



BIG 3

Prediction of Consumers' Urine Leakage Experience based on Raw Material Properties of the Diaper Core

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Prediction of Consumers' Urine Leakage Experience based on Raw Material Properties of the Diaper Core

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Index of Abbreviations

AAP	Absorption Against Pressure
ABL	Absorption Before Leakage
AGM	Absorbent Gelling Material
AQL	Acquisition Layer
AQS	Acquisition System
BLC	Barrier Leg Cuffs
BS	Backsheet
CC	Core Cover
CRC	Centrifuge Retention Capacity
DL	Dusting Layer
DSC	Differential Scanning Calorimetry
EMEA	Eastern Middle Europe Eastern Africa
FSR	Free Swell Rate
IPRP	In Plane Radial Permeability
LA	Latin America
MAP	Medium Absorption Pressure
MDP	Medium Desorption Pressure
NA	North America
NW	Nonwoven
PE	Polyethylene
PET	Polyethylene terephthalate
P&G	Procter & Gamble
PLS	Partial Least Squares
PP	Polypropylene
SABAP	Speed of Acquisition under Balloon Applied Pressure
SFC	Saline Flow Conductivity
STC	Schwalbach Technical Center
TS	Topsheet
WE	Western Europe

Zusammenfassung

Eltern legen bei einer Windel am meisten Wert darauf, das Beschmutzen der Kleidung durch Urin und Fäkalien zu vermeiden. Aus diesem Grunde ist die Auslaufsicherheit der Windel das Hauptkriterium in diesem wettbewerbsreichen Markt.

Für die langfristige Auslaufsicherheit ist der Saugkern am wichtigsten, denn er nimmt den Urin auf und bindet ihn. Dies führt dazu, dass jeder Windelhersteller eine eigene Technologie des Saugkerns mittels verschiedener Rohmaterialeigenschaften entwickelt. Damit soll maximale Auslaufsicherheit bei minimalem Rohmaterialkosten gewährleistet werden.

In dieser Dokorarbeit wird ein Modell entwickelt, das Folgendes darstellt:
Zum einen welche Parameter des Saugkerns das Auslaufen des Urins beschreiben. Zum anderen die Größe dieser Parameter für eine große Bandbreite von Windeln mit verschiedenen Technologien, von verschiedenen Herstellern und aus verschiedenen Ländern.

Das Modell erlaubt es, die Leistung der wichtigsten Komponenten zu beurteilen, die für das Auslaufen verantwortlich sind, namentlich die „Verteilungslage“ und die „Superabsorber- und Zelluloselage“, in Abhängigkeit ihrer physikalischen und chemischen Eigenschaften. Auf Grundlage dieser Leistungseinschätzung wird ein Kosten- Leistungs- Vergleich erstellt. Das Model berücksichtigt den Aufbau des Windelkerns aus seinen verschiedenen Lagen. Auch für die gesamte Windel (Saugkern, Aussenhülle und Verschlusssystem) wird ein Kosten-Leistungsvergleich erstellt.

Die Kernkompetenz des Modells ist, dass es das Auslaufverhalten verschiedener Wettbewerbswindeln schnell und kostengünstig vorhersagt.
Die Arbeit wird abgerundet durch drei praktische Beispiele des Modells in der Geschäftswelt.

Summary

The most important need of a parent regarding diapers is the containment of urine and feces, which prevents clothes being soiled. This basic need of leakage prevention is the key parameter for diapers to achieve a good competitive market position.

The most important part of the diaper in terms of leakage performance is the core, which is responsible for urine absorption and hence for the probability of leakage occurrence. Each diaper manufacturer follows his own approach on core design using different raw materials to achieve an optimized performance with minimum raw material costs.

In this PhD thesis, a model is developed which identifies urine leakage influencing parameters of the diaper core in general, as well as their influence for a wide range of diapers from different countries covering different technologies and manufacturers.

The model allows the performance of the main leakage influencing components, “Acquisition System” and “Absorbent Gelling Material and pulp” layer, to be estimated, based on their physical and chemical properties. Based on the performance assessment, an analysis of the cost versus performance of these raw materials is given. The model includes the applied core technology design. An estimation of raw material costs versus performance of the diaper, as a whole, is given.

The key competence area of the model is to predict the urine leakage performance of competitive diapers in a fast and inexpensive way. The thesis closures by stating three business-related examples of model’s application.

1 Introduction

Every second 4.25 children are born worldwide. The number of births increased from 112 million in 1960 to 134 million in 2002. It will rise up to 137 million in the next ten years.[1] However, the birth rate in industrial nations has declined by 20 percent during the last 30 years. This shows that the world's population growth is a result of increasing birth rates of the developing countries.

For the global diaper market, already worth 22.2 billion USD in 2005, this forecasts an increasing growth rate of 11.5 percent (in total 25.1 billion USD) by 2010. This growth rate is based on emerging countries like Russia, China, Mexico, Brazil and the Eastern European region, which together are forecasted to reach 7.5 billion USD per year in sales, by 2010.[2]

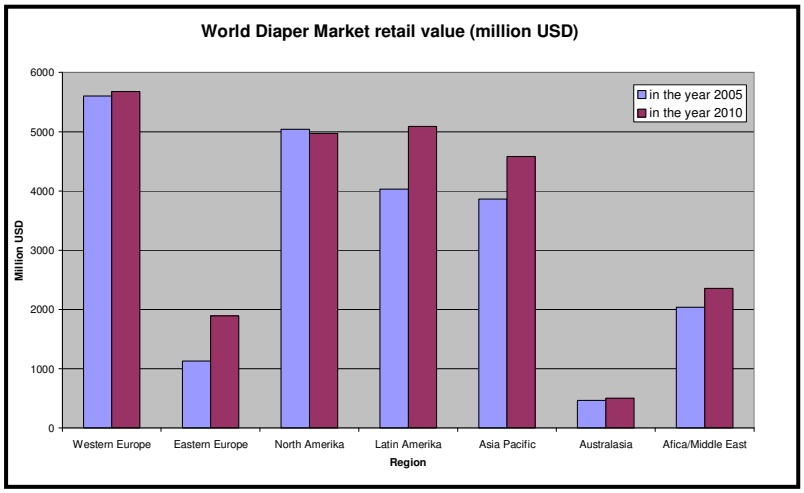


Fig 1.1: World Diaper Market Retail Value[2]

In industrialized regions like North America and Western Europe the diaper product sales stagnate in terms of value and volume based on the declining birth rates. The direct result is fiercer competition in these markets, especially with retailer brands, which gain a high percentage of market shares by the elimination of product quality issues and offering lower priced products. For example, in Germany 36.6 percent of the total diaper value shares (in the Fiscal Year 2005/2006)[3] are owned by retailer brands. Hence the retailer brands are significant competitors of branded diaper manufactures. This competitive market situation forces more innovation and segmentation strategies by branded diaper producers to increase consumers' brand satisfaction to protect their market share.

[1] Lebhardt, G. & Münz R.: Fertilitä und Geburtenentwicklung
[2] Atterby, Nonwoven Industry-World Diaper Market, Jan. 2007; p.26-31
[3] P&G Finance: Germany- Retail Brands Share Tracking; Internal P&G database,

Satisfied consumers are important because they are brand loyal and increase the profit of the company by their higher willingness to pay higher prices, which is directly related to the profitability of the company (Fig.1.2.). Additionally they recommend the product to family and friends.[4]

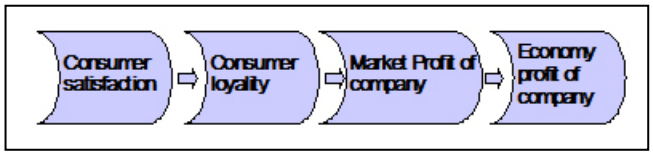


Fig 1.2: Relation customer satisfaction and economy profit of the company[4]

Diaper manufacturers try their best to fulfill consumers' satisfaction in terms of diaper functionality and price. Therefore more and more efforts are made to create innovative models which help to build the bridge between advanced raw material technology and affordable prices for diapers.

The focus of this PhD thesis is the area of model development for predicting consumers' urine leakage experience based on laboratory measurements. The raw material drivers for leakage are not exactly known in terms of competitive products. In this PhD thesis a model is developed which identifies the key drivers of the urine leakage performance of competitive diapers and especially the influence of leakage performance on a wide range of products. Based on this, the model predicts the urine leakage performance to assess products based on five raw material properties. This reduces the time and costs associated with product placement in the consumer test panel. The first part of the thesis gives an introduction of the basic components of a diaper and their functions, as well as the capillary liquid distribution in a diaper. Furthermore the statistical theory used in this project is introduced. The second part of the work comprises the different approaches of model development and describes the final model in detail. The main focus is given on the two most important raw materials of a diaper including a cost versus performance evaluation for all products. The final section states examples for the application of the model.

[4] Homburg, C., Dr.: Kundenzufriedenheit:2006, p. 93-103

2 Theory

2.1 Consumer

Consumer satisfaction can either be a positive disconfirmation, a confirmation or a negative disconfirmation[5](Fig.2.1.). The mission of a company is to achieve at least consumer's confirmation, otherwise they risk their market position[6]. To achieve this goal the manufacturer or brand needs to know and address the most relevant consumer needs.

Consumer satisfaction = perceived performance - expected/ idealized performance

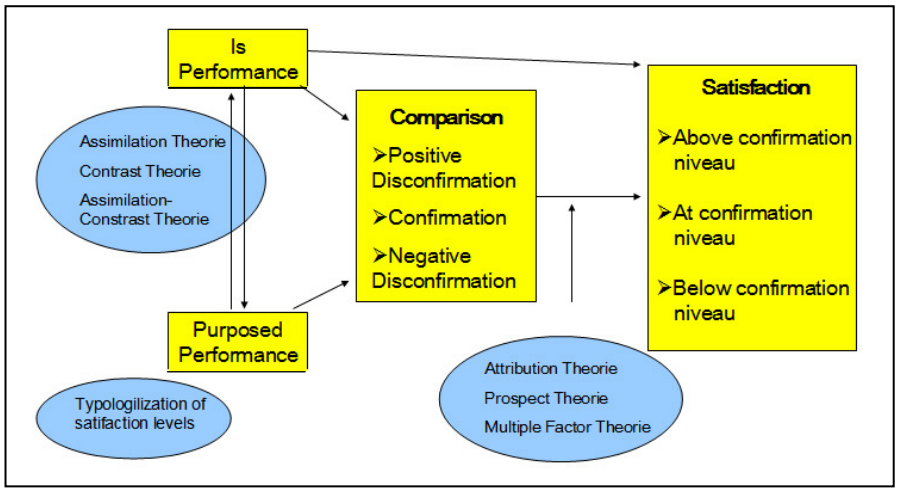


Fig 2.1: Consumer Satisfaction Theory[4]

According to the Kano Model of consumers' satisfaction, products can be divided into three categories: threshold, performance and excitement.[5] The threshold (basic) attributes are a "must" and on their own do not lead to consumer satisfaction. However, the absence or poor performance of these attributes results in extreme customer dissatisfaction[7]. Performance attributes are those for which more is generally better and will improve consumers' satisfaction. Conversely an absent or weak performance attribute reduces consumers' satisfaction. The price a consumer is willing to pay for a product is closely related to the performance attributes[8].

According to the diapers' hierarchy of needs (Fig.2.2.) the four most important things consumers verbalise are feces and urine leakage containment, diaper rash, redmarks and

[5] Ullman, D.G.: The Mechanical Design Process, 1997; p. 105-108
[6] Christianus, D.: Management von Kundenzufriedenheit und Kundenbindung, Expert,1999, p. 58
[7] Hinterhuber, H. & Matzler, K.: Kundenorientierte Unternehmensführung; p. 19-23
[8] Matzler, K. & Pramhas,N.: Kundenorientierte Unternehmensführung, p. 187-197

the assurance of skin dryness.[9] Since urine and feces containment is a threshold attribute, optimising non-leakage performance is a huge objective of diaper innovation. The consumers' positive disconfirmation of a product which also constitutes as satisfaction here, is linked to the profit of the company[10]. Satisfied consumers are loyal consumers[11], which means they buy the product again, try other products from the same brand, recommend the product to family and friends and are more open to price increases of the product[12].

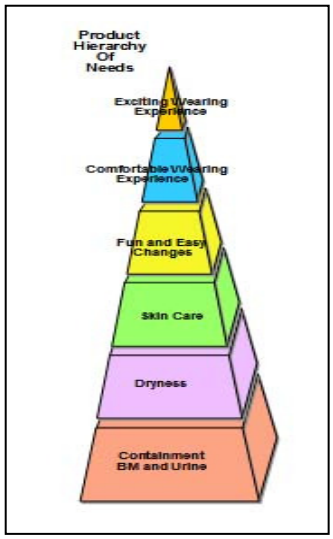


Fig 2.2: Maslow's hierarchy of diaper needs[9]

Different methods exist to determine if a product fulfills its demands. Overall the categorization is split into subjective and objective measurements. The objective measurements are subdivided into laboratory measurements, "on-baby tests" under standardized conditions, and consumer tests ("Expert Panel"). The "Expert Panel" is an objective measurement, because it provides data that is not impacted by criteria like the price of a diaper. Additionally, different diaper performance experiences aren't influenced by right product placement. The subjective measurements are consumer measurements, not related to the "Expert Panel" and result in a measurement of consumers' acceptance and perception of a product and its performance.

Objective measurements are mainly used for competitive benchmarking, because they are inexpensive and reflect consumers' behavior in the market.

[9] P&G Internal Source; Maslow's Hierachy of Diaper Needs: 2004
[10] Homburg, C.: Kundenzufriedenheit,2006, p. 93-103
[11] Heskett, J.L. et al: Putting the Service Project Chain to Work 1994; p. 164-174
[12] Erlbeck, K.: Kundenorientierte Unternehmensführung- Kundenzufriedenheit und –loyalität1999; p. 15-17

2.2 The Disposable Diaper

2.2.1 History of the Diaper

Traditionally, babies' bottoms were wrapped in native materials or strips of linen or wool, but in the late 1800s an efficient alternative method was invented. The progenitor of the modern diaper was a rectangle of linen fixed by safety pins. In 1942 the first disposable diaper was invented in Sweden, which was an absorbent pad made of unbleached crepe cellulose tissue held by rubber pants. The development progressed further in 1946 in the United States with a diaper that had a waterproof covering made from a shower curtain, into which a conventional cloth diaper was inserted. The first completely disposable diaper was invented in 1947. At this time it was a luxury and only used for special events.[13]

2.2.2 The "Pampers" History

In 1959 Vic Mills, a P&G employee invented "Pampers" to make daily life easier for everyone. In spring 1961 "Pampers" was launched in North America, as the first disposable diaper for the mass market. Twelve years later, in 1973, "Pampers" was rolled out in the German market. Until 1989 major improvements have been achieved, such as innovations like the superabsorber, also called "Absorbent Gelling Material" ("AGM"), which makes diapers thinner and the wearing comfort higher. Additional innovations like a waist band and a refastening tape system helped to make life for mother and child more convenient. "Barrier Leg Cuffs" were implemented for better leakage prevention in 1991, followed by the "Acquisition Layer" in 1993. In 1997, a new liquid distribution system was reintroduced. In 1999 the pant diaper was launched, which combined the demands of the technical performance of a diaper with easy handling for potty training, due to their form of training pants.[14]

[13] **Richer, C.:** 50 years of evolution, Diaper History:2004

[14] **Jarke, T.:** Evaluation of diapers to meet consumer needs, P&G Internal Presentation, 2003.

2.2.3 General Design of a Disposable Diaper

A diaper is designed to fulfill a combination of urine and feces absorption and storage, isolating wetness from baby's skin combined with wearing comfort and good fit. In order to understand the role of the different components in the diaper, a general design of a disposable diaper is given.

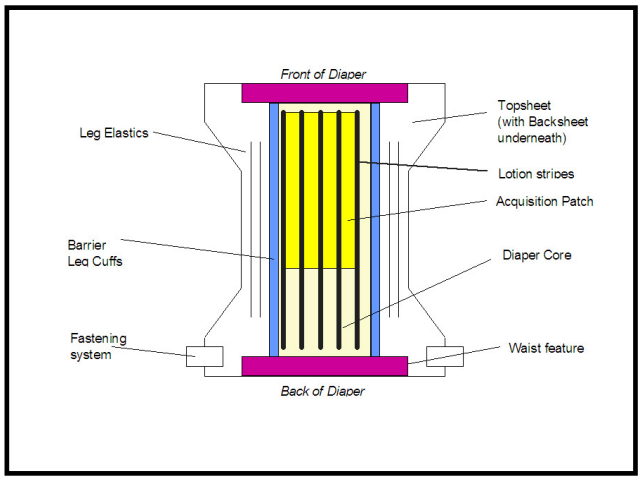


Fig 2.3: Diaper components

The three main parts of a diaper are the **core,** the **chassis and the fastening system**. The core is responsible for the acquisition and distribution of the urine as well as its containment and storage. The chassis, the outer cover of the diaper, together with the fastening system holds the diaper on the baby and by that the core in place.

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2.2.3.1 Absorbent Core Mechanism[15]

The hydrophilic "Topsheet" ensures rapid penetration of urine through the "Topsheet" into the underlying "Acquisition System". The "Acquisition System" distributes the urine away from the pee point on top of the absorbent storage core and provides multiple transfer points to the "Absorbent Gelling Material" and pulp layer. The multiple capillaries transfer the liquid to the storage layer and the strong swelling effect of the "Absorbent Gelling Material" leads to a capillary network based on the fiber/gel structure, which provides a route for further gushes.

[15] **Edana:** Absorbent Hygiene Products Training Course, 2006, Volume two 1998, 1.16-1.21.

The core absorption effect empties the fiber network capillary structure in the "Acquisition System" and thus reconstructs the initial state.

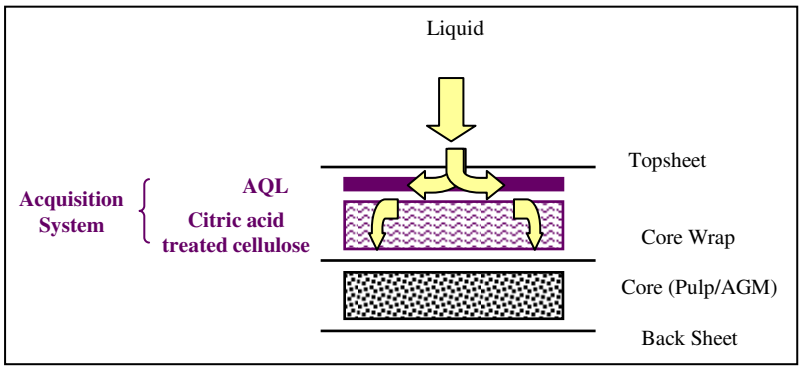


Fig 2.4: Schema of liquid distribution in the diaper core

2.2.3.2 Diaper Components

2.2.3.2.1 Core

The core is the basis for the main part of this thesis and is therefore explained in more detail. The raw materials used for manufacturing the different layers are explained in more detail in chapter 3.3, 3.4. and 3.5.. The storage **core** consists of a "Topsheet" (TS), an "Acquisition System" ("AQS"), a "Core Cover" (CC); an "Absorbent Gelling Material" and pulp layer and the "Dusting Layer" ("DL"). The core of a size four diaper, as used in this project, can be divided in four different zones (each 11cms; fig. 2.5.). The second zone (12-22cm) is the zone into which the baby urinates most often and accordingly the capacity in this zone is very important.

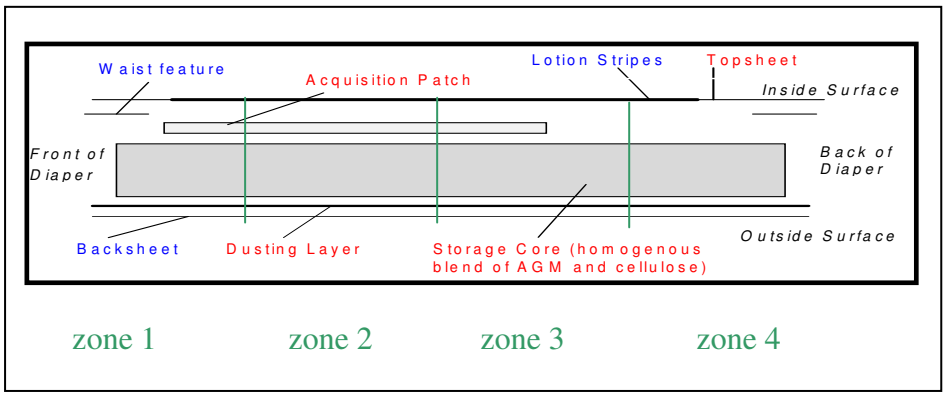


Fig 2.5: Diaper core technology[9]

2.2.3.2.1.1 Topsheet (TS)

The “TS” is the material that stays in close contact with baby’s skin for several hours. Therefore this nonwoven layer, which is the first layer of the core, needs to be very soft to avoid skin irritation. The main function of this material is to lead liquid quickly through into the “AQS”. This is enabled by surfactants, which turn the hydrophobic nonwoven hydrophilic on the upper side of the layer.

2.2.3.2.1.2 Acquisition System (AQS)

The “AQS” is located directly below the “TS” and on top of the absorbent core structure. Its function is the intermediate storage of urine and additionally the distribution of urine along the core structure. The “AQS” needs to lead the liquid quickly and completely into the absorbent core to obtain the full void volume capacity again for the next liquid arrival. Pampers’ diapers, except for low cost executions, have a second distribution layer underneath the nonwoven “Acquisition Layer”. This layer consists of citric acid treated cellulose fibers. The citric acid gives the cellulose fibers an extra curliness and stiffness, which is necessary to keep the ability to uptake and distribute the second liquid arrival. The advantage of the second layer is fast liquid absorption based on the hydrophilic nature of cellulose.

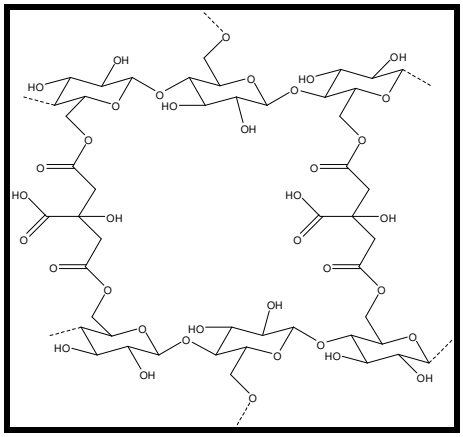


Fig 2.6: Citric acid treated cellulose fibers

2.2.3.2.1.3 Core Cover (CC)

The “CC” has a similar function to the “TS”. It is designed to lead liquid quickly through into the “AGM” and pulp layer, but at the same time it contains the “AGM” particles or the soft gel particles in the core and stops the baby being harmed by hard “AGM” particles.

2.2.3.2.1.4 Storage Core

The main function of the storage core is to store urine and secondly, to distribute urine to other zones of the diaper. Two main designs exist. The most common one is a mixture of cellulose and “AGM”. The cellulose fibers are mixed with “AGM” to enable an equal distribution of the fluid in the core. Their function is to maintain the space between the “AGM” particles. On its own, the “AGM” would swell to block the channels. The pulp and “AGM” mixture allows fluid to pass through, enabling a large amount of urine to be distributed throughout the core.

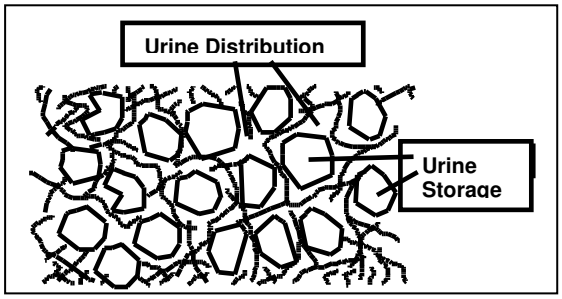


Fig 2.7: Urine distribution in core[9]

The second storage core design is based on a highly advanced “AGM” generation which does not need any cellulose fibers. This is because the “AGM” particles have a strong ability to stay in shape and so channels for the liquid are maintained. The “AGM” (chapter 2.4.2) in general is a material which is capable of absorbing large quantities of fluid (1000 grams of deionized water per 1 gram of “AGM”), while remaining insoluble in the fluid it absorbs. The classification “superabsorbent material” makes it clear that the absorbed fluid is strongly held by osmotic pressure even when external pressure is applied.

2.2.3.2.1.5 Dusting Layer (DL)

The "DL" is a tissue, a layer of pure pulp or more frequently a hydrophobic nonwoven. It protects the "Backsheet" of the diaper from impact of the hard "AGM" particles.

Core Components	Function
Topsheet	Enables liquid to flow quickly into the Acquisition System; soft on the baby's skin
Acquisition System	Intermediate liquid storage; distributes liquid fast horizontally over the core; leads liquid quickly into the storage core
Core Cover	Enables liquid to flow quickly into the storage core; avoids the baby being harmed by hard AGM particles; keeps swollen AGM in storage core
Storage Core (AGM & pulp)	Stores urine and distributes it
Dusting Layer	Stops mothers feeling the AGM particles; protects the "Backsheet" from the impact of hard AGM particles

Fig 2.8: Summary core components and their function

2.2.3.2.2 Chassis

The chassis keeps the core in position by ensuring the diaper is a good fit on the baby. It contains the "Backsheet" (BS), the leg and/or waist elastics, the "Barrier Leg Cuffs" (BLCs) and the "fastening system".

2.2.3.2.2.1 Backsheet (BS)

The "BS" is a hydrophobic outer cover, usually made of two layers - a nonwoven outside and a polymer film inside - which is available from zero to high breathability (300g/m^2/24h). The function of the "BS" is to prevent wetness being transferred to the baby's bed or clothes. The "BS" is the first material a mother touches when she takes a diaper out of the pack and it therefore needs to be soft.

2.2.3.2.2.2 Elastics

Elastics are a stretchable material, most often made of rubber or lycra. They contribute to the fit of the diaper. The elastics are used in the waist, as well as the leg area.

2.2.3.2.2.3 Barrier Leg Cuffs (BLCs)

“BLCs” are made of a hydrophobic nonwoven. They are located on the “TS” and help to prevent the leakage of urine and feces.

