounts. In order to develop the product, the products of competing companies were examined. As a result of the tests carried out by determining the absorbent regions of a famous brand with 3D absorbent regional density, the presence of more SAP &pulp in the 2nd and 3rd regions showed that we are progressing in the right direction in our work. The effect of this distribution difference on product performance is analyzed. We found that the 3rd liquid absorption time in the diaper improved up to 12% compared to our current product. In the rewet and absorbent capacity test, it was seen that the baby diapers produced with 3rd Sample mold were superior to the existing product. Finally, more environmentally friendly diapers are produced than the current product, since less raw material (SAP & Pulp) can be used. A consumer survey was conducted with 25 parents in comparison with the current diaper. Considering the preferences in terms of satisfaction, the 3D core structured diaper (61%) was preferred more than the existing diaper (39%) in terms of equal distribution of the liquid, no leakage and sagging.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM journal belongs to the authors.

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