2.2.3.2.3 Fastening System

The fastening system consists of two parts, the “Landing Zone” and the hooks or adhesive tapes. The function of the fastening system is to stay closed during use, but also to allow for opening and closing while the diaper is being put on.. The “Landing Zone” is composed of a laminated printed nonwoven or film. For nonwoven "Landing Zones", a fastening system of hooks and loops is used. For a “Landing Zone” composed of film, adhesive tapes are used. Additional stretch elements are combined with the tapes to enable a better diaper fit performance.

2.2.3.2.4 Others

Additional elements of the diaper are the lotion and the glue. The lotion is applied to the “TS” to enable a better wetness barrier for the baby’s bottom and to therefore reduce the probability of diaper rash. Glue exists in each diaper to connect the individual parts of the diaper.

2.3 Capillary Liquid Transport

All the core-related layers of a diaper ("Topsheet", "Acquisition System", "Core Cover", "AGM and pulp" mixture) contribute, within their respective position in the sandwich complex, to the leakage prevention of a diaper. The basic principle of the diaper design is to absorb and store liquid in the different layers of the storage core, and to prevent the flow back of the liquid and leakage occurrence. This is achieved by increasing capillary pressure from layer to layer, starting from the "TS" and resulting in the storage core. This chapter explains the basic principle of capillary liquid flow in a fully saturated media to provide a basic understanding of the rules of liquid transport. For ease of understanding, this procedure, which in reality is three-dimensional, is described in this chapter as a two-dimensional process.

2.3.1 Fundamentals of Capillary Science

The liquid distribution in a diaper core can be described using the principal rules used for earth science, because both are porous media and transmit fluid. This chapter gives a microscopic understanding of the phenomena that govern liquid movements in porous materials. The wetting phenomenon is split into two segments. The first one is the liquid flow in microscopic spaces, as in in porous materials. The second segment is the liquid absorption into a non-porous solid. As the diaper is a porous media, only the first one is discussed here.

2.3.1.1 Definition of Interfacial Tension

The driving forces for liquid movement are the surface tension and the interfacial free energy. When a liquid stays in contact with another substance, there is free interfacial energy present between them. This interfacial energy arises from the difference between the inward attraction of the molecules in each phase and those at the surface of contact. "Interfacial tension is defined as the amount of work per unit area that must be performed in order to separate a substance i from a substance k."[16] These forces are generally considered to be of two different types. The dispersion force of attraction

[16] **Rosati, R. & Schmidt, M.:** Capillary Liquid Training, P&G Internal: 2006, Version 10.

affecting neighboring molecules regardless of their composition/charge distribution (Van-der Waals; Lennard-Jones Force). The polar force of attraction results from charge localization within molecules and can be ion-dipole, dipole-dipole, induced dipole or combinations. Intermolecular forces appear within each phase and across a phase interface. These intermolecular forces are the microscopic reason for capillary fluid motion.

2.3.1.2 Interfacial Tension: Liquid- Vapor interface

The interfacial tension exists between two phases with a discontinuous pressure across the separating interface. The degree of the pressure difference depends on the interface curvature and on the air-liquid interface inside the void space. This pressure difference is called capillary pressure.

$$P_c = P_{air} - P_{liquid}$$

In general, in a two-phase system P_c is the difference between the pressure of the non-wetting side of the interface and the wetting one. In the equilibrium, P_1-P_2 is constant over the surface, like a water droplet in air. For spherical interfaces $r=r_1=r_2$, like droplets, the Laplace equation states:

$$P_1 - P_2 = \frac{2\gamma_i}{r}$$

The capillary pressure is a measure of the tendency of the partially-saturated porous medium to suck in water or to repel air. The Laplace formula for capillary pressure is developed as a balance of forces at a point on the curved interface.

2.3.1.3 Interfacial Tension- Solid-Liquid-Vapor System

The liquid on top of a planar surface will remain in the form of a sphere (all radii of curvature are the same and constant). The relationship among the surface tension values (γ) is as described below in Young's equation. ϑ is the contact angle of the system in a

$$\cos\vartheta = \frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}}$$

thermodynamically equilibrium. Cos ϑ is defined by the ratio of the energy released in forming a unit area of interface between a solid and a liquid to the energy required for forming a unit interface between vapor and a liquid.

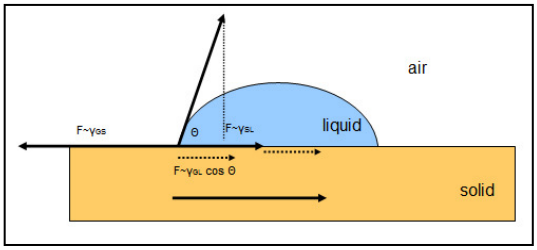


Fig 2.9: Young's equations; picture [12]

In Fig 2.9, the arrows indicate forces proportional surface energies. The contact angle "is formed which is defined as the angle between two of the interfaces at the three phase line of contact."[17] So far, no independent method of measuring either the contact angle (solid vapour) or the contact angle (liquid solid) has been found. Instead, surface tension of the liquid and contact angle θ are frequently used to characterize a solid-liquid-gas system. The contact angle only makes sense for a given solid-liquid-vapor/gas system, because the contact angle on a rough surface is much higher than on flat ones.

2.3.1.4 Definitions of Hydrophobic/ Hydrophilic

Solid surfaces with advancing contact angles less than 90° are called hydrophilic or wetting and those with an advancing contact angle larger than 90° are called hydrophobic, or non-wetting. This rule is only valid for capillaries with walls parallel to gravity. In fibrous systems, as in diapers, the capillary walls are curved and an advancing contact angle larger than 90° may still permit some spontaneous uptake. For many liquid-solid combinations, there is a noticeable difference between the contact angles of advancing and receding wetting. The receding angle is always smaller and the corresponding work of adhesion is larger. The reason for this is that the interface is in contact with a pre-wetted surface. The solid surface has a roughness, structure and surface heterogeneity.

[17] **IUPAC:** Compendium of Chemical Terminology, 1997, 2nd Edition

2.3.1.5 Breakthrough and Bridging Pressure

When measuring the pressure that is required to squeeze liquid through a hydrophobic layer the sample can be placed with a) a hydrophilic layer in direct contact with the lower level of the surface, or b) air underneath it. In case b) the pressure is lower, which is called bridging pressure and in a) the pressure is called breakthrough pressure. Bridging pressures do not depend on the contact angle, as long as the contact angle is larger than 90°. In contrast, the breakthrough pressure depends on the contact angle.

2.3.2 Characterization of Porous Media

2.3.2.1 Porosity

"Pores are void spaces which are distributed extensively throughout the volume of a porous medium."[22] The porosity is the ratio of the void space in a porous medium over the total bulk volume of this medium. Porosity (n) is calculated by the basis weight (BW) of a material (i), the density (ρ) and the caliper (d) of the material (i).

$$n = 1 - \sum \frac{BW_i}{\rho_i * d}$$

The saturation of a diaper is the volume of liquid in the material divided by the total void volume of the material.

2.3.2.2 Pore Volume Distribution/ Capillary Pressure

The diaper is a porous media and within the porous media pores have irregular shapes. The three main types of pores are: closed pores, which are not usable because no liquid can flow in or out; blind pores, which do not lead through the media, but liquid can flow in and out; and through pores, which lead through the whole media. Each pore has an effective radius and the contribution of the pore size to the total free volume is important. The effective radius (R) of a pore is defined by the surface tension of the liquid (γ) the advancing or receding contact angle of the liquid (Θ) and the pressure difference across the liquid air meniscus (Δ PC) using the Laplace equation:

$$R = \frac{2\gamma \cos\theta}{\Delta P_c}$$

For liquid to enter or drain from a pore, the external pressure must be higher than the pressure difference across the liquid air meniscus (ΔP_C).

2.3.2.3 Permeability in fully Saturated Porous Media

Darcy's law describes the liquid flow through a fully-saturated porous material. The permeability (κ) characterizes the porous medium as a flow resistance. The permeability factor takes all the microscopic characteristics, such as the porous medium, porosity, pore volume distribution, tortuosity and specific surface area, into account. The pressure gradient includes any driving force, i.e. capillary pressure, gravity, external pressure. The flow (Q) is equal to the product of the permeability (κ) of the medium, the cross-sectional area (A) to flow and the pressure drop (ΔP), all divided by the viscosity (μ) of the liquid and the length (L) of the pressure drop.

$$Q = \frac{\Delta P * \kappa * A}{\mu * L}$$

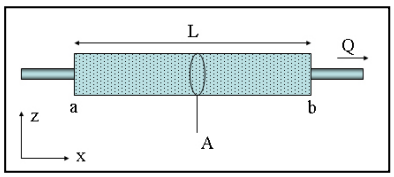


Fig 2.10: Capillary liquid flow[16]

As the liquid advances in a porous medium, the small pores with greater capillary pressure will tend to fill first. They will be the last to empty when liquid is being withdrawn. Only the huge pores in the porous media get flooded. Since at any location only pores up to a certain size are filled, the local flow is somewhat restricted to those filled pores.

2.3.3 Simple Fluid Handling Model- Capillary Tube Model

In a diaper the nonwoven fabrics and, for example, fluff pads have complex pore structure the absorbency data on those materials are treated using a simple capillary tube flow model. The liquid moves into a porous media by the capillary pressure, i.e. differential pressure across the liquid-air interface due to the curvature of meniscus in the narrow confines of the pores.

The amount of capillary pressure is commonly given by the **Laplace equation.**

$$R = \frac{2\gamma\cos\theta}{\Delta P_c}$$

With an idealized tube structure the Hagen-Poiseuille law for laminar flow through pipes is used. The volumetric flow rate (q) is proportional to the pressure drop gradient along the tube.

$$q = \left(\frac{R_C^2}{8\mu}\right) * \frac{\Delta P}{L}$$

RC is the tube radius, μ is the fluid viscosity, L is the wetted length of the tube and ΔP is the net driving pressure. Applied to the capillary rise, L is the height of rise and $\Delta P = p - \rho L g$ for upward flow where p is the capillary pressure for a given capillary tube. Whereas P is the specific gravity of the fluid, and g is gravitational acceleration. By replacing q by dL/dt the Hagen Poiseulle is equation is transformed to:

$$\frac{dL}{dt} = \left(\frac{R_C^2}{8\mu}\right) * \left(\frac{p}{L} - \rho g\right)$$

When an equilibrium is reached, the upward capillary driving force p equals the weight of the column of liquid, the net force on the liquid is zero and the rising of the liquid stops (dL/dt = 0). The equilibrium capillary rises:

$$L_{eq} = \frac{P}{\rho g}$$

The capillary rise between the time of initial contact and the final equilibrium was obtained by integrating the equation as derived by Lucas-Washborn

$$\ln\left(1 - \frac{L}{L_{eq}}\right)^{-1} - \frac{L}{L_{eq}} = C_1 t$$

Where C_1, is a constant and equal to $R_c^2 \rho g / 8\mu L_{eq}$. The last equation shows that the capillary rise approaches the equilibrium value asymptotically. By using L = L(t) we can also calculate uptake as a function of time namely.

$$\boxed{Q(t) = n * A_0 * L(t)}$$

These outcomes are only applicable for fully-saturated diapers in a one dimensional area. Additionally, it must be noted that real fibres are not cylindrical or arranged in parallel. In cellulosic structures water has an influence on the capillary dimensions.

2.4 Raw Materials for Diaper Manufacturing

The most important materials for liquid absorbing and handling processes are the "AGM" and the nonwoven. Therefore, in the following chapter, these two raw materials for diaper manufacturing are described in depth, including their performance properties based on the raw materials used and the technology involved in their manufacturing process.

2.4.1 Nonwovens

2.4.1.1 Introduction and Definition

As of the mid-sixties, the nonwoven sector is a separate, innovative and fast evolving industry. As the demand for nonwovens has steadily increased, it has been met by the technology and ingenuity of raw materials, the equipment suppliers, the nonwoven producers and converters. Today, nonwoven fabrics play key roles in hundreds of everyday products, in hygiene and health care, in automotives and clothing, to name but a few end uses. The production of nonwovens increased by 80 percent from 1997 to 2000, up to 2,857,000 tons, globally.[18]

Therefore, Western Europe is a key player with 36 percent of the global nonwoven production (in the year 2000). The "INDA", North America's Association of the Nonwoven Fabrics Industry, describes nonwoven fabrics as "sheet or web structures bonded together by entangling fibres or filaments, by various mechanical, thermal and/or chemical processes. These are made directly from separate fibres or from molten plastic or plastic film."[19]

The diversity of the industry and thus its products derives from the opportunity to combine different raw materials with different techniques. This diversity is enhanced by

[18] **Turbak, Albin F.:** Introduction to Nonwovens:1998; p.1

[19] **Wilson, A.:** Development of the Nonwovens Industry, 2006, Nonwovens Report International, p.2.

the ability to engineer nonwovens, which have specific properties and perform specific tasks. In general, the manufacturing process of a nonwoven fabric consists[18] of:

1. **Selecting and using various types of fibers,**
2. **Web formation,**
3. **Web bonding: chemically, thermically or mechanically,**
4. **Finishing and converting the formed integral matted structure.**

"The properties and characteristics of a nonwoven web depend to a large part on the type of fiber it is ultimately made of."[20]

Additional characteristics of the web are given by the web strength, which is provided by the bonding of the fibers and the final characteristics set by the web consolidation. Consolidation can be accomplished by using chemical bonding, which can be applied uniformly by impregnating, coating or spraying, or intermittently, like in print bonding. Consolidation can also be reached by cohesion bonding such as partial fusion of the constituting fibers or filaments. Such fusion can be achieved by calendaring, hot through-air- blowing or by ultra sonic impact. Finally, consolidation can also be achieved by mechanical means (frictional bonding), such as needling, stitching, water-jet entangling or a combination of these various means.

This chapter will look in detail at these techniques, which are important in the context of diaper core design, and address the remaining ones only briefly. The most commonly used techniques with regard to diapers are: spunlaid" in combination with "spunbonded" ("Topsheet", "Core Cover") or "spunbonded / melt-blown" ("Core Cover") and for the "Acquisition Layer", "dry-laid" combined with "chemical, thermal and solvent bonding".

[20] **Albrecht, W.& Fuchs, & Kittelmann, H.:** Nonwoven Fabrics, Wiley-VCH Verlag 2003; p. 2.

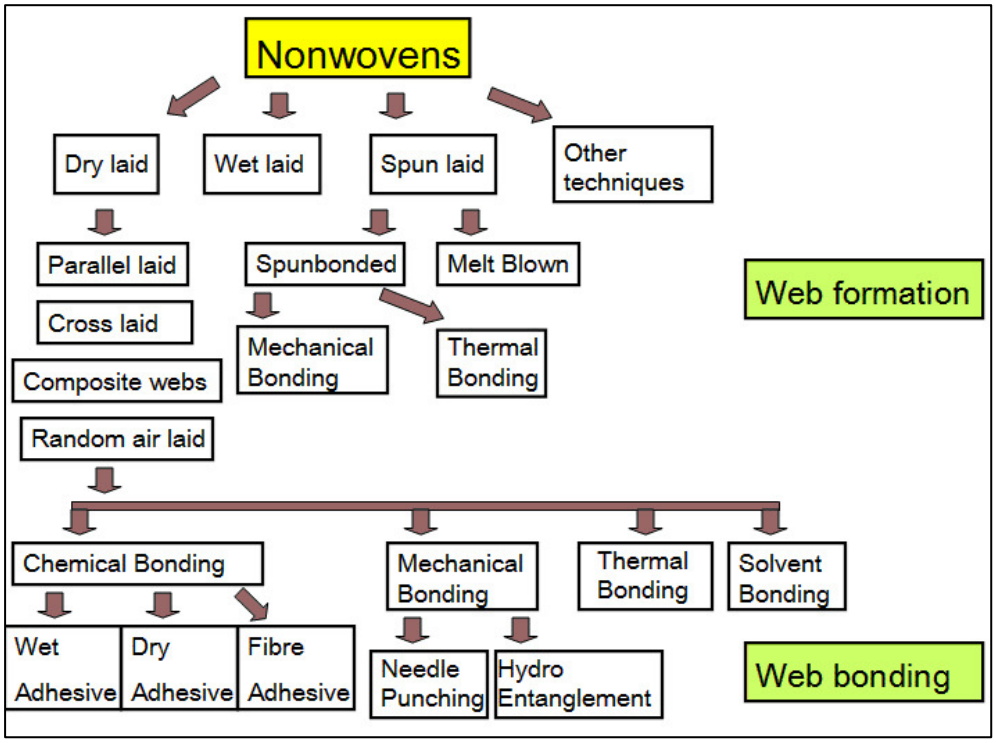


Fig 2.11: Nonwoven manufacturing overview

2.4.1.2 Raw Materials for Nonwovens

For nonwoven production the raw materials can be divided into three groups [21]:

a) Polymer granules or flakes - used for spunlaid and meltblown webs
b) Additives – non fibrous materials added at the web forming stage
c) Fibers – from man-made or natural sources; used for dry-laid, wet-laid and short fiber airlaid processes.

All raw materials, chemical binders and additives used in the manufacture of nonwovens consist of polymers. The term “polymer” is derived from the Greek term “poly”, which means “many” and “mer”, which means “unit”. Therefore, polymer simply indicates many units stuck together. When certain chemical building blocks [A], called monomers, are linked together in various sequences like $[A\text{-}A\text{-}A]_x$, they form polymers.

[21] **EDANA:** Nonwovens Training Course, 2006, Module 2.1.

2.4.1.2.1 Polymers Granules or Flakes

Apart from starting the nonwoven manufacturing process using finished fibers, three fiber technologies exist using polymer granules as feed stock material. The three fiber production technologies (Man-made fibers) are melt spinning (polymer is melt and spun directly), dry solution spinning (the polymer is dissolved in solution and solvent solution is spun, under solvent evaporation) and wet solution spinning (the polymer dissolved in a solvent and the solution of the polymer is forced out into a non-solvent system). The major polymers used for this technique are polypropylene, polyethylene and polyethylene terephthalate. The main requirement to produce an even web is an equal molecular weight distribution.

2.4.1.2.2 Additives for the Polymer Melt

Other non-fibrous materials are added to the fiber structure of the nonwoven to achieve special results in the finished web. Antioxidant and additives are added, the latter ones are used to alter surface properties as hydrophilicity and lubrication (softeners), enabling splittable bicomponent fibers. The advantage in using melt additives is the elimination of processing equipment such as spraying, foaming and drying equipment.

2.4.1.2.3 Fibers

Fibers are a class of materials that are continuous filaments or are discrete elongated pieces. “The total fiber production in the nonwoven industry increased from 1991-2000 from 484,000 tons to 1,060,600 tons (46 percent). Most important in terms of nonwovens, are man-made fibers. In terms of polymer-laid nonwovens, polyolefins are the most widely used resins making up 45-55 percent of the total [22]. The main fiber contributors (in the year 2000) were: Polypropylene with 46 percent (491,400 tons); Polyester with 22% (228,500 tons) and Wood pulp with 11 percent (114,000 tons)[23].

[22] **Bhat,G.S.& Malkan,S.R.:** Handbook of Nonwovens, 2006, p. 143-200.

[23] **Edana:** Edana Conference, 2001

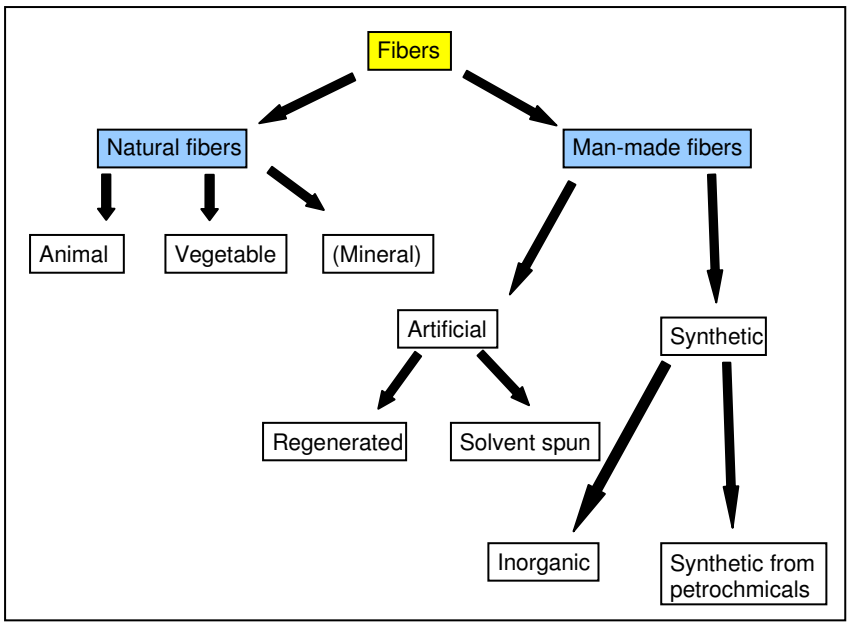


Fig 2.12: Main categories of fibers

Fibers used by man come from a wide variety of sources.[24]

- **Natural fibers** descend from plants, animals, and geological processes. Nearly all natural fibers are formed either by condensing sugar molecules to form carbohydrate polymers, such as cellulose, or by condensing amino acids together to form proteins, like wool. Natural fibers are dived into sub-groups according to their origin:
  - **Vegetable fibers** are generally based on arrangements of cellulose, often with lignin: examples include cotton, linen, hemp, jute, flax, ramie and sisal. Plant fibers serve in the manufacture of paper and cloth.
  - **Animal fibers** consist largely of particular proteins. Examples include spider silk, sinew and hair (including wool).
  - **Mineral fibers** comprise asbestos. Asbestos is the only naturally occurring long mineral fiber.
- **Man made fibers** is produced by human endeavor. Man made fibers can be divided into two classes: **artificial fibers and synthetic fibers**.

[24] **Albrecht W.& Fuchs, H. & Kittelmann, E.:** Nonwoven Fabrics, 2003, p.2

- **Artificial fibers**, – these are based on natural materials but redesigned, and are divided into:
  - **Regenerated fibers,** viscose rayon is the most important example.
  - A new class of **solvent spun cellulosic fibers** is Lyocell.

- **Synthetic fibers - these are** classified as inorganic and synthetic fibers (from petrochemicals).

- The group of **inorganic fibers** includes, for example, glass microfibers, ceramic, silica, alumina, carbon, etc
- **High performance and special purpose fibers** are widely used in the diaper nonwovens industry. **Bicomponent fibers** are one example. They are produced from two different components and are increasingly important as thermally activated binder that can be incorporated in the web process and subsequently activated.
- **Synthetic fibers (from petrochemicals)** are the main components used in diaper manufacturing. They include, amongst others, the following vinyl polymers: polystyrene, polyacrylates, polyvinyl chloride, polyacrylonitrile, polypropylene. Polypropylene ("PP") is the most widely used polymer in the nonwovens sector. They are obtained by linking their component units together by one of the three methods: polycondensation, polymerization or polyaddition.

2.4.1.2.3.1 Most Often Used Raw Material Fibers for Nonwovens

The polyolefin technology is growing faster than any other polymer technology. "A polyolefin is defined as any long synthetic polymer chain composed of at least 85 percent by weight of ethylene, propylene or other olefin unit (monomers)."[25] The reason for the growing use of polypropylene ("PP") and polyethylene ("PE") polymers is their inexpensiveness and availability throughout the world. Additionally, the development of single-site catalysts, which results in identical polymers and minimizes the variability of the polymers, expands the application field of polypropylene. 2.9 million tons "PE", 1.8 million tons "PP" and 0.56 million tons "PET" were produced in Germany in 2006.[26]

[25] **Cain, L.W.:** Fibers and Binders from Nonwovens, 1992; p.223.

[26] **Verband Kunststofferzeugender Industrie**: Kunstoffproduction- Umsatz- Außenhandel

2.4.1.2.3.1.1 Polyethylene

Besides polyvinyl chloride, Polyethylene is the most often produced plastic material.[27] "PE" emerges from ethane, a gas deriving from the petrol chemistry. The comonomer, in combination with the manufacturing process, affects the type, frequency and length of branching that occurs in the molecule and by that the density of the "PE." This results in five main different types of "PE: "PE – High Density" (HD), with low branched polymer chains; "PE-Low Density"(LD), with high branched polymer chains; "PE Linear Low Density" (LLD), a linear "PE" chain with a high amount of short branches; and "PE – High Molecular Weight" and "PE Ultra High Molecular Weight". For diaper nonwovens, mostly low melt flow rate "PE-HD" is used to form bicomponent fibers, and medium to high melt flow rate "PE-LLD" resins are used to form fine denier filaments. In general, "PP" resin is more difficult to extrude than "PE", based on the high shear sensitivity of "PP" resin and, to a limited extent, the higher melting point [28].

The characteristics of "PE" are: low density (0.87-0.965 g/cm^3) and abrasion, high tenacity (2-4.5gpd) and elongation properties. "PE" is semi-crystalline; the higher the crystallinity, the higher the density. It softens as of 80°C and melts between 120-125 °C. Stable fibers made from "PE-LLD" are attracting considerable interest. "PE" has the advantage over "PP" of greater softness. Based on its low melting point in combination with a thermobonding technology like calender bonding, it is a cost-effective process for lighter webs.

	PE-LD	**PE-HD**	**PE-LLD**
Degree of cristallinity (%)	40-50	60-80	10-50
E- module at 23°C (in N/mm^2)	200	1000	60-600
Crystallite area of melting temperature (°C)	105-110	130-135	40-125
Softening Point (°C)	110	140	40-120

Fig 2.13: Parameters of the different Polyethylene types

[27] **FU Berlin:** Kunstoffe zum Kennenlernen: Polyethylene. 2001.

[28] **Cheng,C.Y.:** TappiNonwovens Conference;1994, pp.39-49

2.4.1.2.3.1.2 Polypropylene

For nonwovens, the isotactic homopolymer “PP” is mainly used because this “PP” has a high tensile, stiffness, tear strength and clarity, due to its molecular alignment. [29] The fiber properties are derived from the molecular weights, the molecular weight distribution and the degree of crystallinity of the polymer. The properties, which are linked to the polymerization process of α –Olefins, are the molecular mass distribution, the degree of branching and the tacticity. Generally, the higher the molecular weight and degree of crystallinity, the stronger the fibers are. The narrow molecular weight distributions reduce the melt elasticity and the melt strength of the resin so that the melt stream can be drawn into fine denier filaments without excessive draw force.

In terms of “PP”, different possible arrangements of the methyl group exist, which affect the macroscopic properties of the polymer, such as its melting point, rigidity, elasticity and transparency. The regular arrangement of the methyl groups is the reason for the 60 percent crystallinity of isotactic “PP” and, based on this, the resulting helical structure. These helices can coordinate parallel to each other, which leads to a high tensile strength. Syndiotactic “PP” lacks the stiffness of the isotactic form, but has a better impact and clarity. Atactic “PP” lacks the crystallinity of the other two.

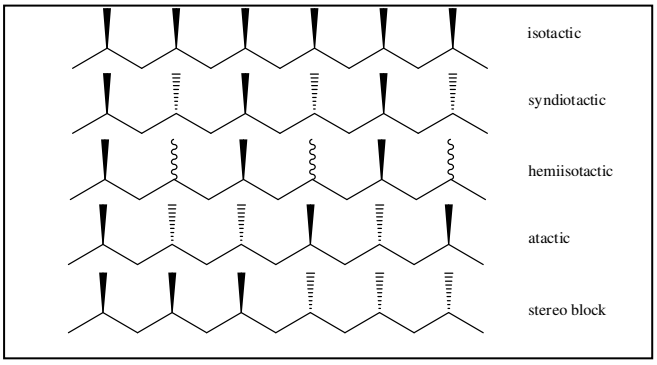


Fig 2.14: Possible tacticity of the PP chain

The tacticity of a polymer describes the specific constitution of the side chains to each other (fig.2.14). Three extreme cases exist – isotactic, syndiotactic and atactic "PP". In isotactic “PP”, all propylene units are located on the same side of the macromolecular backbone. In syndiotactic “PP”, the substituents have alternating positions along the chain. In the case of atactic “PP”, the methyl groups are randomly placed along the chain.

[29] **Brydon, A.:** Handbook of Nonwovens,2006, p.145

The formation of the primary structure of the polymer chain affects the secondary and tertiary structures.

The first useful "PP" was manufactured using the "Ziegler Natta" polymerization (for details, see attachment), because it avoided chain transfer, as in the radical polymerization process of "PE", and therefore produced the desired tacticity of the "PP".

Due to the fact that "Ziegler Natta" catalysts have various catalytic centers, they produce highly non-uniform polymer chains (different lengths and chiral structures – isotactic as well as small amounts of atactic isomers), which leads to a disadvantage in the final nonwoven web properties. Therefore, the use of metallocene catalysts ("single site catalysts") has significantly increased in the manufacturing process, which yield a more uniform chain length and homo "PP" (lower content of atactic "PP"). Highly stereo selective "PP" is produced by using chiral catalysts, as the C_2 symmetric ansa metallocene catalysts. Examples of isotactic polymerization catalysts are given in fig 2.15.[30]

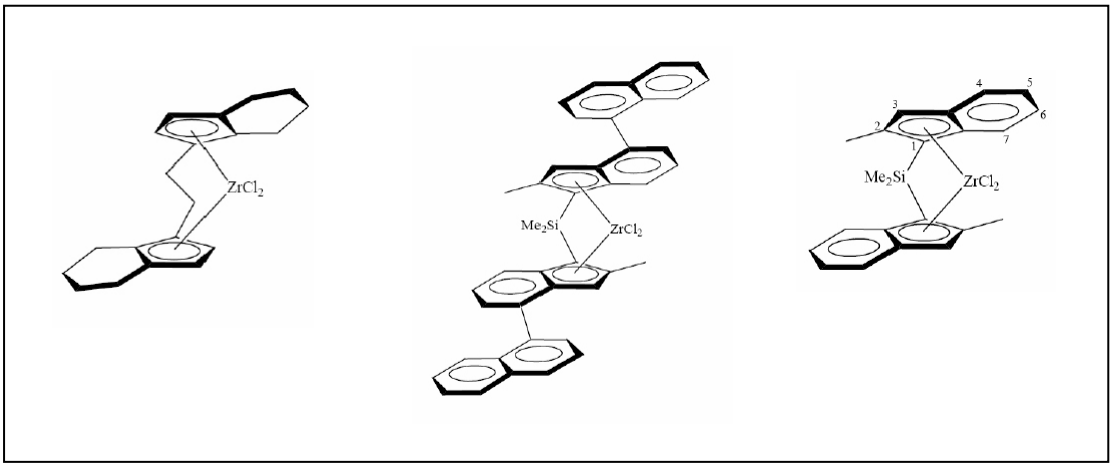


Fig 2.15: Ansa metallocenes

"PP" is by far the major resin used in melt-blown webs because of its low molecular weight and viscosity, narrow molecular weight distribution, ease of handling, good web-forming and good bonding. Also, "PP" has an outstanding property in terms of low density - it is 40 percent lighter than "PET", which results in an excellent volume to weight ratio. Its melting point is 165°C but the disadvantage is that it has low resiliency.

[30] **Mueller:** Koordinationschemie Geschichte und Zukunft, 2005.

Advantanges of PE	Disadvantages of PE
Softness / smoothness	Cardability/crimp retention
Thermal-bonding at lower temperature	Narrow range of thermal-bonding
Stability toward ionizing radiation (sterilization)	Shrinkage at elevated temperatures
Wettability via proprietary surfactants package	Lower bonded fabric strength

Fig 2.16: Comparison of PE and PP characteriszic[24]

2.4.1.2.3.1.3 Polyethylene terephthalate

The most common polyester fiber in terms of nonwovens is polyethylene terephthalate, in the context of nowoven industry used with the abbreviation “PET”. “PET” fibres are produced by a meltspinning process made of polyethylene terephthalate. Polyethylene terephthalate belongs to the group of polyester. Polyesters are all substances that contain ester groups[31] and are made by polycondensation (principle mechanism see attachment). “PET” fibers have an excellent balance of physical and chemical properties, along with a favorable cost /performance ratio. The fibers have high strength and toughness properties, which provide excellent durability, additional they have an outstanding property of a high modulus with excellent recovery which translates into excellent fabric resilience and wrinkle recovery properties. Furthermore “PET” can be processed at high speed on typical nonwoven processing lines and can readily be blended with most other fibers used in the nonwoven products. The fiber is available in a wide range of deniers, cut lengths, fiber finishes and also produced in many fiber variants.

Density	1370 kg/m^3
Tensile strength(σ_t)	55–75 MPa
Elongation at break	50–150%
Glass temperature	75 °C
melting point	260 °C
Thermal conductivity	0.24 W/m.K
Water absorption (ASTM)	0.16
Price	0.5–1.25 €/kg

Fig 2.17: Properties of PET

[31] **FU Berlin:** Kunstoffe zum Kennenlernen: Polyester, 2001

2.4.1.3 Web Formation

As mentioned above nonwoven manufacture starts arranging the fibres in a sheet or web. The fibres can be either staple fibres packed in bales, or filaments extruded from molten polymer granules. Four basic methods are used to form a web, and nonwovens are usually referred to by one of these methods[32]

- **Dry-laid**
- **Wet-laid**
- **Melt spun system**
- **Other techniques**

2.4.1.3.1 Dry-laid

The dry-laid systems are based on well-known textile processes and account for approximately 36 percent of all nonwoven production. There are two methods of dry-laying:

1.) Carded webs

2.) Aerodynamic/Airlaid webs

2.4.1.3.1.1 Carding

Carding is a mechanical process by which fibers (typical length ~ 0.038-0.076m) are opened, cleaned, straightened and orientated. This process is the one used for the "Topsheet", "Acquisition System" and "Core Cover". A carding machine is a rotating drum or series of drums covered with fine wires or teeth, which opens lumps to the scale of the individual fibers and by that, arranges fibers in an oriented way. The web can be parallel-laid, where most of the fibers are laid in the direction of the web travel, or they can be random-laid. A basic web is formed on one card or more, but when the webs are combined to build up the web's final weight/thickness, the webs can be laid down either in the machine's direction or in a crosswise direction.

[32] **Edana:** Edana Nonwovens. 2007

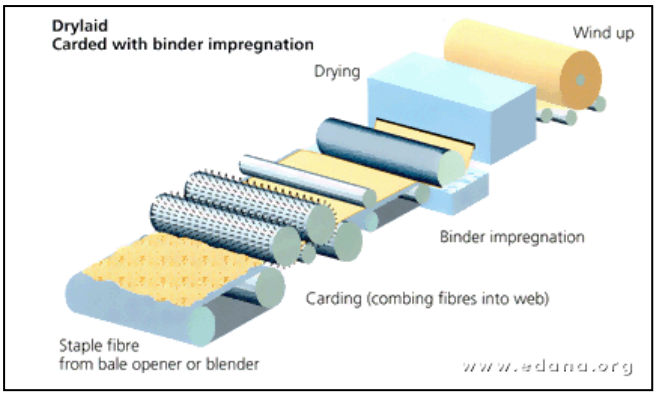


Fig 2.18: Dry-laid, carded with binder impregnation.[39]

The properties of a carded web are:

- bulkiness, resilience and softness.
- high basis weight is feasible (up to 1000 g/m^2).
- fiber orientation from highly parallel to nearly isotropic is feasible.
- it allows for blends of various fibers and layer gradients (different fibers, orientation, density).
- parallel-laid carded webs result in good tensile strength, low elongation and low tear strength in the machine direction.
- final webs produced by laying down webs in a crosswise direction to the machine, result in isotropic strength values.

2.4.1.3.1.2 Air-laying

In the **air-laying process,** the fibers, which can be very short (0.003- 0.012 m), are fed into a rapidly rotating roller which, through centrifugal force, throws the fiber mat off into an airstream. Here, the fibers become randomised and deposited on to a forming conveyor. Air-laid webs offer great versatility in terms of fibers and fiber blends that can be used. Major applications are absorbent cores for feminine hygiene and industrial wipes.

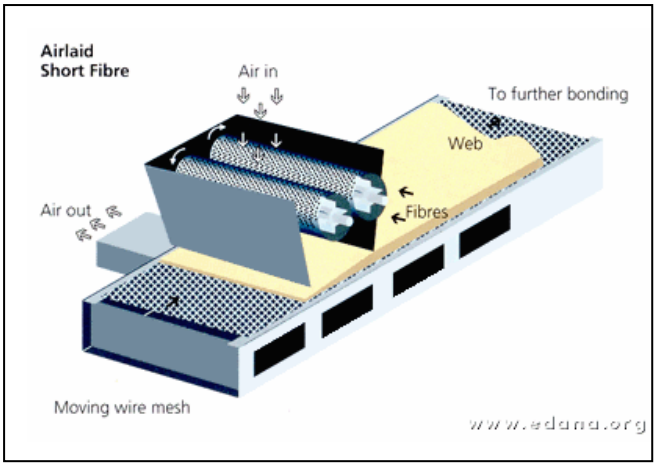


Fig 2.19: Air-laid process to produce short fibers[39]

Properties of air-laid webs:

- softness
- bulk (= low density)
- high absorbency
- relatively low strength
- no laminar structure
- minimum basis weight ca. 50g/m^2

2.4.1.3.2 Wet-laid

For wet-laid nonwovens almost all kinds of fibers can be handled, as far as they are dispersible in water. The fibers are suspended in water and the dispersion of fibers (dilution 0.01-0.05%) is pumped by a machine. After that, the water is removed, leaving the network of fibers behind. These are dried by being pressed between rollers. Impregnation with binders is often included at a later stage of the process. Wet-laid web-forming allows a wide range of fiber orientations ranging from near random to near parallel. Major applications are wet wipes and filtration

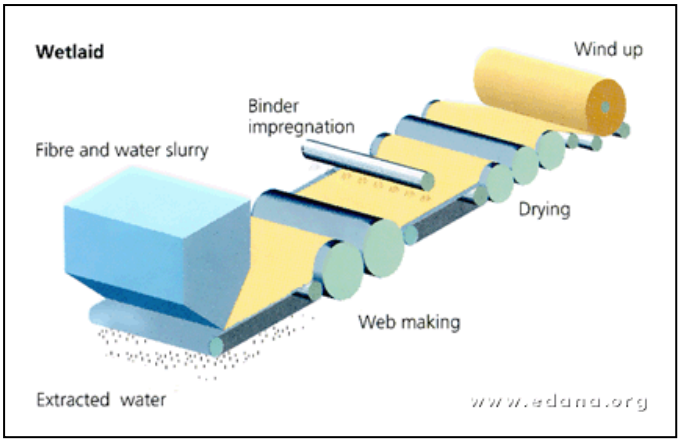


Fig 2.20: Schema of the wet-laid process for web formation[39]

Properties of the wet-laid process:

- high productivity
- rather thin, stiff and dense webs
- yields webs of low but isotropic strength (random web)
- good web uniformity
- highly versatile through choice of fibers, lay down and bonding

2.4.1.3.3 Directly-spun Nonwovens

All natural fibers such as cotton, wood, jute, hemp and flax do not melt but char when heated to high temperatures and, therefore, must be processed by either dry-laid or wet-laid systems. Synthetic polymers which have clearly defined melting points and melt-flow characteristics are typically used to make a wide range of fibers and yarns for textile applications. However, such meltable polymers can also be used to make nonwoven directly from the melt without necessarily first spinning standard textile grade fibers. **Spun-laid** and **melt-blown** are the two main technologies.

2.4.1.3.3.1 Spun-laid

In this process, polymer granules are melted and the molten polymer is extruded through spinnerets. The continuous filaments are cooled and deposited on to a conveyor to form a uniform web. Co-extrusion of other components is used in several spun-laid processes, usually to provide extra properties or bonding capabilities. To improve uniformity, multiple beams are used, whereby one beam will deposit filaments on top of the preceding beam, and so on.

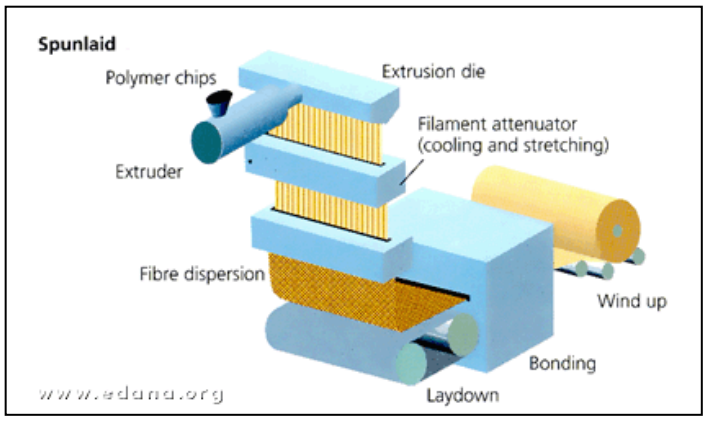


Fig 2.21: Schema of the spun-laid process of web formation[39]

Properties of spun-bonded fabrics:

- low cost
- rather flat structure
- greater tensile strength in cross machine direction at lower basis weight and fuzz resistance.
- constant fiber diameter

A considerable increase in interest is being shown in bicomponent spun-laid webs. With the possibility of producing fine denier bicomponent fibers spun-laid offers the opportunity of producing a low grammage, maintained strength, ultra soft web at acceptable costs.

2.4.1.3.3.2 Melt-blown

Melt-blown fibers/filaments have very small diameters. It is the only technique that produces plastic fibers below five microns. As a comparison, the diameter of human hair is 60 microns. In melt-blown, a high velocity gas stream (480-800 km/h) impinges on a molten polymer stream as the polymer extrudes from a small capillary in the melt-blowing die. The high-velocity air stretches and fractures the film into fibrils, which themselves may be micro-fibrillated along the length of their surfaces. This results in six times more surface area and thirty-six times more fibers in a melt-blown web of one to three microns, than in an equivalent fiber weight of a typical carded or spun-laid web.

Properties of a melt-blown fabric:

- composed of very fine fibers (good area coverage, small pore sizes).
- acts as water barrier in combination with polyolefins.
- fibers are non-oriented and weak (no intrinsic strength, prone to fuzz and tearing).

2.4.1.3.3.3 Other Techniques

This includes a group of specialized technologies in which the fiber production, the web structure and the bonding usually occur at the same time and in the same place. For diapers, processes are often used in which two or more web-forming techniques are used in tandem. The spun-laid/melt-blown process is an example, where one or more melt-blown webs and spun-laid webs are combined.

2.4.1.4 Web Bonding

After the web-forming stage, fibers are just rather loosely arranged and not bonded together. The web must therefore be bonded in some way. The choice of method is very important for the ultimate functional properties of the web, because it can impact on the softness, loft, hand feel or other desired properties of the web.
Bonding systems can be categorized as:

- **chemical bonding**
- **thermal bonding**
- **mechanical bonding**

2.4.1.4.1 Chemical Bonding

Chemical bonding is the most frequently used bonding method in the nonwovens industry. A binder not only holds fibers together but also affects the final properties of the nonwoven fabric, including its strength, stiffness, softness, waterproofness, breathability and flammability[33]. The most important binders are latexes of emulsion polymers. These fine dispersions of specific polymers in water are applied in a number of different ways to nonwoven webs. Their viscosity is close to water and hence they can penetrate thick nonwoven structures by immersion. After the application of the binder, for example by saturation bonding, the nonwoven is dried and the water evaporates. Typically, the binder

[33] **Chapman, R.A.:** Handbook of Nonwovens,2006, p.330-348

forms an adhesive film across or between the fiber intersections and fiber bonding is obtained. For already-formed fibrous webs from carding, short fiber airlaid or others, there exist different techniques to apply the latex binder on/into the web, such as gravure printing, spray, foam or saturation bonding. Saturation bonding is widely used for diapers ("Acquisition Layer"). During the water evaporation process, the latex binder forms a film via different stages. The continuous film over the fibres is formed by reaching the minimum film forming temperature of the emulsion polymer. This temperature is usually several degrees above the glass transition temperature. When the water evaporates the particles move closer together and become less mobile until they touch each other. They can be imagined as an agglomeration of spherical particles packed closely together in layers. As water evaporates from the surface of the agglomerated spheres, it is replaced by water from lower layers. The capillary forces squeeze the water out and further compress particles together to micelles. The binder micelles form a dense, closed packaging, followed by a packaging of deformed particles. The outer region of these micelles is the hydrated hydrophilic groups with bound water.

It results in a more or less homogeneous film (physical and chemical entanglement; not completely discovered until now). The functional groups and additives influence the film forming (crosslinkable versus non crosslinkable, hydrophilized versus non hydrophilized and emulsifier). The "feel" of the fabric is mainly determined by the glass transition temperature; the lower the temperature, the softer and the less strong the fabric is; the higher the temperature, the stiffer and the more strong the fabric is.

Web strength is driven by the morphology of "film sails" and depends on:

- web density
- binder amount
- chemical and physical properties of the binder
- application method parameters
- dryer method parameters

The binder content contributes to the overall web strength until the sweet spot is reached. However, as more binder is added, the web becomes hard, stiff and brittle. The hydrophilicity of the finished nonwoven is strongly influenced by the particular binder.

The properties of chemical bonding:

- high durability and elasticity
- high bulk and resilience (= recovers after compression)
- binder can add further functionality (e.g. permanent hydrophilicity)
- it is a low speed-, complex- and energy-intense process

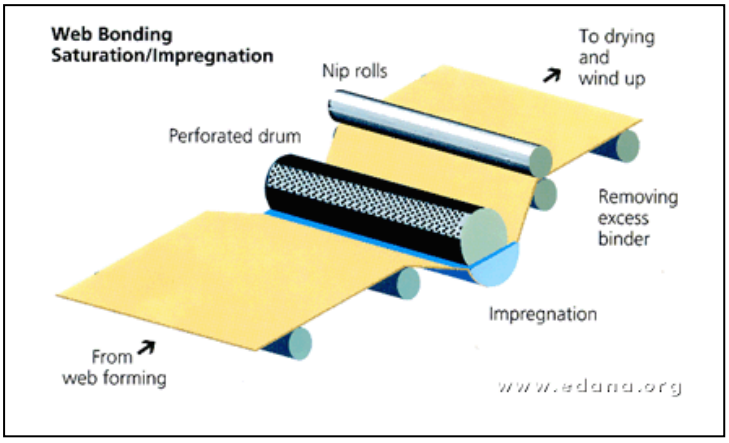


Fig 2.22: Web bonding by saturation/impregnation[39]

2.4.1.4.1.1 Latex Binders- Emulsion Polymerization

An emulsion polymer is a colloidal dispersion of discrete polymer particles with a typical particle diameter of 0.01-1.0 microns in water, for example. Common polymers are acrylates, styrene-butadiene copolymers, acrylonitrile-butadiene copolymers and ethylene vinyl acetate. A latex polymer is made of the binder component, surfactant, initiator, chain transfer agent and buffer.

Surfactants are molecules that consist of a water-carrying portion (hydrophilic) and water-repelling portion (hydrophobic). Two primary types of surfactants exist - ionic and non-ionic. The hydrophilic portion of ionic surfactants consists of cationic or anionic surfactants. The hydrophobic portions of ionic surfactants consist of long chain hydrocarbon residues.

Non-ionic surfactants can also be divided into two groups:

1.) Zwitterionic surfactants where the surface-active portion contains positive and negative charges which cancel each other out.

2.) Non-ionic surfactants, where the surface-active portion bears no apparent charge.

When a surfactant is introduced into water it will align in such a manner as to minimize the surface free energy. The hydrophilic portion is directed toward the bulk phase and the

hydrophobic portion is directed away. As the surfactant concentration is increased the liquid/air interface becomes saturated and increased amounts enter into the aqueous bulk phase in surfactant aggregates, the micelles.

The process of latex formation is realized by distributed monomer droplets in water, which are stabilized by emulsifiers or surfactants. These emulsifiers or surfactants accumulate at the interface to the water phase. The emulsifier has hydrophilic and hydrophobic parts. If their concentration reaches a critical value they form a micelle. This is a spheroidal collection of about a hundred emulsifier molecules with their hydrophobic parts pointing inwards to accommodate other hydrophobic substances such as monomer molecules. The initiator, which forms water-soluble free radicals, reacts with several monomer droplets that are dissolved in water. This yields a short polymer chain which is called oligomer radical and which is no longer soluble in water. It precipitates and is stabilised by the emulsifier, which accumulates at the newly-formed interface. This is now a latex particle. Additionally, emulsifier micelles, containing monomer molecules, need to be considered. If the oligomer radical meets an emulsifier micelle, which contains monomers, the monomers polymerise and form another latex particle. This occurs only above the "critical micelle concentration" (= high concentration of emulsifiers). When the formation of latex particles is completed, they start to grow. Through the flow of monomers in the water and the flow of monomer droplets to the latex particles, the latex particles grow by polymerization and build closely-packed round molecules.

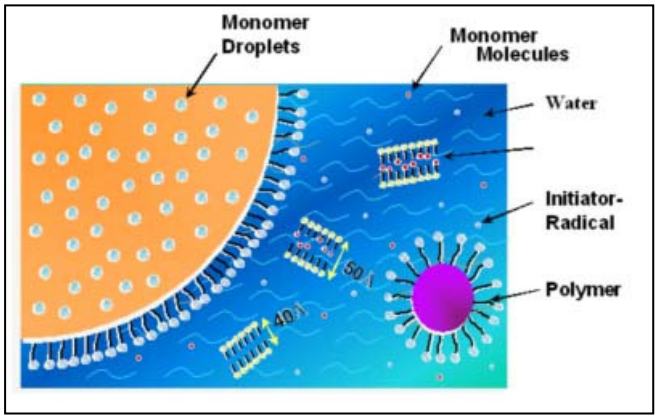


Fig 2.23: Emulsion Polymerisation[34]

[34] **Kamath, M.G. et al.:** Chemical Bonding.2004.

2.4.1.4.1.2 Solvent Bonding

This technique requires the partial dissolution of the surfaces of the filaments/fibers creating an adhesive from the fibers themselves. Removal from the solvent causes the reconsolidation of the surface layer and bonding at the fiber crossover points. (e.g. hydrochloric gas to dissolve for nylon fiber webs). This is, however, seldomly applied in hygiene applications.

2.4.1.4.1.3 Hydrogen Bonding

In wet-laid nonwovens where the fibrous material make-up includes wood pulp or cotton as a source of cellulose fibers, the cellulose fiber component is induced to split into fibrils. These fibrils are very fine fibers and expose many hydroxyl groups to the surrounding water. The water is bonded by the hydroxyl groups of the fibres. When the water is removed, the cellulose fibrils collapse and form a web-like structure over and around the other fibers. The effect is the reason for the strength of the wet web.

2.4.1.4.2 Thermal bonding

In contradiction to chemical bonding, thermal bonding does not insert special chemicals, but creates a bond using melted polymer fiber parts. This technique involves the incorporation of a heat sensitive material into the nonwoven web, usually at the web-forming stage. Heated rolls or air are used to bring the web to a temperature at or near the melting point of this material. The possible bonding materials are fusible fibers alone, fiber blends or bonding powders. Where only fibers are used, “PP” and “PET” are the most common. “PP” has the advantage of having a fairly open process window with a low point of fusion (125°C).“PET” is used when web resiliency is required. In thermal bonding, bicomponent fibers are also used in a wide variety of forms. The form influences the binding properties in a strong way. The last group of materials are powder-bonded materials. Usually they are a dry-laid, carded, staple fiber precursor web to which a powdered heat-melt adhesive is added. The advantage of this is that the thickness will increase four to six times the original.

2.4.1.4.2.1 Calender Bonding

In calendar point bonding fibers are locally melted, driven by heat and pressure to form film-like reinforcing structures. The advantages of this technique are high line speeds and low energy consumption. The key application areas are carded and spun-laid webs. The

advantage of calender bonding is that the non-bonded fibers provide the fabric with better softness, drape and moisture absorbency than overall-bonded fabrics. Through the smart selection of properly-raised surface patterns, strength and flexibility in the fabric can be optimized.

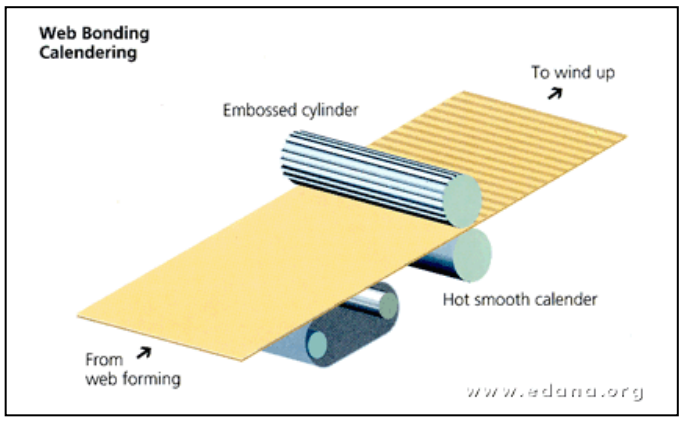


Fig 2.24: Process of web bonding by calendering[39]

The web strength is driven by calendar parameters such as bond area (10-16 percent for spun-bonded and 20 percent for carded) and bond pattern. Historically, the bond pattern was diamonds. More and more, this is replaced with ellipses, resulting in smoother webs with better strength. In addition, the point arrangement, (hexagonal or rectangular) plays a role as well as the calendar pressure, temperature and diameter. The final fiber properties play a huge role in the chemical and mechanical parameters such as softening, melting point, fiber titer, -toughness and -length. Last but not least the web parameters, such as basis weight, homogeneity, orientation and speed are also important.

Properties of a calendar bonded web:

- high web strength
- low thickness (flat web structure)
- limited to low basis weights

2.4.1.4.2.2 Through-air Systems

Two types of through-air systems are available, the flat-bed conveyor type and the rotary cylinder type. Through-air binding requires the use of bicomponent fibers (high melt core, low melting sheath). The web is heated above the softening point of the fiber sheath and the softened sheaths stick together as crosspoints. (Melting point “PE”: 126-135°C, “PP” 140-170°C, “PET” 230-260 °C). A disadvantage is that bicomponent fibers are more expensive. Approximately 20 percent of the total basis weight must be derived by bicomponent fibers, which are 150-200 percent more expensive than staple fibers.

Properties of through-air bonding

- low complexity, mid energy process.
- uniform bonding up to very high basis weights
- higher tensile strength than calendar bonded
- high softness
- high loft
- lower resilience compared to resin bonding

2.4.1.4.2.3 Ultrasonics

This technology enables the bonding of two or more plies of materials which have a common melting point by the use of high frequency vibrations. The principle is to apply mechanical vibratory energy (sound waves at frequencies above 18,000Hz), which creates intermolecular mechanical stress within the material. Thermal energy is released as a result of this, causing softening to occur at points of limited contact. Ultrasonics melt the material from the inside out and as a result bonding takes place only at the point of contact between the horn and the drum pattern. This provides high loft, soft, breathable and/or high absorption nonwovens.

2.4.1.4.3 Mechanical Bonding

In mechanical bonding (friction bonding), the strengthening of the web is achieved by inter-fiber friction as a result of the physical entanglement of the fibers.

2.4.1.4.3.1 Needlepunch

Needlepunched fabrics start with carded, airlaid or spun webs. In this old technique barbed needles are punched vertically through the web, hooking tufts of the fibers across it and thereby reorientating fibers and leading to entanglement in z-direction. Friction from the densified fibers in the needling holes gives the bonding strength. Needlepunched fabrics are characteristically bulky with weights from 50-200 g/m^2. Also, webs of different characteristics can be needled together to produce a gradation of properties difficult to achieve by other means.

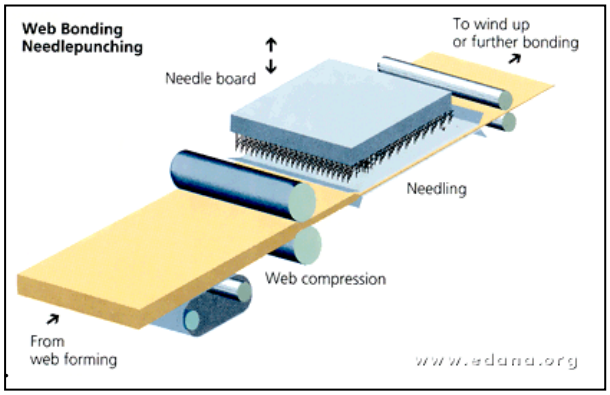


Fig 2.25: Process of mechanical web bonding by needle punching[39]

The web properties of needlepunched webs are driven by:

- web density and basis weight
- needle density and orientation
- needle parameter (shape and number of barbs, thickness)
- needling parameter (needling depth, needling density, line tension)

2.4.1.4.3.2 Hydroentanglement

Hydroentanglement (spunlacing) is a mechanical bonding process where the fibers or filaments are entangled together by means of high-pressure water jets instead of steel needles, as in needlepunch. By impacting the nonwoven web with such jets, fibers are rearranged within all three directions of the structure and significant bonding, without the

use of added binders, can be achieved. Hydroentanglement is mainly applied to carded or wetlaid webs. The process is most efficient for webs in the basis weight range 30-150g/m^2, for example, in Baby Wipes.

Web properties are driven by:

- web density and basis weight
- pressure and angle of water jets
- nozzle shape
- Structure of screen (smooth web, structured web, hydroapertured web)

Properties of the hydroentangled web:

- soft and dapeable, abrasion resistant
- high cross direction elongation, high machine direction strength
- high basis weight flexibility (15-600g/m^{-2})

2.4.1.5 Web conversion, treatment and finishing technologies

There is an opportunity to meet the desired characteristics even more precisely by modifying or adding treatments to fiber properties. Fiber finishes are applied to virtually all manufactured fiber during production, in a countless variety of processes and formulations. They contribute to quality, consistency and efficiency, and can add performance characteristics in response to individual preferences in the industry's widely diverse customer base. These finishes are an increasingly small component of the total weight of any fiber, but they can be essential elements in product differentiation and competition in the sector.

Their composition is frequently a proprietary asset of the finish product[35]. Finishing treatments can be classified as:

[35] **Barker, R.:** Comments Submitted By The American Fiber Manufacturers Association On The Reach Proposal. European Comission.

- mechanical finishing process, which includes calendaring, brushing, embossing, laminating, creping and crushing[36]
- chemical finishing process, including bleaching, coating, dyeing, printing, surfacing, sizing, antimicrobial treatment, and flame-retardant finish. A variety of different chemical substances can be employed before or after binding, or various mechanical processes can be applied to the nonwoven after binding. By using those, nonwovens can be made conductive, flame-retardant, water-repellent, porous, antistatic, breathable, absorbent, etc. The current work has been focused on rendering the fibers antimicrobial[37] mainly by chemically-reacting different antimicrobial agents onto the fibers.
- converting operations, because nonwoven roll goods are seldom in the form required by the customer when they are produced at the end of the manufacturing unit. Converting includes slitting, rewinding, sheet cutting, die stamping, lotion application, etc.

36 Turbak, A. F.: Nonwovens: Theory, Process, Performance, and Testing, 1993

37 Ramachandran, T. et al: Antimicrobial Textiles – an Overview, 2004, 84.

2.4.2 Absorbent Gelling Material

2.4.2.1 Introduction and Definition

Commercial superabsorbent polymers "Absorbent Gelling Material" ("AGM") are partially neutralized polymers of acrylic acid that have been lightly crosslinked. These crosslinked polymer networks are hydrophilic, are insoluble in aqueous media and can absorb and retain extremely large amounts of water relative to their own mass[38]. Today, the largest share of superabsorbent polymers is used in disposable baby diapers[39], this is largely due to its cost effectiveness compared to regular fluff pulp (in diapers, "AGM" is the main component that absorbs and stores the liquid permanently). These properties have been utilized for many different application areas. Apart from hygiene products, they are also used for wire and cable water blocking, fire protection and filtration applications. 4,450,000 tons of acrylic acid are produced each year. 41 percent are for coatings, adhesives and the nonwovens industry and 29 percent go into superabsorbers (1,500,000 tons).

2.4.2.2 Basic Principle of AGM Absorption

The mechanism of swelling ionized, crosslinked polymer networks is based upon the concept of osmotic pressure. The polymer contains carboxylic acid groups, which are partially neutralized by sodium hydroxide and which dissociate in water. The polymer chain itself is negatively-charged leading to electrostatic repulsion that is "pushing" the chains apart and therefore increases swelling. The positively-charged sodium ions can freely diffuse within the swollen network. This leads to an electrostatic shielding outside of the AGM particle, which becomes the driving force behind the swelling. Positively-charged ions are also contained in the liquid that is being absorbed. These ions lead to more electrostatic shielding and therefore decrease the swelling of the "AGM". The ionic strength of the liquid (how many dissolved ions are present) is therefore important.

[38] **Horie,K. & Braun, M.:** Definitions of Terms Relating to Reactions of Polymers and to Functional Polymeric Materials, 2003, p.889.

[39] **Buchholz, F.L., Graham, A. T.:** Modern Superabsorbent Polymer Technology,1997,p. 69.

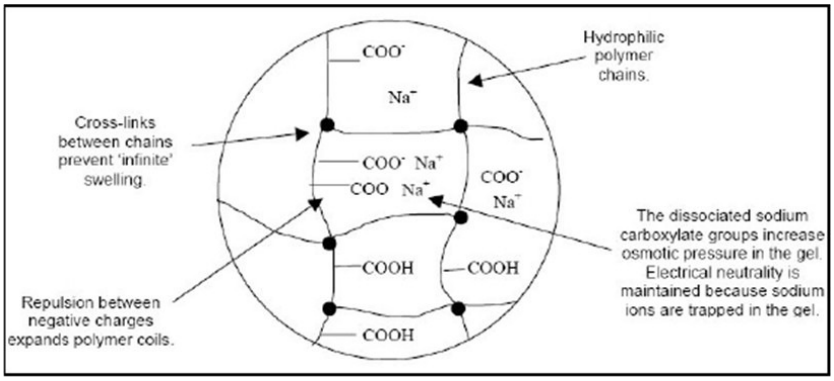


Fig 2.26: Illustration of part of the polymer network

2.4.2.3 Synthesis of Polyacrylate

For superabsorbent polymer manufacturing two main routes exist; the solution polymerization and the suspension polymerization.

2.4.2.3.1 Solution Polymerization

Liquid-state reactions are the most easily manageable at any scale and therefore the most often used. The process includes the monomer mix, prepared from acrylic acid, water, a crosslinking monomer, and in many cases a base. Oxygen is removed from the liquid using nitrogen, and a free radical initiator, e.g. persulfate or redox couples (such as ascorbic acid and hydrogen peroxide) causes the monomer mix to polymerize under heat evolution. The choice of crosslinker, through the crosslinker reactivity ratio, in combination with other polymerization parameters will affect the amount of soluble polymer produced. Afterwards the gel is cut, dried, grinded and sieved to achieve the final product particle size distribution. Fine particles are unacceptable in the commercial diaper products due to safety concerns (respiration of fine particles) and gel blocking. The outer surface of a tightly-packed mass of particles swells too quickly, which prevents the penetration of the liquid into the interior particles, whether by diffusion or by capillary action. The remaining particles are then post-treated. More recently, superabsorbent products, with an improved combination of swelling capacity and absorption under compressive loads, have been realized using such structured particle technology.

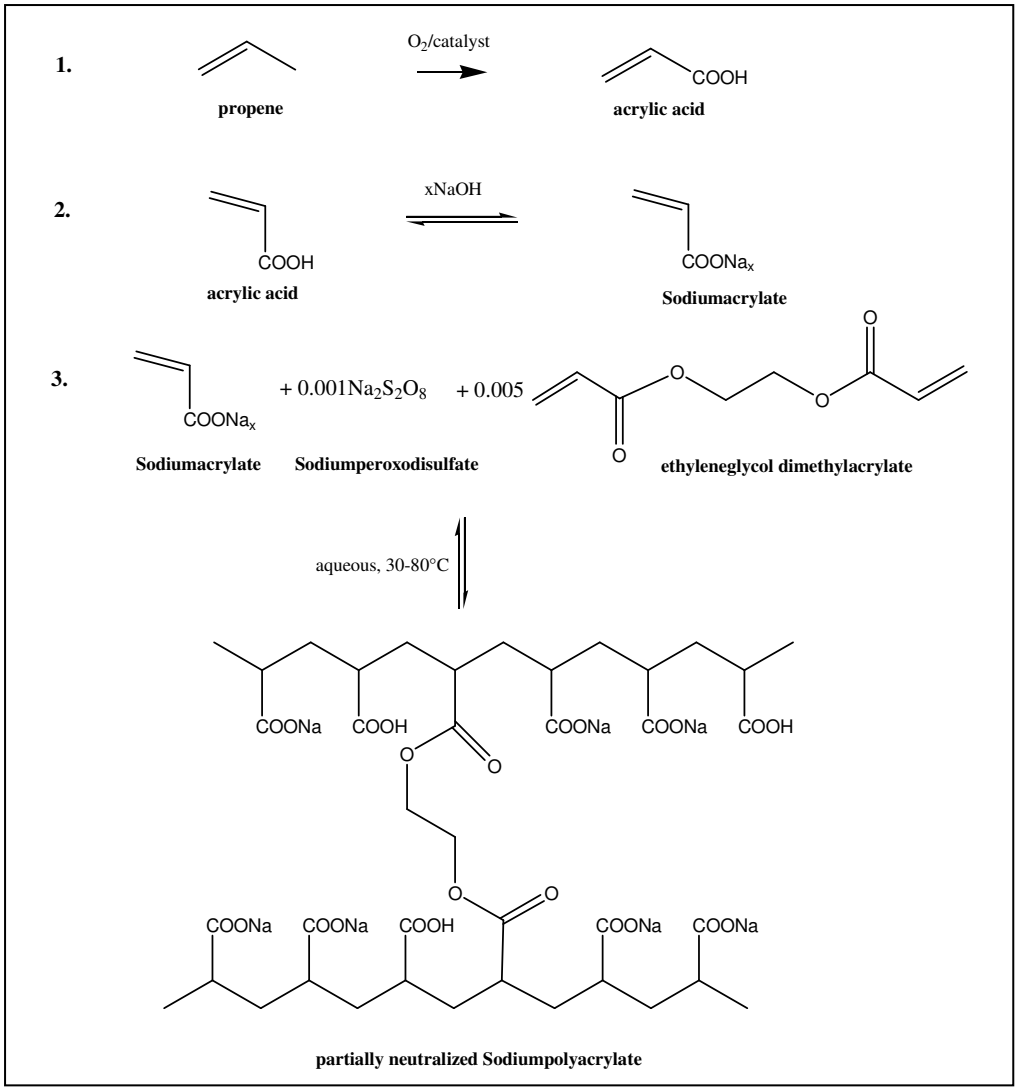


Fig 2.27: Free-radical polymerization of acrylic acid

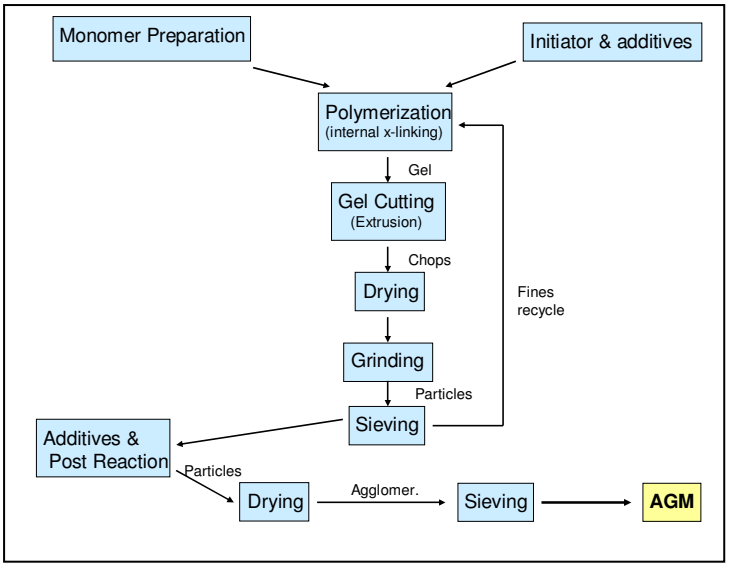


Fig 2.28: Flow diagram of a generic solution polymerization process[44]

2.4.2.3.2 Suspension Technology

Another method to the partially-neutralized sodium polyacrylate is suspension technology. The primary requirement of a suspension aid is to stabilize the droplets against coalescence before, during and after polymerization. Suspending agents impact on particle size through their interfacial tension with the disperse phase and through the coverage of the surface of the dispersed-phase particles. There are several ways to obtain large particle size or higher molecular weight - polymeric suspension aids may be used, including, amongst others, ethylene-co-maleic anhydride[40], cellulose esters such as acetates, propionates and butyrates. "AGM"s can be prepared in a variety of particle shapes by the suspension technique. Typically suspension polymerizations yield spherical particles, because this shape yields the minimum single-particle surface energy. Non-spherical shapes are preferred in terms of diaper application, because round particles roll around in the diaper and can be therefore located in the wrong area, when a gush occurs, which causes leakage. Additionally, the minimal surface area leads to a slow absorption rate when compared to particles of the same sieve cut prepared by grinding the product from a bulk polymerization. The surface area is, for example, increased by creating porosity in the particle. One way of doing this is via vapour bubbles during the gelation process. The bubbles leave behind pores in the product and this leads to higher absorption rates.[41]

2.4.2.3.3 Samples of Commonly-Used Vinyl Core-Crosslinker

Crosslinkers play a key role for the performance of the finished polymer. They influence, based on their chain length and functionality, the capacity behaviour of the "AGM". The crosslinkers contain at least two double bonds per molecule. When they are incorporated into the growing radical chain, they can chemically link two polymer chains and thereby build the network of an "AGM" particle.

[40] **M. Nakamura et al :** US Patent 5, 1993,180,798.

[41] **Buchholz, F.L. & Graham, A. T.:** Modern Superabsorbent Polymer Technology,1997,p. 109.

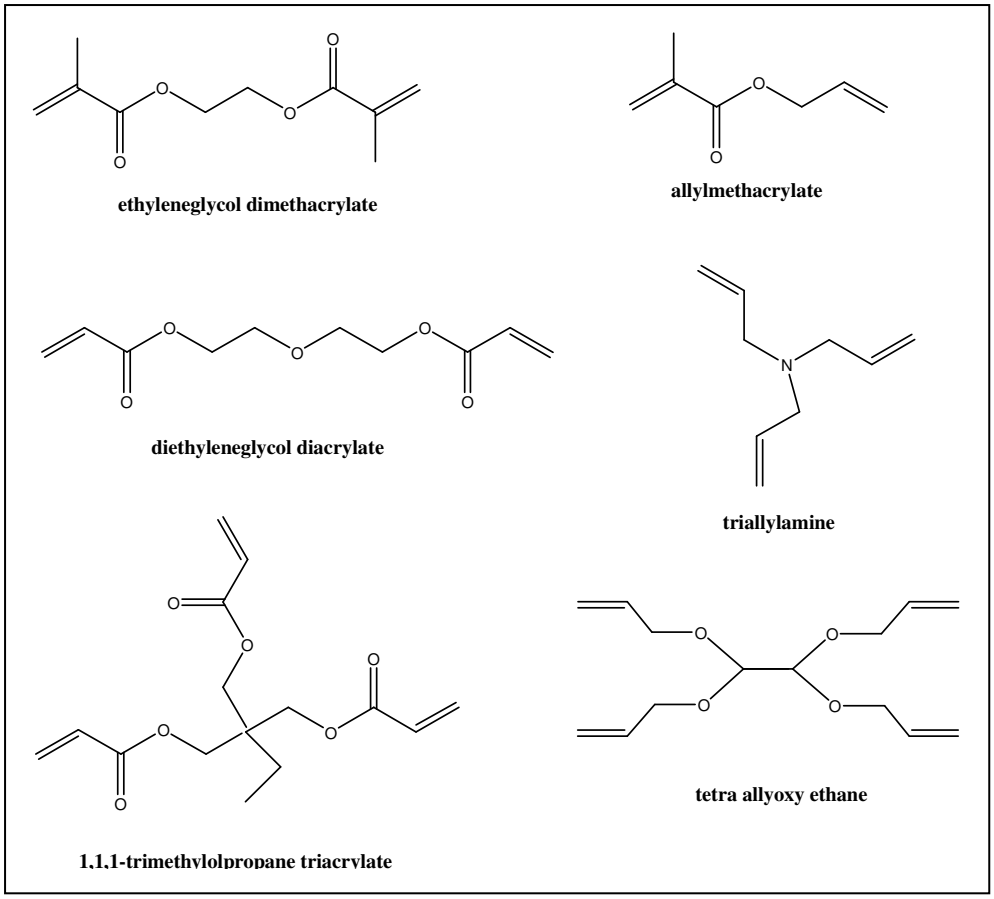


Fig 2.29: AGM most common used crosslinkers

2.4.2.3.4 Post Polymerization

To strengthen the superabsorbent polymer properties, post-polymerization crosslinking is often undertaken. For surface crosslinking[42], a reagent is used, which is capable of reacting at least difunctionally. It is first mixed with preformed polymer chains, and then a coupling reaction between the agent and functional groups on the polymer chains is triggered. Quaternary amines are used[43], but ester crosslinks are the most common reagents to form surface crosslink density. These surface crosslinking agents include polyhydric alcohols, glycidil compounds and alkene carbonates. Inorganic particles, such as silicates, are used in addition to controlling the hydrophilic/hydrophobic balance of the treatment reagent. They are used in combination with high-speed blending of the reagents, to control agglomeration during the reagent addition process. Two different types of post-polymerization crosslinking agents are used: ionic and covalent.

[42] **Tsubakimoto,T & Shimomura,Y. Irie:** U.S. Patent 4, 1987, 666,983

[43] **K. Nagasuna et al.:** Eur. Patent Appl.,1994, 605,150

2.4.2.3.4.1 Ionic Crosslinking

Multivalent cations (positive charges ions) can associate with more than one carboxyl group on polycarboxylated chains, forming at least a transient crosslink. The divalent cation in the external liquid diffuses throughout the gel and causes over crosslinking. To diffuse, the cation dissociates from at least one site at a time and moves through the bulk of the gel. Trivalent or higher cations such as aluminium(III) (Al^{3+}) can serve as useful crosslinkers, due to the fact that the diffusion through a gel is slower since at least two association sites must release to allow enough chain relaxation for the ion to move to a new location. Use of metallic ions as post-polymerization crosslinkers requires contacting all portions of the gel mass uniformly, which is difficult as aluminium(III) diffuses slowly through the polyelectrolyte network. Complexion agents can be used to delay association with the network relative to diffusion. Therefore, it is a good way to incorporate aluminium triacrylate in situ and incorporating it as a copolymerized crosslinker. Polyquarternary ammonium salts are also used as crosslinkers. To be an effective crosslinker, a species must contain at least two charged sites.

2.4.2.3.4.2 Organic Reaction with Carboxylic Acids

Esterification of the numeros pendent carboxyl groups on typical superabsorbents is another common strategy for post-polymerization crosslinking. In addition to ester linkage, amide groups are formed from the reaction of polyamines with the carboxylic acid groups. Several patents disclose the use of diglycidil ether (EDGE) to effect surface crosslinking. As a typical approach, a mixture of EDGE and a solvent is added to the surface of dried and sized gel particles. As with other systems, the depth of penetration, and thereby the crosslinking density of the surface, can be controlled to some extent by the water concentration in the coating.

2.4.2.4 Performance Properties of AGM[44]

The properties of a final AGM are determined by different physical measurements, such as free swell rate, saline flow conductivity and capacity of the polymer particles. The important physical properties of an AGM are gel permeability, particle shape, crosslinking and surface crosslinking. These properties depend on the chemical components and the manufacturing process of the AGM.

2.4.2.4.1 Physical Forces Responsible for the AGM Performance

Within an AGM particle driving and retractive forces exist. The driving forces are caused by the desire of the polymer to dilute or dissolve, so-called polymer/solvent interactions (Pmix) and the electrostatic pressure caused by the osmotic pressure of the counterion (Posm). The retractive forces contain the network elasticity, springs formed by crosslinking and the external pressure from the baby on the diaper. In the equilibrium, the driving forces are equal to the retractive forces

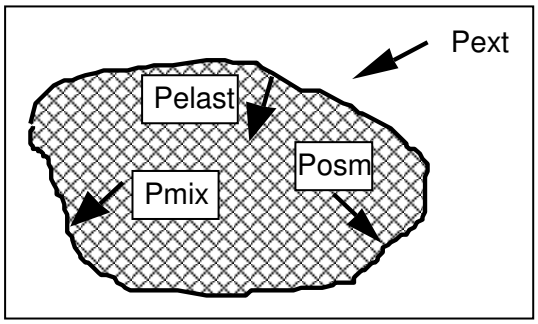


Fig 2.30: AGM effecting forces

2.4.2.4.2 Important Physical Parameters of the AGM Performance

The overall performance of AGM is driven by the **gel permeability**, which is related to particle size distribution, particle shape and **compressibility or modulus of the swollen gel.** In general, the absorbency under load **increases as the modulus of the swollen gel increases**, which again is related to the crosslink density which keeps the particles in shape during the swelling process. The connectedness of open pores (porosity) in the gel mass allows the free liquids to flow. If the shape of the particle initially is spherical, the shape becomes disc like under compression and the swelling rate must decrease because of the longer diffusion path in the flattened particle.

The **swelling rate** discloses how fast liquid is absorbed by the superabsorbent polymer. The principal factors for swelling kinetics are the size of the polymer particle, its morphology (e.g. monolithic, porous, smooth or rough surface) and its shape (e.g. spherical, irregular granular or flakes). With larger particle sizes or smoother surfaces, the time required to reach equilibrium increases.

Another important factor in terms of superabsorbent polymer properties, is the **molecular weight** and **molecular weight distribution** of the backbone polymer. These affect the quality and performance of the polymer. Low-molecular weight chains have a lower

probability to be incorporated into the network and therefore they are the soluble or extractable fraction. As a result of the presence of the soluble polymer in the gel, the delta of the chemical potential of the water between the gel and the external phase is increased, which is the driving force for swelling. The soluble polymer slows the flow of the liquid through the mass of particles by increasing the viscosity of the external liquid phase. Additionally, the amount of soluble polymer present in the polymer sample affects the rate of swelling because of an increasing driving force for swelling - the swelling rate of non-ionic gels is increased by the presence of soluble polymer in the gel.

The degree of crosslinking affects the final product performance properties in terms of swelling and modulus (strength of the gel). Also, the degree of neutralization affects the swelling behaviour of the end product

The non-homogenously surface crosslinked superabsorbent polymers share the feature that the swelling capacity of the particles decreases with decreasing particle size, whereas homogeneously crosslinked superabsorbent polymers show no particle size dependence on the swelling capacity. The advantages of surface crosslinking is a higher gel strength and by that, a higher SFC, which avoids gel blocking (since water is no longer able to penetrate the gel layer).

Without post-treatment the surface of the massed particles swells rapidly to form a soft, deformable layer. The resulting particle deformation and interparticle adhesion reduces interparticle porosity and limits the swelling rate of the polymer mass to the diffusion rate of liquid through the partially swollen mass. The shell of a higher crosslinked density provides a more rigid surface layer during swelling and thereby prevents gel-blocking.

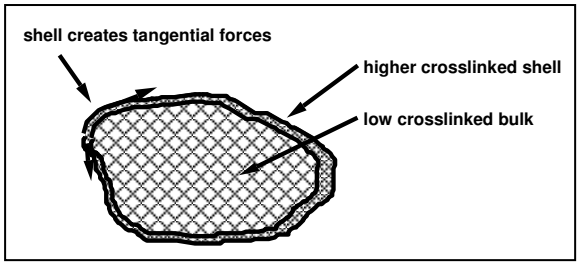


Fig 2.31: AGM particle

2.5 Impact of Raw Material Costs on the Gross Sales of a Product

This chapter states the relation of the impact of raw material costs on the gross sales of a product.

The aim of each manufacturer is to make high profit. The profit is the "net sales" ("net-outside sales") minus costs[44]. The "net- outside sales" are "gross sales" minus "rebates", like returns, discounts and allowances. In other words the profit is defined as the proceeds minus the costs. The proceeds are the price of a product multiplied by the amount of sold products minus the costs.[45] As the price of the product is a result of demand and supply in open markets.[46] the manufacturer can not increase the prices of the products arbitrary, because in competitive markets, as the diaper market, consumers change the brand. Therefore the manufacturer needs to reduce his costs. Costs are the estimated, target related consumption of goods within a certain time period.[47] The costs of the manufacturer to produce the product are composed of fixed and variable costs. The fixed costs are everything which is independent from the activity of the business, within the relevant scale of production or time period. Variable costs change, in principle, in relation to the activity of the business. Variable costs also include the raw material costs as well the intensity modifications of the operating speed of machines[45]

The impact of raw material costs on the cost part of the "gross sales" or better "net-outside sales" are as follows:

Subtracting the "Total Delivered Costs" from the "Net Outside Sales" yields the "Gross Margin". The "Total Delivered Costs" are the costs to convert raw material and packaging material into finished product and distribute it to consumer.[48] Therefore the "Total Material Cost" consists of the "Finished Product Logistic Costs" and the "Product Supply Administration".

The "Total Material Costs" include the cost of "Raw Materials", "Packaging", Manufacturing Charges" and "General Manufacturing Charges". The "Finished Product Logistic Costs" includes "Warehousing", "Freight", "General Logistic Charges" and "Special Local Costs". The last component of the "Total Delivered Costs" is "Product Supply Administration", which consists of "Local Administration" and "International

[44] Thommen, J.-P-,Dr. & Achtleitner A.-K.,Dr., Dr.: Allgemeine Betriebswirtschaftslehre, p.242
[45] Coenenberg,A. G. Dr.: Kostenrechnung und – analyse: 2003, p.262
[46] Dichtl E., Dr. & Issing, O. : ahlens Großes Wirtschaftlexikon;1993, Band 2, p.1678- 1694
[47] Wöhe, G. Dr. Dr.h.c. & Döring, U., Dr: Einführung in die Allgemeine Betriebswirtschaftslehre, 2005; p.342
[48] Zhand, C.: Finance Knowledge, P&G Training: 2006, p.19

Administration and Development". For Western European diaper mainline products, branded as well as Private Labels, approximately 65 percent of the "Total Delivered Costs" are based on the raw material costs. [49]

The "Gross Margin" minus the "Marketing Support Expense" and the "Selling, Research and Administration" results in the "Value Contribution" and by that into the "Profit Before Tax". The "Marketing Support Expense" is based on the "Market Development Expense", which are the indirect sales support activity and the "Brand Support Expense". In the latter, the media production and air-time; special packs; public relations and manipulation costs are included. The "Selling Research and Administration" contributes to "overheads" mainly regarding "headcounts" in the areas of "Customer Business Development", "Product Development" and "Brand, Finance".[50]

Based on the proportion of the raw material costs to the overall costs of the products, huge differences exist between "Private Labels" and branded products. To illustrate the difference examples of a "Private Label" and a branded product in Western Europe are given. In terms of "Private Labels", the "Total Delivered Costs" are 82 percent and all the remaining ones for "Selling, Research and Administration" etc. are 18 percent. In terms of branded products, the "Total Delivered Costs" and the remaining costs are equal, both accounting for 50 percent.

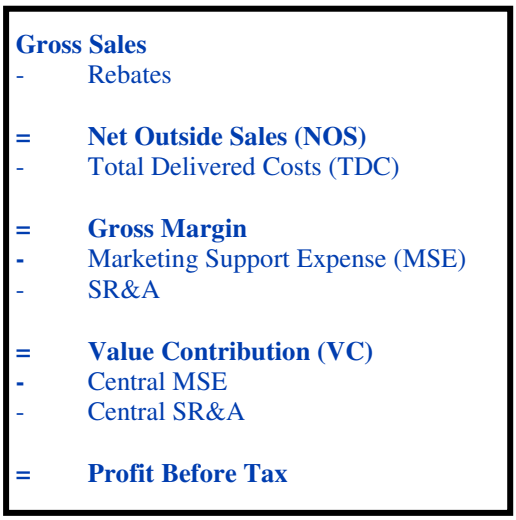


Fig 2.32: Overview how raw material costs fit in Gross Sales[52]

[49] **Vejaux, L.:** Total Delivered Costs, 2006, 2006 1216

[50] Weinmüller, S. et al : Finance for non finance people, P&G Training, 2006

2.6 Statistics

2.6.1 Multiple Linear Regression[51,52, 53, 54, 55]

In social and natural science, multiple regression analyses are widely used to answer the general question "what is influencing…?", because the general purpose of multiple regression is to learn more about the relationship between several independent or predictor variables and a dependent variable.

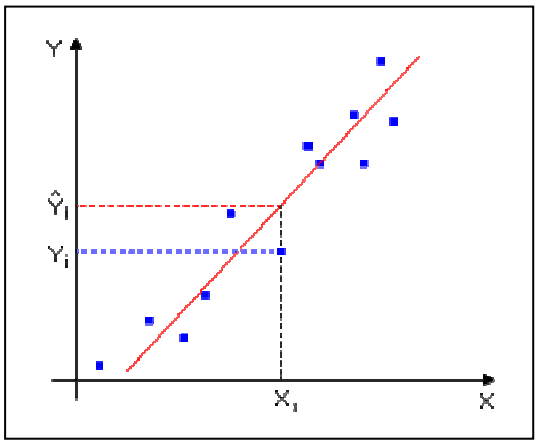


Fig 2.33: Linear Regression[59]

A simple linear equation is $\hat{Y}_i = a + bX_i$., where the difference between $\hat{Y}_i$ and Y_i is called residual ε_I. The residual represents the value that is made by the prediction of Yi based on X_i. The best assimilation of all points X_i can be obtained by the minimization of the sum of all squares of the residual $\varepsilon_{i.} = \sum \varepsilon_i^2$

Multiple linear regression follows the same principles as linear regression with the only difference being that more than one independent variable exists, which are incorporated in the model. An example of this equation for a multiple regression is:

$$y = a_0 + a_1x_1 + a_2x_2 + ... + a_nx_n + \varepsilon_i$$

a_0 is the interception point of the regression line and the y axis, ε_i reflects the failure with the median from zero. The equation itself defines a hyperplane in the n-dimensional space. The $a_{0...}a_n$ need to be adjusted to achieve the least square fit by the sum of the

[51] **Garson, D.:** Partial-Least-Squares-Regression, 2006

[52] **Brünner, A.:** Lineare Regression-Methode der kleinen Fehlerquadrate, 2002

[53] **StatSoft:** Multiple Regression, Statistika, 2006.

[54] **Lohninger,H.:** Grundlagen der Statistik., 2006

[55] **Bamberg, B. & Baur, F**:Regressionsrechnung, Statistik, 2002, p.42-51

single squares. In detail, the "a"s are the regression coefficients, representing the amount the dependent variable "y" changes when the corresponding independent changes one unit. The residual "a_0" is the constant, where the regression line intercepts the "y" axis, representing the amount the dependent y will be when all independent variables are 0. The standardized version of the "a coefficients" are the beta weights. The ratio of the beta coefficients is the ratio of the relative predictive power of the independent variables. Important the beta values reflect only the unique contribution and not the joint contributions, which are reflected in "R^2".

Multiple regression works if the inputs are not correlated. If they are correlated multiple regression is misleading. The reason for this is that, associated with multiple regression is "R^2", the multiple correlation, which is the percent of variance in the dependent variable explained collectively by all of the independent variables. The issue that can occur using beta weights is the underestimation of the importance of a variable which makes strong *joint* contributions to explain the dependent variable, but which does not make a strong *unique* contribution. This inter-correlation of independent variables is called multicollinearity. Therefore, it is particularly important to check the correlation of the independent variable with the dependent variable.

2.6.2 Correlations[56,57, 58, 62]

The most commonly-used correlation coefficient is the "Pearson Product Moment Correlation Coefficient", known as simply "Pearson coefficient". It indicates the strength and direction of a linear relationship (+1/-1) between two variables. It is calculated by the covariance of the two variables divided by the product of their standard deviation.

[56] **Bamberg, B. & Baur, F**:Korrelationsrechnung,2002,p.37-39
[57] **Janssen, J**.: Korrelation und Distanzen, 2003, p. 361-267
[58] **Fahrmeir, L. et al:** Multivariate Deskription und Exploration, 2007, p. 135-140

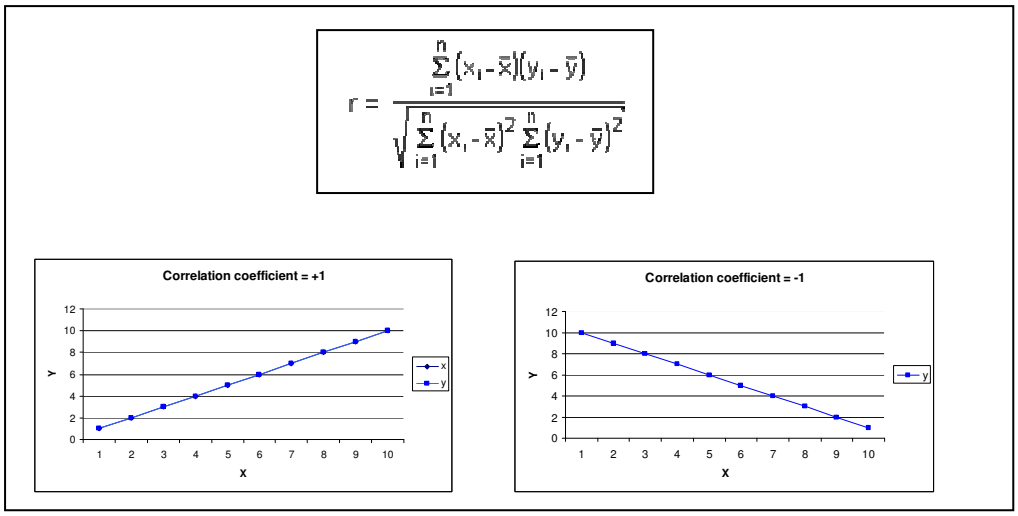


Fig 2.34: Correlation coefficient[59]

The assumptions made for this are: a linear relationship between "x" and "y"; continuous random variables; normal distributed variables and "x" and "y" are independent from each other.

For multiple correlations, the "Pearson's R^2" is the percentage of variance in the dependent variable explained, uniquely or jointly, by the independent variables. A disadvantage can be that the magnitude of "R^2" mirrors not only the unique covariance, but also uncontrolled effects like multicollinearity. In other words, the "R^2" reflects the numbers of errors made when using the regression model to guess the values of the dependent, in ratio to the total errors made when using only the dependent's mean as the basis for estimating all cases. "Adjusted R^2" is an adjustment for the fact that, when having a large number of independents, it is possible that the "R^2" will become artificially high simply because some independents' change variations.[58] By using a few independents, "R^2" and "adjusted R^2" are close, because it is noticeable the more independent variables are in relation to the dependent, the lower the "adjusted R^2" gets.

2.6.3 Partial Least Squares Model[54, 56, 59]

"Partial Least Squares" ("PLS") regression is a technique that generalizes and combines features from principle component analysis and multiple regression. This method is the least restrictive of the various multivariate extensions of the multiple linear regression models and can therefore be used in the case of correlated "X" or correlated "Y". "PLS" allows fewer observation variables than predictor variables to be dealt with.[60] Basically,

[59] **Abdi,H.:** Partial Least Squares (PLS) Regression, 2003

the principal components “X” and “Y” are reduced to lower dimensions via this technique. These dimensions are related and by that a model is achieved.

When “Y” is a vector “X” is fully-ranked, this goal can be achieved using multiple regression. When using a higher number of “X” variables than “Y” variables, “X” is likely to be singular and the regression approach is no longer feasible. Several approaches are developed to cope this issue, in addition to stepwise multiple regression, principal component analysis also exists. The goal of “PLS” is to generate the main components for the matrices of “Y” and “X” separately and to build a regression model based on the score of the main components and not on the original data. First of all, the matrix “X” is split in the Score Matrix “T”, the Loading Matrix “P” and an error matrix "E". The same is accomplished for Y. These two equations are the “outer relationship”. The aim of the PLS is to minimize the error term “F” and to get, at the same time, a correlation of “X” and “Y” by relating “U” and “T”. This relationship is called inner relationship “B= U*T”. An important point in the PLS analysis is the decision about the number of main components. The optimal number is achieved by using the cross validation. The principle of the cross validation is that the model data is split into two alternative quantum, a larger trainings quantum and a smaller test quantum. The larger base size is used to build the model and the smaller one is to validate it. To estimate the performance of the model the “Predictive Error Sum of Squares” (PRESS) is used, because it is the sum of all prediction failures calculated in a cross validation.

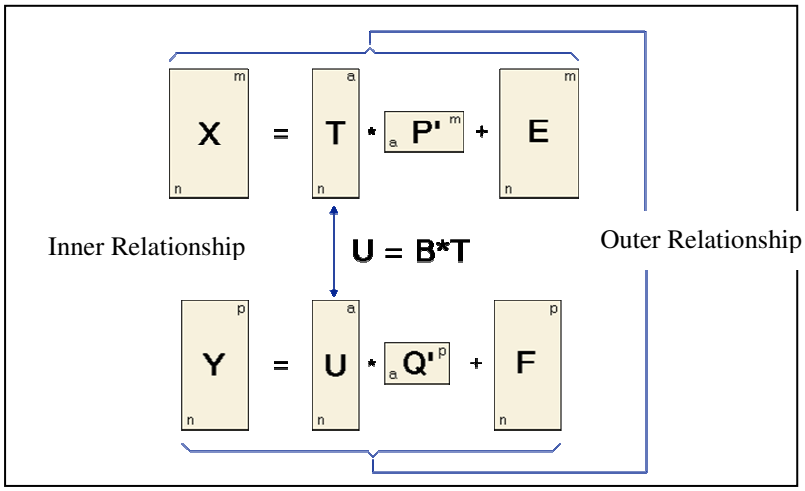


Fig 2.35: Scheme of the” Partial Least Squares” Model

The advantages of “PLS” are: the ability to model multiple dependents as well as multiple independents; the ability to handle multicollinearity among the independents; robustness in the face of data noise and missing data and creating independent latents

directly on the basis of crossproducts involving the response variables, making for stronger predictions. Disadvantages of the method are: the difficulty of interpreting the loadings of the independent latent variables which are based on crossproduct relations with the response variables, not based, as in conventional factor analysis. On correlations among the manifest independents and, because the distributional properties of estimates are not known, no significant except can asset through bootstrap induction. “PLS” is less satisfactory as an explanatory technique because it is low in power to filter out variables of minor causal importance. Overall, “PLS” is a predictive method and not an interpretive one, such as multiple linear regression. As an extension of the multiple regression model, “PLS” shares the assumptions of multiple regression.

3 Practical Part

3.1 BIG 3

The name “BIG 3” derives from the three pillars of this project; consumer, holistic lab measurements and raw material properties. By having an understanding of consumers, the right physical measurements and the right raw material combinations, the market share can be increased.

“BIG 3” is a model which predicts leakage occurrence of competitive products based on the raw material properties of the core. This model helps to build exacter market forecasts; based on the identification of key drivers for leakage in the different competitive core systems, which expose the competitor’s innovation strategies.

This practical part of the PhD thesis presents the general idea and approach of the model-building. Starting with product selection (ranging from low to high performing products), identification of the end-price relevant performance parameters, necessary material properties and required laboratory measurements. This part is followed by an “Expert Panel” analysis and data transformation to make the data usable for this project. Afterwards, a “First Principle Based Model” is developed to reduce the dataset of input variables by applying physical rules. This part is followed by different approaches to realize the model. The final statistical model, a “Partial Least Squares” model, connects raw material performance with the consumer urine leakage experience. Based on this model, a cost versus performance ranking is given on the important “Acquisition and storage core" (“AGM and pulp” layer). Within the performance ranking, the important layers and their physical and chemical performance are explained in more detail. Then, a complete cost versus performance ranking for the products is given. The thesis is rounded off with examples of how the model can be applied to predicting diaper core performance with minimum cost increase or a raw material cost saving in the core. Finally, the impact on urine leakage for competitive products in the case of an “AGM” cost increase is modelled as an example of an application in competitive benchmarking.

3.1.1 BIG 3 Basics

3.1.1.1 General Approach

The basic idea of "BIG 3" is to link the diaper raw material properties to the holistic laboaratory methods of diapers and afterwards to consumers' leakage perception. This step approach is chosen in order to determine influences in the consumers' leakage data, such as bias, baby dimensions, diapering habits and baby influences, which would lead to slightly different results than those created in the laboratory. The raw material properties, as well as the holistic performance measurements, of the diaper are all measured in the laboratory, in contradiction to consumers' leakage perception, which is generated in the "Expert Panel".

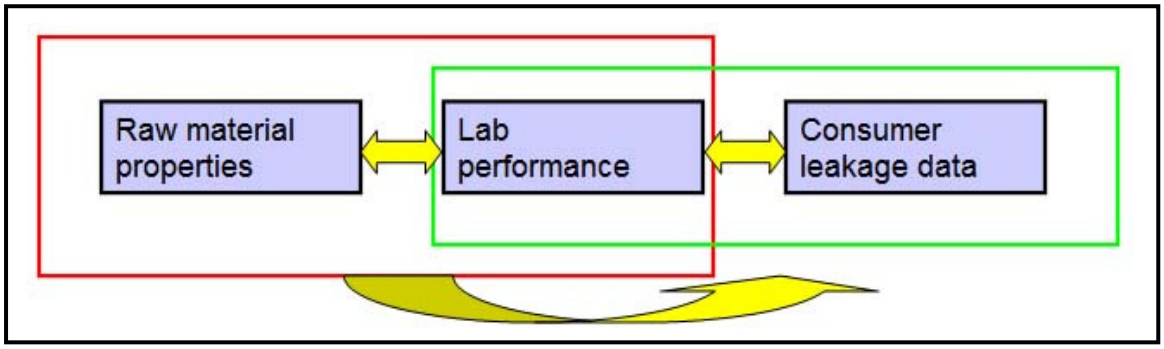


Fig 3.1: BIG 3 general idea

Urine leakage is related to unbonded liquid in the diaper.[60] In this study, the basic assumption is made that leakage is a function of the **time** of liquid absorbency and the **capacity** of the core. The faster the liquid is absorbed, the smaller the probability of leakage occurrence. Additionally, the higher the capacity of a diaper, the better the diaper leakage prevention at higher loads.

The second assumption is that "BIG 3" incorporates only the **diaper core** in the model. Based on an internal study of P&G,[61] the key factors for absorbent capacity and absorbent time are the "AGM and pulp" layer and the "Acquisition System". "Core Cover" and "Topsheet" are of minor importance and are only time-relevant. This "leak-locking"- study itemizes, in addition to the already-mentioned factors, the ""Barrier Leg Cuffs" and "Elastics" and with medium importance the "Fastening System". As mentioned in the introduction (chapter 2.2.), disposable diapers consist of two parts - the chassis and the core. Apart from "BLC", "Elastics" and "Fastening System", all the

[60] **Ehrnsperger, B.:** A first Principles Model to Predict Diaper Leakage, 2005

[61] **Booz et al:** Competitive Cost Analysis, 2003

factors mentioned are related to the diaper core. The study only focuses on core properties. The basic assumption of treating **leakage as a function of capacity and time** is used throughout the whole project. Therefore, this assumption is applied to the holistic measurements of the diaper in the laboratory as well as the diaper raw material measurements.

First, a stable model is built between holistic laboratory measurements and raw material measurements and, in a second step, it is expanded to the consumers' perception of urine leakage. To realize the first part further **simplifications** need to be considered.

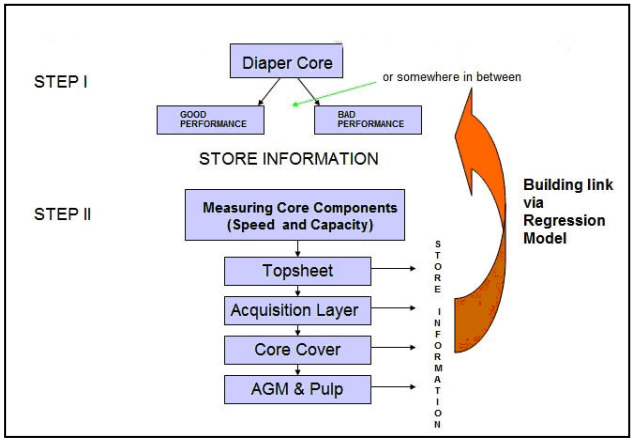


Fig 3.2: Connection raw materials and holistic measurements

All the raw materials of the diaper are measured **fully-saturated.** This simplification needs to be taken into account because nowadays it is not feasible to include the kinetics of the swelling AGM in a moderate way depended on load and time. Therefore for the holistic measurements only the fourth gush is considered. A gush is the amount of urine a baby urinates at once; in the laboratory a specific amount of liquid is applied in a defined flowrate, for a size four baby it is 60 milliliters with a flowrate of 15 ml/sec.

3.1.1.2 Product Selection

Due to different regional market developments and manufacturing processes, different core technology approaches are used to fulfil the price versus performance demands in the best way. Diapers from all over the globe are selected. The first criterion of diaper selection is the volume share of the competitive manufacturer in the respective region. For example, for Europe, Middle East, and Africa (EMEA) the "Private Labels" have a volume share of 28.7 percent (JA 2004-2005)[68], followed by manufacturer "2" with 12 percent (see fig.3.3.). The next step in the data selection is to focus on products with

"P&G" relevant competitive activities[62]. Therefore, a global claims database is used in which all products with the main competitive focus are listed per region. In additional, the respective contact person for each region is contacted to ensure the database is continually updated. The different diaper products mirror the wide variety of approaches from the different manufacturers to achieve consumers' satisfaction.

For the manufacturer "I", chosen representative products are a tier two product ("A"), a tier three product ("B") and a tier four product ("K"). A tier is the categorization of the product, the lower the tier, the better the product is in terms of leakage prevention, but also the more expensive it is. Tier one products are neglected in this study because the main difference between tier one and tier two products from the same manufacturer is the chassis.

Region	Manufacturer	Product	Tier	Volume share [%] of manufacturer per region[63]
Europe Middle East Africa	I	A, B	2,3	43.8
Europe Middle East Africa	II	C	2	12
Europe Middle East Africa	III	D*	2	28.7
Europe Middle East Africa	IV	E*	2	28.7
Europe Middle East Africa	V	F*	2	28.7
Europe Middle East Africa	VI	G*	2	28.7
North America	I	A	2	36.8
North America	II	H	2	36.1
North America	II	I*	2	36.1
North America	VII	J*	2	3.5
North Ease Asia	I	K	4	13.4
North Ease Asia	VIII	L	2	35.8
North Ease Asia	IX	M	2	14.9
North Ease Asia	II	N	2	13.9
Latin America- Chile	I	A ,B	2,3	45.7
Latin America- Chile	II	O	2	27
Latin America- Chile	X	P	3.5	14.6
Latin America- Venezuela	I	A , B	2,3	24.4
Latin America- Venezuela	II	Q	2	22.6
Latin America- Mexico	I	B		10.2
Latin America- Mexico	II	R	3	54.6
Latin America- Mexico	XI	S	3	17.2

Fig 3.3: Overview about selected diapers (= Private Label Manufacturer)*

[62] **P&G:** Global Competitive Claims Database, 2005

[63] **Nielson, AC:** Volume Shares Baby Diapers- National Retail Index, 2005

3.1.1.3 Identification of Core End Price Relevant Variables

Via an internal P&G study[66] the most influencing raw material components for a diaper in terms of costs are identified. The combination of this information with the core relevant layers lead to the identification of the following end price relevant variables.

Raw Materials	Price influencing properties
Absorbent Gelling Material	Capacity under pressure
Absorbent Gelling Material	Capacity without pressure
Absorbent Gelling Material	Permeability
Acquisition System	Technology
Acquisition System	Basis weight
Acquisition System	Type of fibres
Acquisition System	Durability of Finish
Topsheet	Technology
Topsheet	Basis weight
Topsheet	Type of fibres
Topsheet	Durability of Finish
Core Cover	Technology
Core Cover	Basis weight
Core Cover	Type of fibres
Core Cover	Durability of Finish
Fluff pulp	Basis Weight
Fluff pulp	Dry Density
Fluff pulp	Fiber length
Fluff pulp	Fiber type

Fig 3.4: Influencing properties of the raw material price of the core

3.1.1.3.1 Identification of Performance Relevant Parameters

The above described price influencing properties of the core raw materials describe not sufficient the performance of the raw materials (chapter 2.4.).

Therefore additional measurements need to be considered. The measurements can be split into two groups, those relevant for the holistic product and those important for the raw materials. The measurement methods on the holistic product give an overall performance estimation of the product, including the additional performance caused by the interaction of the different layers together. The diaper raw material measurements provide information about the raw material performance and physical and chemical properties.

Therefore the diaper raw material measurements, which need to be considered in addition to the price related ones, are:

Raw Materials	Performance influencing properties
Acquisition System	Strikethrough
Acquisition System	In Plane Radial Permeability
Acquisition System	Capsorption
Topsheet	Strikethrough
Core Cover	Strikethrough
Abosrbent Gelling Material	Free Swell Rate

Fig 3.5: Diaper performance influencing raw material properties

The holistic measurements, included in this project for holistic product performance estimation, are:

- Speed of Acquisition with Balloon-Applied Pressure
- Capacity 0.3psi
- Dunktest
- Topsheet Run Off
- Barrier Leg Cuffs Run Off
- AGM Titration

3.1.1.3.2 Laboratory Measurements used for BIG 3

Fig. 3.6. gives an overview about the 23 different objective, technical measurement methods (see attachment) are applied to the 18 products. With at least three replicas, this ends up as 1674 single measurements. Despite the high number of methods, all these methods need to be considered because it is not known which method is important in the final urine leakage model.

The objective, technical measurements used for “BIG 3” are divided into diaper **raw material**, **semi-holistic** and **holistic measurements**. To accomplish the raw material measurements on competitive products, the diapers are first separated into their individual layers. For semi-holistic measurements, a sandwich of different layers is measured instead of the single layers. This is done, for example, for the determination of core capacity where, due to the loose structure of the “AGM & pulp” layer, measurements without the “Core Cover” on the one side and the “Dusting Layer” and the “Backsheet” on the other side, are not possible. The holistic measurements are executed on the whole product core without any kind of separation process.

Methods	Layer
Strikethrough	TS, CC
Surface Tension Reduction	TS, CC
Differential Scanning Calorimetry	TS, AQL, CC
Capsorption	AQL
In Plane Radial Permeability	AQL, AGM & Pulp
AGM amount	AGM
Saline Flow Conductivity	AGM
Centrifuge Retention Capacity	AGM
Absorption Against Pressure	AGM
Free Swell Rate	AGM
PartAN	AGM
Staining- Toluidine Blue	AGM
Staining – Bromocresol green	Diaper
Element Analysis	AGM
Technology determination	TS, AQL, CC
Speed of Acquisition with Balloon Applied Pressure	Diaper
Absorption Before Leakage +	Diaper
Topsheet run off	Diaper
Capacity 2.07kPa	Diaper
Dunktest	Diaper
Barrier Leg Cuffs run off	Diaper
Capacity core	AGM & Pulp
SEM –pictures	AGM, AQL

Fig 3.6: Overview about applied measurement methods

3.1.2 BIG 3 Models

3.1.2.1 Expert Panel

To capture the consumers' urine leakage perception, the urine leakage data of the "Expert Panel" data are used alongside the laboratory methods. From comparisons of the "Expert Panel" urine leakage data of the 18 different products from the different regions, unexpected low urine leakage data for the North East Asia region was identified. "A" is composed of 12.2g of "AGM" and, in comparison,"N" of 11.1g. Additionally, "A" absorbs the 60 milliliter liquid faster (108 sec) than "N" (201 sec), although "N" shows 1.44 percent urine leakage in the load cluster of 240-300 mililiters, where "A" has 6.56 percent leakage. Based on this unexpected leakage data, urine leakage percentages of the same product "K" from the same production code were compared – one placed in the "Schwalbach Technical Center" and one placed in China (fig.3.7.). The product placed in China shows in average 12 percent less urine leakage than those placed in the "Expert

Panel" in Schwalbach. This high difference in urine leakage can not only be referred to a low tier product placed in Western Europe country. The explanation is related to the different diapering habits and mindests of consumers in different regions.

Product "K"	STC Expert Panel	China Study
Loadcluster	%leakage	%leakage
1- 60	18.75	10.07
61-120	29.56	11.49
121-180	20.43	14.19
181-240	37.93	24.14

Fig 3.7: "K" placed in STC and China

Reasons for the different urine leakage values are consumers' diapering habits (in some regions consumers' close the diaper very loosely and in others very tightly) and/or their mindset (they claim leakage is their fault and therefore do not note it down in diaries). This means for this PhD thesis that the product set of 18 different products is reduced to the 10 products tested in one "Expert Panel" in Schwalbach. This means, for example, that babies who drink and urinate a lot will do this continuously over the whole diaper range. The same applies to mothers; those mothers who count a drop of urine out of the diaper as leakage will do this independently from the diaper. The same applies for mothers who first claim leakage when the clothes are complete wet. Based on an internal "P&G" study, urine leakage is only correlated to the diaper load and not to the time the baby wears the diaper.[64] Different possibilities exist to include the diaper urine leakage perception of "Expert Panel" mothers in the model:

- Total urine leakage, which is the percent of leakage over all urine changes.
- Total urine leakage, separated in day and night loads.
- Average between day and night urine leakage, clustered and not clustered by load

The urine leakage is separated in some studies into day and night. The night diapers are defined as diaper worn over midnight. The differentiation is made based on the fact that during the night the diaper has a higher load, because the diaper stays on the baby for longer (fig.3.8.). The average load of a diaper during the day is 180 milliliter and during the night is 210 milliliter, - these data are based on internal studies. Additional influences of the baby, like baby's movements are lower during night. A further possibility is not to use the average urine leakage data per average load but to cluster the load areas of the

[64] **Liedtke, C.:** Has Mothers' perception influence on leakage occurrence?; 2007

diaper to gain more detailed information about the urine leakage occurrence in the single load areas.

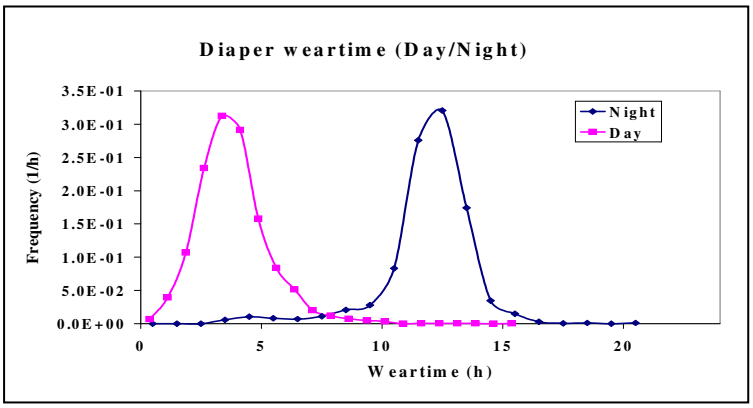


Fig 3.8: Day versus night wearing time

For this project 60 milliliter load clusters were chosen. For the decision over day or night urine leakage, or both, the "Expert Panel" urine leakage data are split into day and night and clustered in 60 milliliter load clusters. The pink line in fig.3.8. shows the average percentage of day urine leaked changes of the EMEA products and the blue line does the same for night urine leaked changes. Both lines show similar curve progressions in the respective load clusters and therefore no differentiation between night and day urine leakage is accomplished for this project.

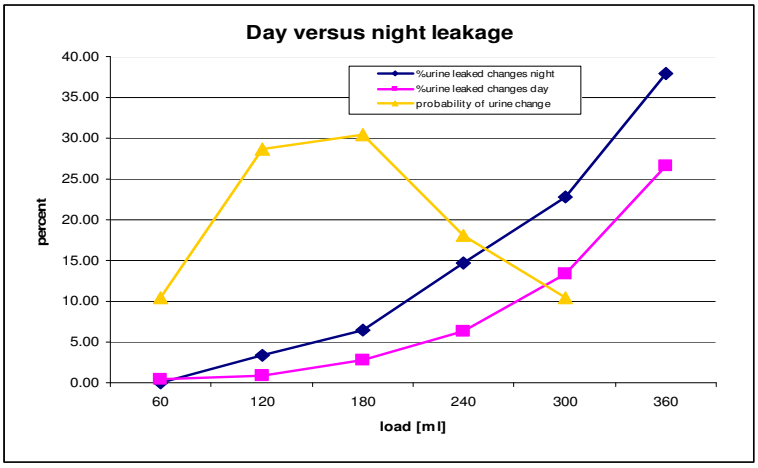


Fig 3.9: Percent leaked urine changes day and night

The analysis of the "Expert Panel" urine leakage data leads to the determination of three main leakage areas, as shown here by an example of "A" (fig.3.9.). In the first area, between 0-100ml, no leakage occurs, in area two (101-230milliliter) a slow rise of curve progression is visible. In the third area (as of 300 milliliter) a step increase of the curve follows accompanied by irregular increases and decreases of the curve.

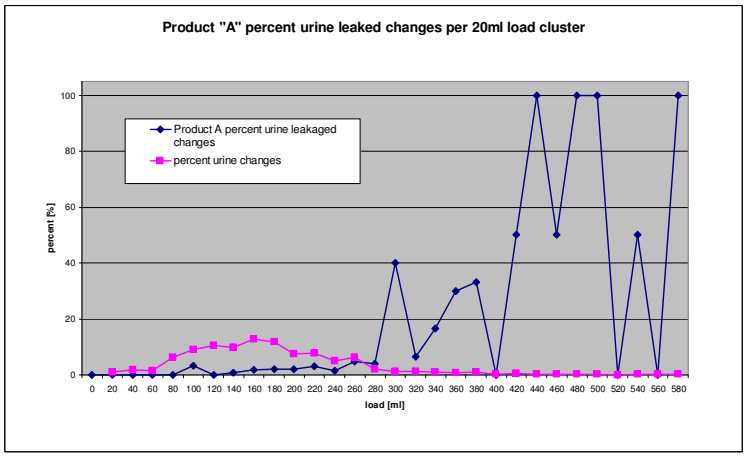


Fig 3.10: Percent diaper changes versus load (ml)

The shaky part of the curve is the area where only five percentage of urine changes are accomplished. Additionally, this area is identified as the area above the theoretical capacity of the core. The theoretical capacity of the core is a calculation of the maximum liquid uptake of the core. As "BIG 3" is a model only focusing on the core ("TS", "AQS", "CC", "AGM and pulp" layer), all leakage data above the theoretical capacity are neglected. The following equation is used to calculate the theoretical capacity of the products.[80]

$$\text{Theoretical Capacity} = (g_{AGM} * CRC) + (4 * g_{Pulp})$$

Fig 3.11: Equation to determine the theoretical capacity of the core[77]

3.1.2.2 First Principle Based Model

The three main parameters for the "BIG 3" model are: the "Expert Panel" urine leakage data (output), the diaper raw material variables (input) and the data of the holistic measurement (input). The "Expert Panel" and holistic measurement data are both defined.

For the raw material variables, for each layer the important variables for time and capacity are determined (left column fig.3.12.). The list of influencing variables is built on approximations, such as the fully saturated diaper (layers). This approximation is done because the swelling kinetics of the pre-swollen "AGM" changes constantly over time, which makes it impossible to execute an accurate measurement of the partially saturated "AGM & pulp" layer. In addition, the possible difference in "AGM amount" for each diaper zone is incorporated by the partitioning of the "AGM & pulp" layer in the four zones (chapter 2.2.3.2.1.) of the diaper. This means the time and capacity is determined for each of the four zones. By applying these simplifications, the number of influencing

variables adds up to 152. To build a stable statistical model the number of input variables, here raw material variables, need to be at least similar to the number of output variables; here, the urine leakage data of the 18 products.

The first step in the model-building process in terms of raw material variables is therefore the reduction of the amount of variables, which is accomplished by a "First Principle Based Model". This kind of model uses physical relations to reduce datasets (fig. 3.12).

As an example, the time and capacity relevant variables for the "Topsheet" are the length (l), the width (w), the caliper (c), the porosity (n), the capillary pressure (P_c) and the permeability (χ) of the medium. The first four variables can be merged into the variable "void volume" by the following equation:

$$\text{Void volume (V)} = w*l*c*n$$

The remaining two variables can be combined to the flowrate where the capillary pressure is replaced by the "Medium Absorption Pressure" ("MAP") of the material (right column fig.3.14.). The flowrate as well as the "MAP" are variables that can be measured in the laboratory.

$$\text{Flowrate} = w * c * \frac{\chi * MAP}{\mu * L}$$

The capacity measurements are only accomplished on thick layers. Therefore, only the flowrate of the "Topsheet" is included in the model. By applying the physical simplifications to all layers the amount of influencing variables is reduced to 15. Flowrate as a measurable variable is converted into time by including the liquid amount of 60 milliliters.

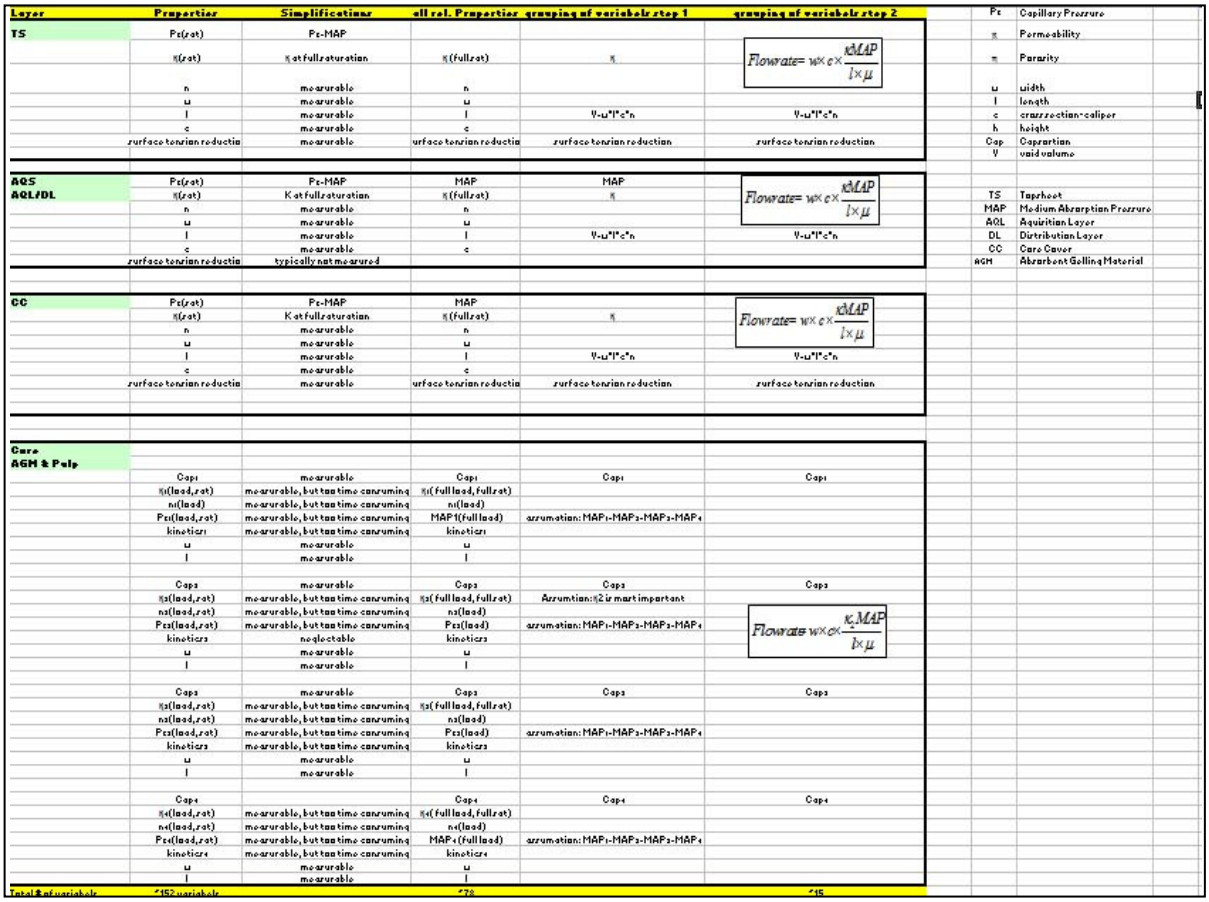


Fig 3.12: Variable reduction based on First Principle Based Model

3.1.2.3 BIG 3 –Model Approaches

The prepared input and output variables are used to build firstly a statistical model between raw material measurements and holistic measurements, which explains the raw material influences on the holistic measurements. In a second model, the link between holistic measurements and consumer urine leakage perception shall be built. This step explains how huge the impact of time and capacity is for urine leakage. Afterwards, the raw materials predicting time shall be used to replace the time independent proportion of leakage and the same shall be accomplished for capacity. For each model, the statistical as well as the physical relation needs to be right to yield a useful model.

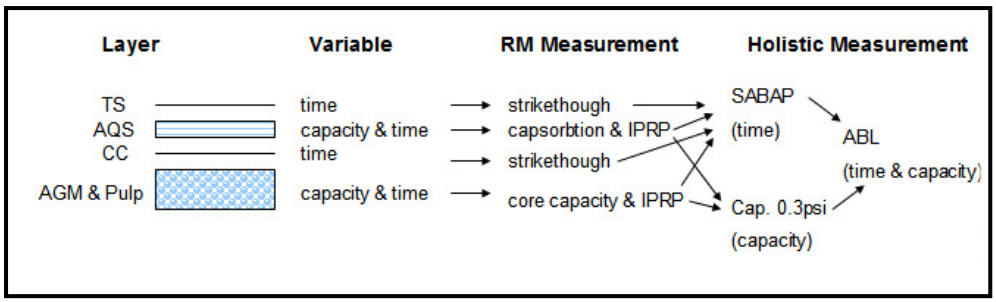


Fig 3.13: Schemata of the connection of raw material properties and holistic lab measurements

3.1.2.3.1 Relation Raw Material Properties and Holistic Lab Measurements

A simple "Linear Regression" model is used with time and capacity as independent variables to build the link between raw material properties and holistic lab measurements. The 15 raw material variables, emerged from the "First Principle Model" are used as input factors, which means the time and capacity variables for the thick layers ("AQS", "AGM & pulp") and the time part of the thin layers ("TS", "CC"), due to the high failure of their capacity measurement.[81] Further on, only the second zone of the diaper core is implemented by raw material variables. This simplification is included based on the fact that the baby urinates in zone two and accordingly the capacity and ability of horizontal liquid distribution is most important in zone two. From a statistical point of view, the failure generated by the mathematical calculation of the different zones is huger than those for the calculation of only one zone. All failure sources in the model need to be minimized to ensure a stable model.

The holistic data set consists of the only time measurement method on holistic products, called "SABAP" and the capacity measurement method "ABL+". "ABL+" is chosen, because it is the only laboratory capacity method which includes the chassis. It is accomplished on a baby doll, with the weight of baby wearing diaper size four, which is closest to reality. All measurement methods use as standard 60 milliliter of 0.9 percent saline solution for one gush. The minimum amount of applied gushes is four for the holistic measurements to assure the full saturation of the diaper core. All raw material measurements are also accomplished on the fully saturated layers. As "SABAP" data the sum of the time for all four gushes is used.

Two model approaches are accomplished. In the first one all raw material measurements are linked to "SABAP" and in the second one they are linked to "ABL+".

Holistic Method	Raw Material Measurement
SABAP, ABL+	Core time zone 2
SABAP, ABL+	Core capacity zone 2
SABAP, ABL+	AQL time
SABAP, ABL+	AQL MAP
SABAP, ABL+	AQL length
SABAP, ABL+	AQL width
SABAP, ABL+	Strikethrough TS
SABAP, ABL+	Strikethrough CC

Fig 3.14: Overview raw material to holistic model approaches

In statistics only valid "Linear Regression" models are considered which explain the outcomes (R^2) to more than 50 percent[65]. Between raw material measurements and the holistic capacity method "ABL+", no stable model (R^2= 40%) can be built. Besides "Linear Regression", "Partial Least Squares" and "Structural Equation Modelling" techniques are used which lead to models with an R square of a maximum 40 percent.

In terms of "SABAP", "Linear Regression" builds a stable model. The correlation of the predicted value by the model and the measured "SABAP" value is 87 percent (fig.3.16) which is a stable model. The model identifies the time the AQL needs to distribute 60 milliliters horizontally, the "Medium Absorption Pressure" (MAP) of the AQL and the core ("AGM & pulp") capacity of zone two as the three factors which explain "SABAP". For all other factors the influence is so low that it is therefore neglected. The strength of influence of the three raw material variables on the overall "SABAP" value is visible in the coefficients of the equation below. The higher the coefficient of the single variable, the higher the predictive influence of the variable on the "SABAP" value. The first term in the equation is the intersection of the straight line with the "y-axis".

SABAP = -187.414 + 1.591*AQS time+ 50.329*AQS MAP2 - 6.083*Capacityz2

Fig 3.15: Equation predicting "SABAP" valueas based on raw material variales

[65] **Osborne, J.W.:** Prediction in Multiple Regression, 2000

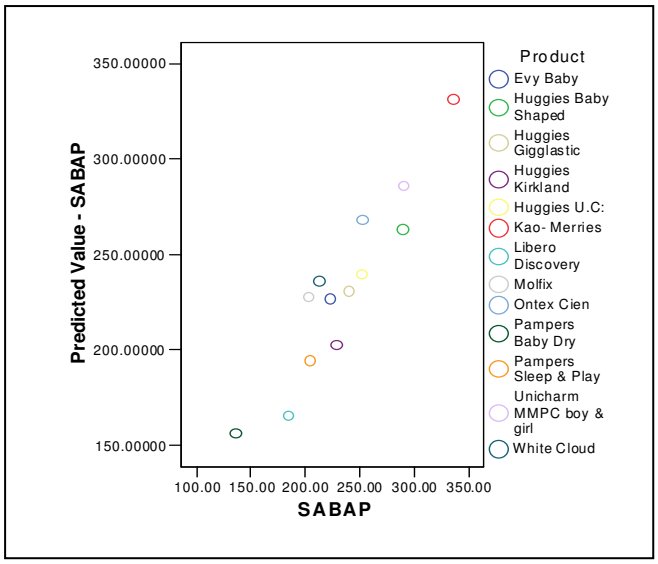


Fig 3.16: Predicted versus measured SABAP values

The statistical model between "SABAP" and the raw material variables is also proven from a technical diaper design point of view. The first variable is "AQS time". This variable is positively-correlated to "SABAP", which means the longer the "AQS" needs to distribute the 60 milliliters of liquid, the longer the time for the liquid absorption of the whole diaper is. This statement is correct because as more liquid is distributed over the "AQS", the less liquid is available at the point where the liquid arrives and the conductive electrons measure the liquid. The second term "AQS MAP", which shows the suction power of the "AQS", also discloses a positive correlation with "SABAP" in the equation (fig. 3.15). This term states that the higher the suction power of the "AQS", the longer the time until the liquid is absorbed by the diaper. This statement makes no sense from a design point of view because the higher the suction power of the liquid, the faster the liquid should be drawn away from the surface of the diaper, and the shorter the time taken for the conductivity electrodes to measure liquid at the pee point. The last term in the equation is "Core Capacity Zone 2", which is negatively correlated to "SABAP". This means the higher the capacity of the core in the second zone, the faster the liquid is absorbed. This makes sense from a design point of view.

Overall, the equation for "SABAP" works from a statistical point of view, but makes no sense from a technical diaper point of view. Therefore, **no predictive model can be built** between the **holistic capacity and time measurements** and the **raw material methods**.

3.1.2.4 Relationship between Holistic Measurements and Consumer Measurements

In the project, alongside to the relationship between "Raw Material and Holistic Measurement" model the relationship between "Holistic Measurements and Consumer's model is accomplished. This identifies the proportion of time- and capacity-related impacts on urine leakage. For all models related to consumers, the outcomes of the consumers' "Expert Panel" study (chapter 3.1.2.1.) are considered. This means only the 10 EMEA products are used and the "Theoretical Capacity" of the core is included in the models. For the link between holistic diaper and consumer measurements, two approaches exist. The first one treats time and capacity as dependent; the second one treats them as independent variables.

3.1.2.4.1 Time and Capacity as Dependent Variables

For this approach, **time and capacity are handled as dependent variables**. Meaning, when the liquid enters the diaper very quickly, the capacity is the limiting factor, which eventually leads to leakage. The other extreme is that with a high capacity, the time it takes until the liquid is absorbed by the diaper is infinitesimally slow, which means that the maximum capacity will never be reached and therefore leakage occurs. As boundary conditions, the "Theoretical Capacity" is considered to be 100 percent of the core capacity of the different diapers and a 5 minute (300 seconds) time limit is chosen abutted to the holistic lab measurements "Capacity 2.07kPa", "ABL+" and "SABAP". In each of these measurements the time interval between the four gushes is five minutes.
First, the limiting factor (time, capacity) for leakage occurrence is determined. This is accomplished by a time versus load chart. Due to the fact that "SABAP" and urine leakage values show correlations[66], the "SABAP" data are used to drive the decision between time- or capacity-caused leakage. The chart (fig. 3.18.) is an example of how this decision is accomplished. The single "SABAP" loads and the respective time the diaper needs to absorb the amount of liquid is plotted. The time for the liquid absorption of the fifth gush, giving a total volume of 300 milliliters in the diaper, is calculated for each of the 10 products. If the calculated time for liquid absorption is longer than the 300 seconds, the diaper will leak based on the time limit. If the "Theoretical Capacity" is reached before the 300 seconds borderline, the diaper will leak based on the capacity of

[66] **Ehrnsperger, B.:** Urine Leakage und SABAP Correlations, 2007

the diaper. The results of the extrapolation and the theoretical capacity are shown in fig. 3.17. for the EMEA products.

Product	Capacity at (300sec)	Theoretical Capacity	Reasons for Leakage
P	425.3	303.16	Capacity
G	437.08	469.47	Time
C	405.38	375.32	Capacity
E	449.88	413.24	Capacity
F	452.28	486.39	Time
D	342.87	468.6	Time
A	410.88	345.37	Capacity
B	347.88	234.87	Capacity
C	506.8	267.8	Capacity

Fig 3.17: Leakage reasons by product

In fig. 3.18, products “C” and “D” give examples of leakage caused to products due to the effects of capacity and time. The red line in the pictures illustrates the time borderline and the blue one shows the theoretical capacity of “C” and the green one those of “D”.

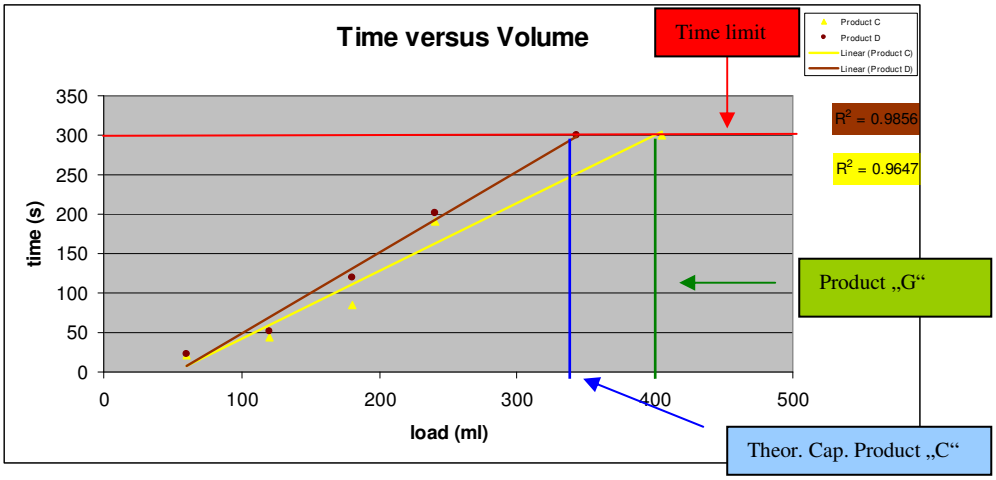


Fig 3.18: Leakage caused by different effects.

The outcomes of this part of the study are transferred into a leakage versus load chart. To assimilate the urine leakage data to the “SABAP” data they are also clustered into a loadcluster of 60 milliliters. Different approaches exist to get the time part incorporated into the leakage curve. The first strategy is to use the “y- axis intercept of the different average urine leakage values per load cluster, but this approach does not lead to an appropriate explanation on the time versus capacity part of leakage. The second approach is to use the leakage data and the “SABAP” values in the load cluster and explain the capacity proportion by the gap between them. Therefore, the “SABAP” data are aligned

with the percent leakage data. Using the "R square" as indicator for prediction (100= perfect), it shows that overall a quite good linearity is achieved for the single products (fig 3.19).

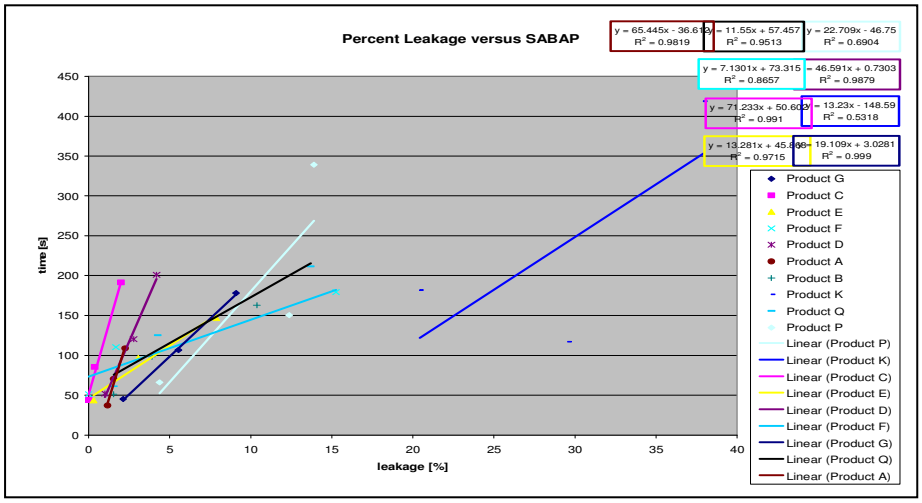


Fig 3.19: SABAP versus urine leakage

A three axis diagram (fig.3.20.) is used to link the three factors of load, time and percentage together. This also does not lead to a positive result because the urine leakage curve and the "SABAP" time curve are twisted and it is not possible to put them in the right order for all products in the same way. Additionally, the gap between the urine leakage curve and the "SABAP" value includes the capacity and chassis proportion which cannot be split. Therefore, this approach including "Linear Regression" and dependencies of the time and capacity input variables is aborted, which is valid because no link between holistic and raw material measurements can be built with time and capacity as dependent variables.

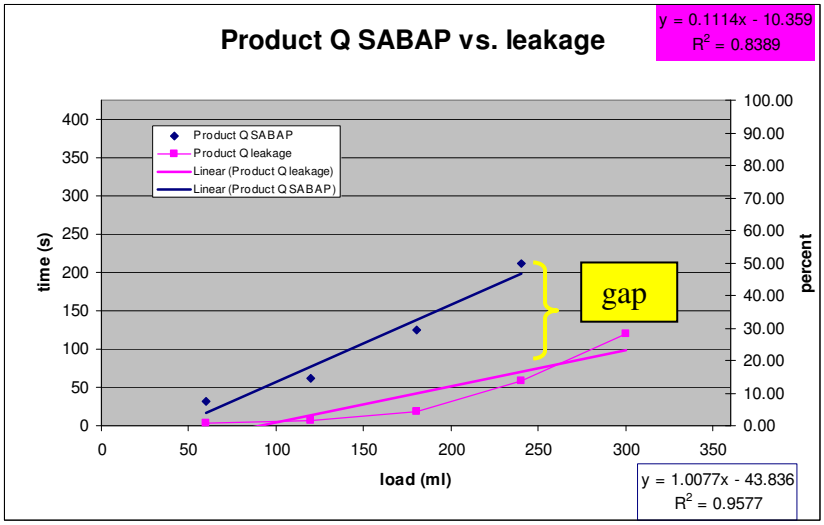


Fig 3.20: Speed of acquisition versus load versus leakage percentage

3.1.2.5 Time and Capacity as Independent Variables (Linear Regression)

Another way to build the link between raw material and holistic methods is to treat time and capacity as independent variables. In addition, only EMEA products are considered in terms of leakage versus single variable connections. The independent input variable assumption allows the use of “Linear Regression” as a statistical method under the restriction of fewer input than output variables. (chapter 2.6.1.).

To avoid multicollinarity, “Linear Regression” is accomplished for each variable on its own first. Multicollinearity is caused when two input variables correlate with each other. The final results can be distorted due to their relationship to each other. Afterwards, the highly influencing variables, those with an “R square” over 50 percent, are examined via “Pearson Correlation” to identify relationships between them. Correlated variables are then represented by one of the variables. By doing this several times, a tree chart (fig.3.24) grows which explains how leakage is related to the single variables.

The approach to simplify the model starts with total urine leakage, which is the percentage of leaked urine changes divided by all urine changes. As a first step, the total urine leakage is related, via “Linear Regression”, to each of the holistic, semi holistic and raw material methods on its own. The outcomes (yellow) are shown in fig. 3.21. The yellow highlighted variables represent an “R square” over 50 percent. Variables which are close to 50 percent, such as “AGM amount” are considered as important from a technical design point of view, therefore they are also included in the analyses.

Variable	R^2	Influence positive/negative	Right/wrong from a design point of view
SABAP total (sum of all 4 times)	68.6	+	✓
ABL+	40.2	-	✓
Dunktest	59.9	-	✓
Capacity 2.07 kPa	49.0	-	✓
Core capacity zone 2	52.4	-	✓
Core time zone 2	29.2	+	✓
AGM amount	46.5	-	✓
Pulp amount	15.4	-	✓
AAP	3.6	-	✓
CRC	1	0	-
SFC	18.7	+	X
Strikethrough TS	0	-	X
Strikethrough AQS	2.2	-	X
Strikethrough CC	24.3	-	X
AQS x-time	12.2	-	X
AQS caliper	5.9	-	✓
AQS length	10	+	X
MAP2	4.4	-	✓

Fig 3.21: Outcomes of the Linear Regression Analysis

The urine leakage perception of consumers is correlated to "**SABAP total", "Dunktest", "Capacity 2.07kPa"; "Core Capacity Zone 2"** and with a weaker influence **"AGM amount".** The advantage is that all these influence factors have the expected direction of correlation. For example, for "SABAP total" this means the more time the diaper needs to absorb the liquid, the higher the leakage occurrence in reality. The permeability of the swollen AGM ("SFC"), the "Strikethrough" of the "AQS", the "Strikethrough" of the "CC" and the time for liquid distribution of the "AQS" as well as "AQS length" show an unexpected direction of influence, which can be related to their low correlation. The variables with the unexpected direction of the correlation have no influence on the actual model because their "R square" is too low and therefore they are not implemented in the model. To avoid factors influencing the end result by being correlated, a "Pearson Correlation" is carried out to identify the correlations in the dataset. Again the borderline of 0.5 is used to state an existing correlation.

Via the Pearson Correlation, the "**SABAP total"** is identified to be correlated to:

- "ABL+" (-.854);
- "Core Time Zone 2" (.665);
- "Capacity 2.07kPa" (-.781);
- "Maximum Uptake AQS" (-.68)
- "Dunktest" (-.733).

When input variables are correlated to each other they must be either reduced to one factor or replaced by each other. The only important variable which is not correlated to "SABAP total", but has an "R square" over 50 percent, is "Core Capacity Zone 2".

"Core Capacity Zone 2" is correlated to the following raw material properties:

- "Maximum Uptake AQS" (.622);
- "AAP" (.632);
- "AGM amount" (.568);
- "Strikethrough CC" (.518).

Again a "Pearson Correlation" is used to identify whether the variables are dependent from each other or not and, in case of dependency, they are further reduced to one variable. The remaining independent variables, which explain "**SABAP total"** are "**AGM Amount"** and **"Core Time Zone 2".** Carrying out again a "Linear Regression" analysis leads to the quite low "R square" of 55.1 percent. The same procedure done for "Core Capacity Zone 2" leads to "Strikethrough CC"; "AGM amount" and "AAP" as independent variables. By applying "Linear Regression" the variables obtain an "R square" of 65.2 percent.

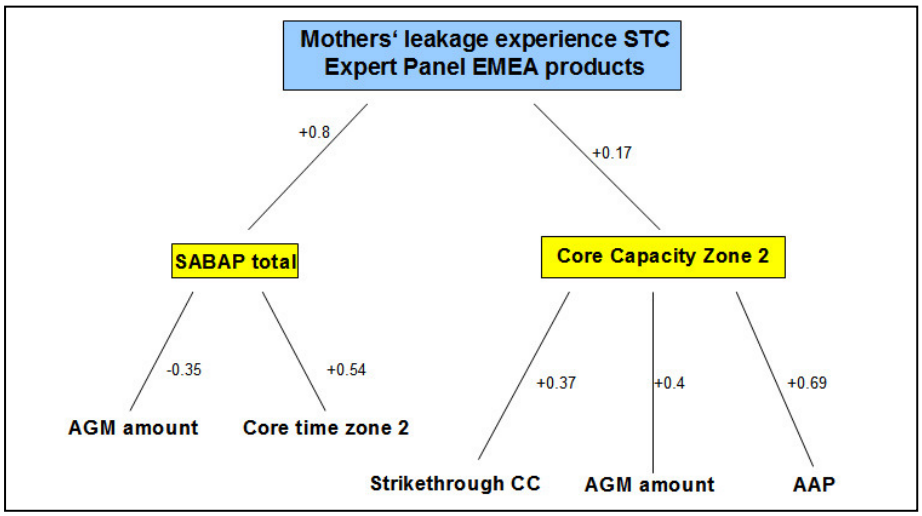


Fig 3.22: Outcomes Linear Regression Analysis

In fig. 3.22 the numbers over the connecting lines are the coefficients and by that the strength and direction of influence on the higher variable.

The urine leakage perception of mothers in the "Expert Panel" (in the "Schwalbach Technical Center") is explainable to 88 percent. Looking at the single "Linear Regression" outcomes (fig.3.23 and fig. 3.24), the "SABAP total" also has a higher influence on urine leakage explanation than "Core Capacity Zone 2".

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.938(a)	.880	.845	1.65852

a Predictors: (Constant), SABAP total, core capacity zone 2

Coefficients(a)

Model		Unstandardized Coefficients		Standardized Coefficients	T	Sig.
		B	Std. Error	Beta		
1	(Constant)	17.485	5.489		3.186	.015
	core capacity zone 2	-.172	.051	-.477	-3.358	.012
	SABAPtotal	.018	.004	.646	4.551	.003

a Dependent Variable: change base

Fig 3.23: Linear Regression Analysis (created with SPSS 12.0)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.828(a)	.686	.646	2.50699

a Predictors: (Constant), SABAPtotal

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.724(a)	.524	.464	3.08663

a Predictors: (Constant), core capacity zone 2

Fig 3.24: Linear Regression Analysis (created with SPSS 12.0)

The model is a good approach to explain urine leakage based on holistic measurements. The "R squares" of the "Raw Material to Holistic Measurements" in this approach are not as high as expected with 55.1 percent. Therefore, explaining consumers' urine leakage perception by the raw material measurements yield with an "R square" of 24.2 percent not in a stable model. Therefore this approach is also aborted.

3.1.2.6 BIG 3 – Partial Least Squares Model

Neither the "Raw Material to Holistic" model nor the "Holistic to Consumer" model can be built by using “Linear Regression”. Therefore another statistical technique is used, called “Partial Least Squares” (chapter 2.6.3.). This technique is first applied to the data set "raw materials to consumers’ urine leakage perception" and afterwards to the "holistic measurements to consumers’ urine leakage perception" dataset. The main part of this thesis is based on the first model, because with this model the key drivers for urine leakage can be determined. The "holistic to consumer perception" model is important for “P&G" to reduce the amount of holistic measurements and save money and time.

The “**Partial Least Squared Model” (“PLS”)** is applied to this data set due to its ability of handling data sets with a higher amount of input than output variables. Time and capacity variables are treated as independent variables throughout both models.

Stronger models result as fewer input variables as possible are used. First of all, the linear and quadratic correlations amongst the variables are proven to exclude multicollinearity due to correlations of variables amongst each other. This leads to a reduced input variable set. Additionally, the consumers’ urine leakage perception data are split into four 60 milliliter load clusters (61-300 milliliters) to stay in line with the laboratory measurements, which are generated by four gushes á 60milliliters.

The total leakage of one product is calculated by the sum of the probability of urine leakage in the single load clusters multiplied with the probability of having a urine diaper change in the respective load cluster (fig. 3.25). Due to the fact that the load area of 1-60 milliliters is excluded, as well as the area above 300 milliliters, the total amount of urine changes is 86 percent instead of 100 percent.

Overall Urine Leakage = 0.27*Leakage1 + 0.31*Leakage2+ 0.18*Leakage3+ 0.10*Leakage4

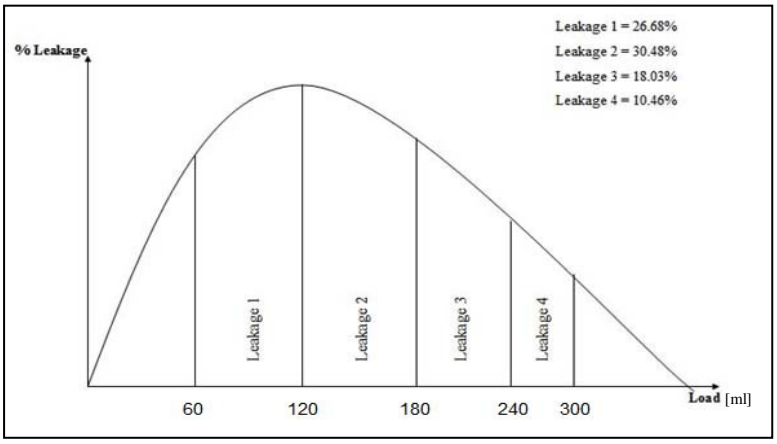


Fig 3.25: Basic idea of PLS model

3.1.2.6.1 Ranking of Quality of Measurement Methods

The reproducibility of the dataset is important for the correlations of the input variables, because if two variables are correlated with each other, one of them is chosen to represent both. In terms of statistical model-building, the variable with the lowest measurement failure is always chosen because the higher the failure in the measurement method, the more reduced is the predictability of the model, due to considerable fluctuations in the data generation. So far, a determination of the instrumental measurements failure per method does not exist; therefore, within this project a ranking method is developed to identify the quality of the methods. The quality of a measurement method is given by the reproducibility of the dataset for the sample replicas. In this project, for one product sample the measurements are repeated four times, this multiplied by the 18 products results in an overall measurement base size of 72. For each of the four single repeated measurements on one sample the median is calculated, as well as the percentage of the standard deviation. To achieve comparability between the single products, the mean of the percentages of the single standard deviations for one method is calculated. This procedure is accomplished on each measurement method. The quality of the method is determined by comparing the mean of the percentages of the methods' standard deviations (fig. 3.26). The quality of the measurement method is reflected in a ranking scale. The color-coding is given based on a statistical weight distribution. The green fields are the 25 percent of all measurements, the yellow ones are 50 percent weight and the red ones are the 25 percent weight. The first 25 percent (green fields) highlight the methods with a good average percent of standard deviation; the yellow ones represent a medium average, and the red fields indicate measurement methods with a high failure rate for analyzing products.

ranking #	method	averagde % stdev
1	Dunktest	0.03
2	CRC	0.63
3	AAP	1.58
4	Cap.2.07 kPapsi	5.36
5	AGM amount	5.81
6	MDP2 AQS	7.2
7	ABL	7.93
8	SABAP 2nd	9.32
9	Core Capacity Zone2	9.45
10	MAP2 AQS	10.15
11	AQS caliper	10.93
12	SABAP 3rd	12.8
13	AQS speed	13.99
14	Surface Tension Reduction AGM	14.4
15	SFC	16.53
16	Surface Tension Reduction NWs	16.81
17	SABAP4th	22.94
18	Strikethrough TS,CC	29.98
19	Coret Tme Zone 2	37.2

Fig 3.26: Ranking of measurement methods

3.1.2.6.2 Analyzes of Variable Correlations

The simplest correlations are linear correlations, because they can explain relationships in an understandable way and most often give the basis for higher correlations, such as quadratic ones. The “Pearson Correlation Coefficient” is used to identify highly-linear correlated variables. Data from all 18 products are included to analyze the relationships on a high base size. In addition, quadratic correlations are considered, because in reality pressure also has an influence on the single variables and the pressure is not linear correlated to leakage. In general, quadratic correlations are slightly higher than linear correlations, but only significant higher quadratic correlations are considered in this analyzes. The correlations are divided into three parts: raw material measurements amongst each other, holistic measurements amongst each other, and holistic measurements and raw material measurement.

3.1.2.6.2.1 Raw Materials

In the table below (fig. 3.27) all identified correlations between raw material properties are listed. For this dataset, more quadratic than linear correlations exist, the last ones are considered in terms of variable reduction.

Variable x	Variable y	R^2_{Linear} [%]	$R^2_{Quadratic}$[%]
AQS time	AQS length	59.1	87.4
AQS time	CRC	3.2	53.5
AQS time	AGM amount	38.2	69.3
AQS length	CRC	44.8	51
SFC	Strikethrough AQS	16.5	57.6
SFC	Pulp amount	61.6	78.6
Pulp amount	AAP	25.3	51.3
MAP2 AQS	MDP2 AQS	50.6	51.2

Fig 3.27: Quadratic and linear relations of variables

By incorporating these correlations and the outcome of the measurement method ranking, the following variable substitutions can take place:

- "Pulp amount" is substituted by "SFC";
- "AQS length" by "AQS time";
- "AQS time" by "AGM amount" and
- "MDP2 AQS" by "MAP2 AQS".

Of the 16 initial variables, the remaining 11 for each load cluster are:
The medium desorption pressure of the "AQS" ("MDP2 AQS"); the strikethrough measurements of the "TS" ("TS time"); the permeability of the swollen "AGM" ("SFC"); the absorption capacity under pressure of the "AGM" ("AAP"); the "AGM amount"; the strikethrough measurement of the "CC" ("CC time"); the capacity of the "AGM" without pressure ("CRC"), the capacity of the second zone of the diaper ("corecapz2"); time for 60 milliliters of liquid distribution in zone two ("Core Time Zone 2"); the maximum liquid uptake of the AQS ("Maximum Uptake AQS").

3.1.2.6.2.2 Holistic Measurements

The same procedure of correlation application and variable reduction is accomplished for the holistic measurements (fig. 3.28). The holistic measurement correlations are split into four areas according to the leakage clusters, because the different "SABAP" values are only valid for one leakage cluster. For example, "SABAP 2" is the time a diaper (already filled with 60 milliliters from the first gush) needs to absorb a further 60 milliliters of liquid.

Variable x	Variable y	R^2_{Linear} [%]	$R^2_{Quadratic}$ [%]
SABAP 2	ABL	54.7	81.6
SABAP 2	Dunktest	25.8	63.4
SABAP 3	ABL	46.3	66.7
Core Timez Zone 2	Dunktest	5.1	57.6

Fig 3.28: Holistic measurements linear and quadratic correlations

The remaining variables in the different leakage clusters are:

Leakage 1 (61-120ml):

"SABAP2"; "Core Capacity Zone 2"; "Dunktest"; "Capacity 2.07kPa"

Leakage 2 (121-180ml):

"SABAP3"; "Core Capacity Zone 2"; "Dunktest"; "Capacity 2.07kPa"

Leakage 3 (181-240ml):

"SABAP4"; "Core Capacity Zone 2";; "Dunktest"; "Capacity 2.07kPa"

Leakage 4 (241-300ml):

"SABAP5"; "Core Capacity Zone 2";; "Dunktest"; "Capacity 2.07kPa"

3.1.2.6.2.3 Holistic Measurements – Raw Materials

To explain the influence of the raw materials on holistic measurements, the same kinds of correlations are accomplished (fig.3.29)

Variable x	Variable y	R^2_{Linear} [%]	$R^2_{Quadratic}$ [%]
SABAP2	AQS time	43.1	50.4
SABAP2	AQS length	51.6	56.7
SABAP3	AQS time	66.3	69
SABAP3	AGM amount	41.6	66.9
ABL	AAP	8.8	50.7

Fig 3.29: Holistic Measurements- Raw Materials Measurements linear and quadratic correlations

"SABAP 2" is quadratic correlated to "AQS time" and "AQS length", whereas
"SABAP 3" is only related to the "AQS time" and the "AGM amount". "ABL", as the only capacity method, is correlated to the capacity of the "AGM" particle under pressure ("AAP"). Based on the previous raw material-holistic studies in this project and the inconsistent outcomes of the correlations, meaning "SABAP 4" and "SABAP 5" show no correlation to the "AQS" or "AGM amount", this part of the study is aborted.

3.1.2.6.3 Development of the BIG 3 Raw Material Model- EMEA Products

The "Partial Least Squares" model is accomplished separately in the four load clusters to determine the changing strength of influence of the single variables on the urine leakage probability in the respective load cluster. The main focus of the "BIG 3" is to explain leakage based on raw material properties, therefore, the reduced amount of variables, emerged from the variable reduction (chapter 3.1.2.6.2.), as well as their quadratic terms, are used as input variables. The quadratic terms are used, because the more a diaper is saturated, the higher the influence of pressure on leakage is.
The model-building is accomplished in each leakage area in the same way. All variables, their matching quadratic terms and all products tested in the "STC Expert Panel" are used in the first step. The tested products are "A","B","C","D","E","F","G","K","Q" and "P". For the model-building, all input factors are generated to one matrix and all output leakage factors to another one (chapter 2.6.3.). Then, an equation with the highest correlation and smallest failure between these two quanta is determined. For this part a statistical program[67] is used, which also highlights the quality of predictions; using "R^2_x" as an indicator of how accurately the input variables are summarized and "R^2_y" as an indicator of how accurately the outputs are modelled. Additionally, the value "Q^2" is reported, pointing out the "predictability" of the model equation. All these three quality indicators of the model ("R^2_x", "R^2_y", "Q^2") own a borderline of 50 percent. This means, is one of theses indicators below 50 percent the model is not stable model and by that not applicable.
The procedure for achieving the final model, final urine leakage equation, of the single load clusters is explained in detail using "Leakage 1" as an example.

[67] UMETRICS: SIMCA

3.1.2.6.3.1 Leakage 1 (61 -120ml)

In leakage cluster one, 26.68 percent of all urine changes between 61-300 milliliters are accomplished, using a base size of 100 mothers over a ten week product placement. As an initial step, all linear and quadratic terms are used as input variables for the "Partial Least Squares" model, as well as the single urine leakage observations in load cluster one of the ten different products. The resulting model has an "R_x^2" of 36.8 percent; a "R_y^2" of 82.7 percent and a "Q^2" of 29.2 percent. The "R_x^2" points out that 36.8 percent of the inputs using this one underlying latent variable (to be seen as a factor – see chapter 2.6.3.) can be summarized. The "R_y^2" highlights that 82.7 percent of leakage can be explained, and the "Q^2" is an indicator of the accurately-predicted predicted future values. In this case the "Q^2" of 29.2 percent is quite small. As previously explained, above 50 percent is the limit for a good predictive model. To control the outcomes of the model, the next step in the analyzes is to consider the predicted versus real leakage chart. This identifies that the "R_y^2" is artificially high due to one product and negative leakage predictions are obtained, which is not possible (fig. 3.30).

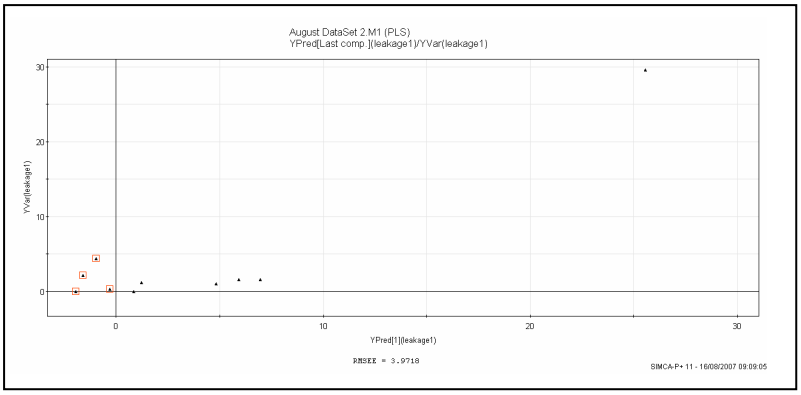


Fig 3.30: Predicted versus real leakage1; all input variables and products considered

To improve the model the product "K" is removed from the dataset, based on two reasons. First of all, the difference between the remaining values and this data point is too huge and the chance exists that the model between "K" and the remaining dataset is non linear. Secondly, including the product "K" always results in negative predicted-leakage values, which is not feasible. After removing "K" from the dataset and running the model again, including all quadratic and linear terms, a "R_x^2" of 21 percent, a "R_y^2" of 77.6 percent and a "Q^2" of 5.7 percent, result. This model is not as good as the first one, which is expected due to the removal of the influencing point. In addition, it shows a poor predictability. Again the values of predicted versus real leakage (fig.3.31) are checked

and this time no negative predictions exist, which indicates no further removal is necessary.

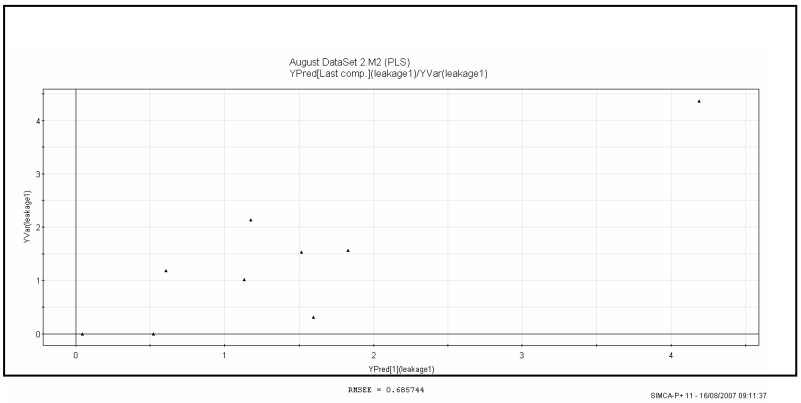


Fig 3.31: Predicted versus real leakage 1: product "K" is removed

The coefficients need to be standardized to compare them against each other. The model fit is assessed by the number of diagnostics, the standardised model coefficients and the "Variable of Importance" ("VIP"). A rough guideline, from practical experience, states that coefficients > 0.1 or < -0.1 and VIPs > 0.8 are the limits to keep variables in the model. Values in yellow do not meet these criteria and are candidates for removal. However, they do not need to be removed if they make sense from a physical or chemical point of view.

Input	Standardized coeff	VIP
$constant	0.9918	
AAP	-0.1073	1.19
AAP²	-0.0950	1.06
AGM amount	-0.1824	2.03
AGM amount²	-0.1724	1.92
AQS caliper	0.0583	0.65
AQS caliper²	0.0700	0.78
CC time	0.0036	0.04
CC time²	-0.0043	0.05
Core Cap. Z 2	-0.1472	1.64
Core Cap. Z 2²	-0.1386	1.54
Core time Z 2	0.0217	0.24
Core time Z 2	0.0148	0.16
CRC	0.0882	0.98
CRC²	0.0896	1.00
MAP2 AQS	-0.0051	0.06
MAP2 AQS ²	-0.0268	0.30
Maximum uptake AQS	-0.1045	1.16
Maximum uptake AQS²	-0.1110	1.24
SFC	-0.0507	0.56
SFC²	-0.0162	0.18
TS time	0.0293	0.33
TS time²	0.0267	0.30

Fig 3.32: First model equation for leakage one

The outcomes of the first model identify that quadratic terms are not important, therefore the model is built using only linear terms ("R_x^2"=22.3%; "R_y^2"= 76.5% and "Q^2"=6.9%). The resulting model (fig. 3.33) is very similar to the previous one, which confirms the low influence of the quadratic variables on urine leakage in load cluster one. Again the yellow highlighted variables in fig. 3.33. are candidates for removal based on their low strength. "AQS" caliper is kept in as all variables are capacity variables and the thickness of the "AQS" is an indicator for the capacity of the "AQS".

Input	Standardized coeff	VIP	
$constant	0.9918		
AAP	-0.2037	1.17	
AGM amount	-0.3465	1.99	
AQS caliper	0.1107	0.64	Kept in
CC time	0.0068	0.04	Removed
Core Cap. Z 2	-0.2797	1.61	
Core Time Z 2	0.0413	0.24	Removed
CRC	0.1675	0.96	
MAP2 AQS	-0.0096	0.06	Removed
Maximum Uptake AQS	-0.1986	1.14	
SFC	-0.0962	0.55	Removed
TS time	0.0556	0.32	Removed

Fig 3.33: Model for leakage one- linear terms only

Removing the yellow-indicated candidates and running the model again, yields a good model in terms of leakage explanation, but with a low predictability **("R_x^2"=37.1%; "R_y^2"= 77% and "Q^2" = 36.1 %).** The coefficients and "VIP" values indicate that no more variables should be removed. The chart below (fig 3.34) points out that no negative predictions occur. Additionally, two confidence intervals of 95 percent are given. The brighter one is based on the individual values and the darker one on the fitted line. The latter is more meaningful in this context and will therefore be used. The products "G" and "E" are not outliers from a statistical point of view, but they deviate from the remaining dataset. Reasons for the deviation can be either chassis-related or based on deviations of the influencing input variables of these products from the remaining dataset. The last one is not the case, which is visible in fig. 3.38., otherwise the dots would be outside the red line.

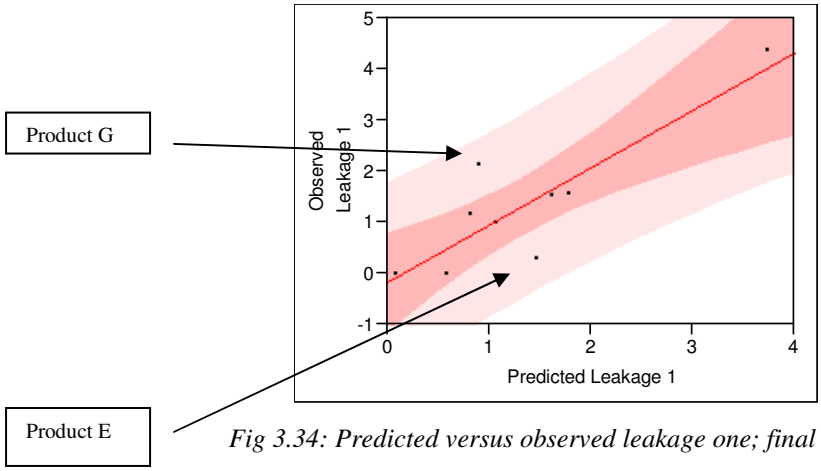


Fig 3.34: Predicted versus observed leakage one; final model

Thus, the final variables of the model are:

Input	Coeff	VIP
$constant	0.9918	
AAP	-0.2135	0.88
AGM amount	-0.3631	1.50
AQS caliper	0.1160	0.48
Core Cap. Z 2	-0.2931	1.21
CRC	0.1755	0.73
Maximum Uptake AQS	-0.2081	0.86

Fig 3.35: Final model for leakage 1

The un-scaled coefficients that relate to the raw data are obtained:

Input	Coeff
$constant	9.9889
AAP	-0.0699
AGM amount	-0.2189
AQS caliper	0.1484
Core Cap. Z 2	-0.0326
CRC	0.0657
Maximum Uptake AQS	-0.4047

Fig 3.36: Leakage 1 final model un-scaled coefficients

Influencing variables for leakage one are therefore “AGM amount” (“VIP”:1.5); the capacity of the core in zone two (“VIP”: 1.21); the capacity of the “AGM” under pressure (“AAP”) (“VIP”: 0.88) and the maximum liquid uptake of the “AQS” (“VIP”: 0.86). All these input variables are capacity related. In Fig. 3.37, the predicted versus the observed leakage values are compared.

Product	Δ	Δ in % from Obs	Pred	Obs
G	1.23	58	0.90	2.13
C	0.58	-	0.58	0.00
E	1.15	371	1.46	0.31
F	0.09	-	0.09	0.00
D	0.05	5	1.06	1.01
A	0.36	31	0.82	1.18
B	0.09	6	1.62	1.53
Q	0.23	15	1.79	1.56
P	0.64	15	3.73	4.37

Fig 3.37: Leakage 1 predicted versus observed leakage

The model does not predict urine leakage in the load cluster one very well. This is caused by the fact that the product "P" is the only influencing point in terms of leakage and therefore has an over-proportional influence. By removing this point, a cloud of data points remains, which makes it impossible to put one straight line through them. The input variables for leakage are all proven in terms of their prefix. The fig. 3.38 points out positive or negative correlations. The first row represents leakage one and each column gives one influencing input variable. For example, "AGM amount" has a negative influence on urine leakage in the load cluster one, which reflects the technical viewpoint, because the higher the "AGM" amount of a diaper, the less leakage will occur. A second important factor is the "Core Capacity Zone 2", which highlights the same negative correlation as "AGM amount". The explanation is that the more capacity in zone two, the more liquid is absorbed and the less urine leakage occurs. The factors "AAP" and "Maximum Uptake AQS" are negatively correlated. "AAP" represents the capacity of the "AGM" under pressure and "Maximum Uptake AQS" represents the maximum absorption of liquid without pressure. In both cases the correlations are in the right direction.

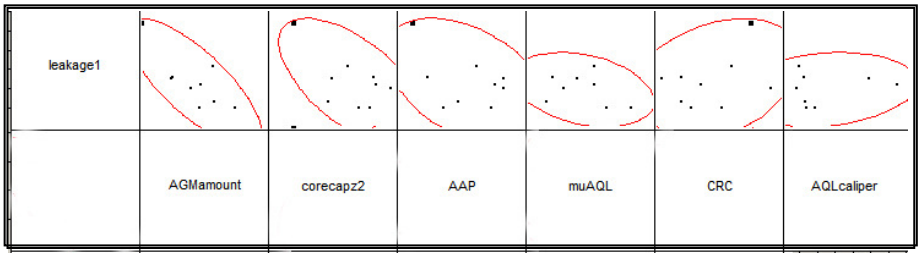


Fig 3.38: Leakage one; correlation indication

The predicted values are, in most cases, not exactly like the observed values and in two cases deviate more than 100 percent, therefore, this model cannot be used to make exact predictions but it allows the area of leakage probability to be roughly determined.

This model is meaningful from a technical liquid-handling point of view, but, due to its low predictability (Q^2=36.1%) and its low ability of variable explanation (R^2_x = 37.1 %;), it is not possible to use this model alone for competitive analysis. Further products are needed which are located between the product cloud and the urine leakage value of product "P", or even close the gap between product "K" and the remaining products. A further reason for the low correlation is probably the fact that all raw material properties are measured completely-saturated, which is not warranted in this load cluster (61-120milliliters). "Leakage 1" contributes to the overall leakage equations (chapter 3.1.2.6) with the probability of 31 percent of all urine changes (sum of all four load clusters is 100 percent).

3.1.2.6.3.2 Leakage 2 (181ml-240ml)

Leakage area two is the area in which 30.5 percent of all urine changes (day and night)[82] are accomplished. The model-building process is analogue to leakage one (chapter 3.1.2.6.3.1.). From a statistical point product "K" is identified as an outlier, due to the fact that it is an extreme value in the literal sense, it is not removed from the dataset. All variables with "VIP" values below 0.8 and coefficients below 0.1 are removed from the dataset and the model is run again with the reduced amount of variables. The important variables (including their quadratic terms) which explain leakage two are: the "Maximum Uptake AQS"; the "SFC" (the permeability of the swollen "AGM" gel bed) which is negatively-correlated to pulp amount and the "Core Time Zone 2". "AGM amount" plays a minor role and should be excluded following the 0.8 rule of thumb for "VIP" values, but to stay consistent over all leakage areas it is kept in the model (fig.3.39).

Input	Standardized Coeff.	VIP
$constant	17.0405	.
Maximum Uptake AQS	-0.8772	1.17
(Maximum Uptake AQS)^2	-0.0504	1.13
(SFC)^2	0.0003	1.08
(Core Time Z 2)^2	0.0002	1.00
SFC	0.0250	0.93
Core Time Z 2	0.0313	0.92
AGM amount	-0.2941	0.70

Fig 3.39: Explaining variables for leakage 2 (181-240mls)

The quality of the model has a "R_x^2" of 73.8 percent; a "R^2_y" of 73.2 percent and a "Q^2" of 57 percent. Product "P" and "B" differ from the remaining dataset.

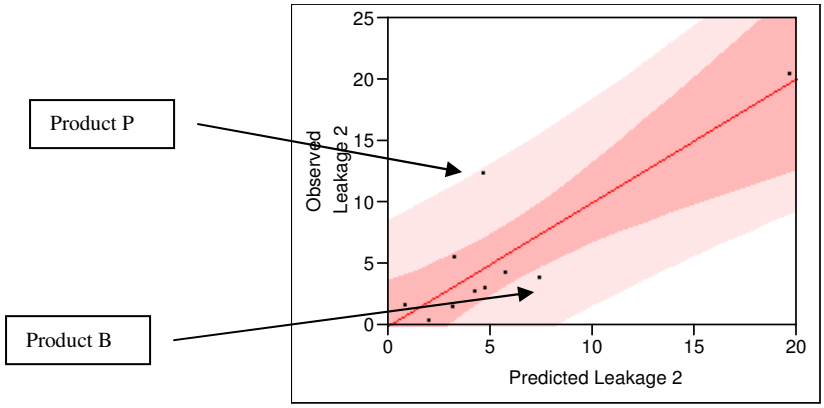


Fig 3.40: Predicted versus observed leakage[2]

The percentage confidence interval of the correlation of the influencing variables and urine leakage two (fig. 3.41) indicate that product "P" and product "K" may be considered as outliers, because they are outside the 95 percentage confidence interval. This is expected, based on the fact that these products, as low "Tier" products, have extremely high leakage values, therefore, they are not removed from the dataset.

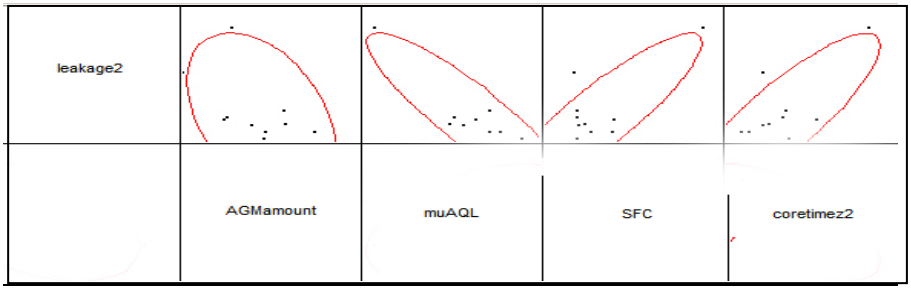


Fig 3.41: Correlations of leakage2 and the single important input variables

In fig. 4.43, all variables show the right direction of correlation in terms of leakage except "SFC". This implies the more "AGM amount" a diaper contains and/or the higher the "Maximum Uptake of the AQS" is, the less urine leakage occurs. For "Core Time Zone 2", it means the faster the liquid distribution in zone two of the core is, the less leakage occurs. In terms of "SFC", the model leads to the wrong conclusion that the higher the permeability of the swollen gel bed, the more leakage occurs. According to the fact that the "AGM" is not completely swollen in this area, "SFC" is replaced by its highly negative-correlated variable "pulp amount", which leads to the meaningful statement: the more pulp, the less leakage. In general, the direction of correlation influence is mainly driven by the extreme values of product "K" and product "P".

For seven out of the ten products, the failure of the predictions is 50 percent or higher and no direction in a general over- or under-prediction of the model can be determined. This

percentage is calculated by the difference between observed and predicted urine leakage value (**Δ**).

For the two products “P” and “B” which are not in the 95 percent confidence interval, product “B”, the assumption is the determination of the brand logo by “Expert Panelists” and therefore a lower actual leakage performance. For product “P”, an LA product which is completely unknown for the “STC Expert Panelists”, the assumption for the higher-than-predicted leakage value is chassis-based.

Product	Δ	Δ in % from Obs	Pred	Obs
G	2.32	42	3.22	5.54
C	1.6	421	1.98	0.38
E	1.66	54	4.72	3.06
F	0.84	50	0.85	1.69
D	1.45	52	4.22	2.77
A	1.62	105	3.17	1.55
B	3.5	90	7.40	3.90
K	0.78	4	19.65	20.43
Q	1.51	35	5.78	4.27
P	7.71	62	4.66	12.37

Fig 3.42: Predicted versus observed leakage values

Overall, the model explains the input variables and leakage well (“R_x^2”=73.8%, “R_y^2”= 73.2%). The prediction of the model is, with 57 percent, to low to use it for exact competitive leakage value predictions, but it can identify the probability area of urine leakage of the product. Compared to “Leakage 1”, “Leakage 2” also contains time-dependent factors. The most influencing variable is the “Maximum Uptake of the AQS”, followed by “SFC” and “Core Time Zone 2”, including their quadratic terms. Due to the fact that “Leakage 2” is not an area where the “AGM” is completely swollen, “SFC” is not used for the interpretation, but its negative correlating variable “pulp amount”. That means for leakage prevention it is important how much liquid the “AQS” can absorb, how much pulp is present in the diaper and how fast the liquid is distributed away from the second zone of the core. The “AGM amount” of the whole diaper is of minor importantance in this leakage area due to the fact that all tested diapers have, at this point in time, enough capacity.

3.1.2.6.3.3 Leakage 3 (181-240ml)

18 percent of all urine changes are accomplished in this load cluster.[82] As in the previous models, first, all quadratic and linear terms of the input variables, as well as all products, are taken into account for the analysis. Product “K” is again, from a statistical point of view, identified as an outlier but is kept in the analysis due to the fact that it is the only “tier four" product and therefore an extreme urine leakage value is to be expected. The remaining variables are “SFC”, “Core Time Z 2”, “Maximum Uptake AQS” and “CC time”. The low “VIP” value points out the smaller influence of the “AGM amount” on the overall model (fig. 3.43). The model is not as good as leakage two in terms of the explanation and predictability of the different factors (“R^2_x” = 62.5%; “R^2_y”= 71.0% and “Q^2”= 40.4 %).

Input	Coeff	VIP
$constant	22.8069	
SFC^2	0.1433	1.32
(Core Time Z 2)^2	0.131	1.21
SFC	0.131	1.21
Maximum Uptake AQS	-0.128	1.18
(Maximum Uptake AQS)^2	-0.123	1.13
Core Time Z 2	0.118	1.08
(CC time)^2	0.09	0.81
CC time	0.08	0.73
AGM amount	-0.043	0.4
(AGM amount)^2	-0.04	0.37

Fig 3.43: Important input variables on leakage 3

Like for “Leakage 1” a cloud of products is located in the left bottom corner of the predicted versus observed urine leakage chart (fig.3.44) and one product, located in the top right corner influences strongly the model.

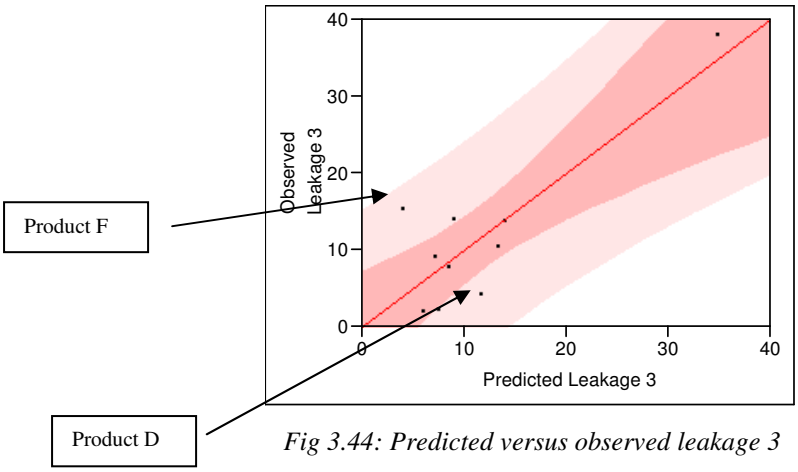


Fig 3.44: Predicted versus observed leakage 3

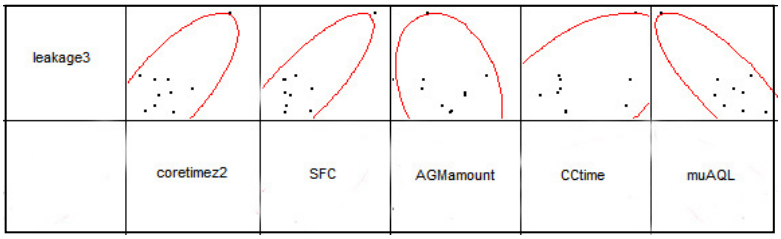


Fig 3.45: Correlation leakage 3 and important input variables

Fig. 3.45 highlights the strong influence of product "K" on the correlation of the single variables with the urine leakage in load cluster three. The five strongly-influencing urine leakage variables have a meaningful prefix, apart from "SFC", which is again replaced in the explanation through the negatively correlated "pulp amount". "Maximum Liquid Uptake AQL" and "AGM amount" have a negative correlation, which states the more liquid is absorbed, the less leakage occurs. "Core Time Z 2" and "CC time" have a positive correlation, which reveals the higher probability of urine leakage occurrence in dependency on the longer liquid distribution time.

As no noticeable deviation in the variable set of product "D" and "F" exists, the deviation of more than 95 percent from the remaining dataset is explained by the chassis.

Four out of 10 products own a delta (observed versus predicted urine leakage) value, which is 50 percent higher than the actual observed value (fig.3.46). The lower predictability of the model is expressed by the high differences between the predicted and observed values for some products, which make the single value prediction not meaningful.

Product	Δ	Δ in % from Obs	Pred	Obs
G	1.86	20.5	7.23	9.09
C	4.04	202	6.04	2.00
E	0.69	8.8	8.57	7.88
F	11.34	74.3	3.92	15.26
D	7.49	179	11.68	4.19
A	5.27	234	7.52	2.25
B	3.01	29	13.39	10.38
K	3.13	8.3	34.80	37.93
Q	0.37	2.7	14.07	13.70
P	4.9	35.3	9.00	13.90

Fig 3.46: Leakage 3: predicted versus observed leakage data

The model partly explains the output and input variables ("R^2_x" = 62.5%; "R^2_y"= 71.0%). However, the predictability ("Q^2"= 40%) is not meaningful and therefore, it cannot be used to predict the *exact* urine leakage value in terms of a competitive benchmarking analysis, but the *area* of urine leakage for the different products can be predicted. The

important capacity-related variables are: “Maximum Uptake AQS” and “pulp amount” and the time related ones are: “Core Time Zone 2” and “CC Time”. The “AGM amount” has no influence in this model, which is probably still due to the fact that all tested products have enough capacity.

3.1.2.6.3.4 Leakage 4 (241-300ml)

The last model is built for the urine leakage load cluster four (241-300ml). Due to the introduced “Theoretical Capacity” limit of the core (chapter 3.1.2.1.), neither product “B” nor product “K” are included in this analyzes. The higher the load cluster the fewer products (output variables) are incorporated in the model. This leads to the fact that a high number of input variables are correlated to a few number of output variables and by that the strength of the model suffers. The model has a “R^2_x” of 81.9 percent, a “R^2_y” of 84.6 percent and a “Q^2” of 50.4 percent. The important influencing input variables are “AAP”, ”AGM amount”, “Core Capacity Zone 2”; “AQS caliper” and “SFC” (fig. 3.47).

Input	Standardized coeff	VIP
$constant	95.5732	
AAP	-0.6957	1.23
AGM amount	-1.4203	1.21
AAP²	-0.0182	1.16
Core Cap. Z 2	-0.2189	1.10
(AGM amount)²	-0.0559	1.09
(Core Cap Z)²	-0.0012	1.06
(AQS caliper)²	-0.2917	0.92
SFC	-0.0095	0.86
AQS caliper	-0.8869	0.86
SFC²	0.0010	0.80
MDP2 AQS	-0.0014	0.76
(MDP2 AQS)²	0.0012	0.76

Fig 3.47: Important input variables on leakage 4

The chart (fig. 3.48) highlights a linearity in the dataset, with or without removing one data point. Product “F” (red square) differs the most from the other products, but, from a statistical point, it is not an outlier and therefore the reasons for the deviation are not discussed here.

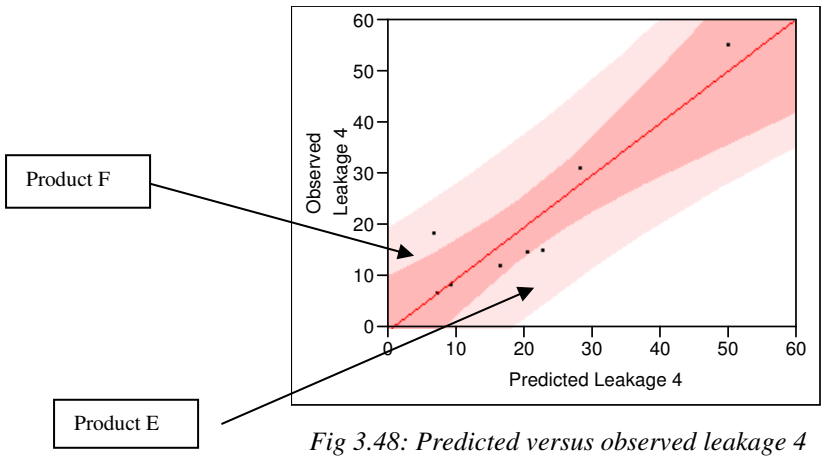


Fig 3.48: Predicted versus observed leakage 4

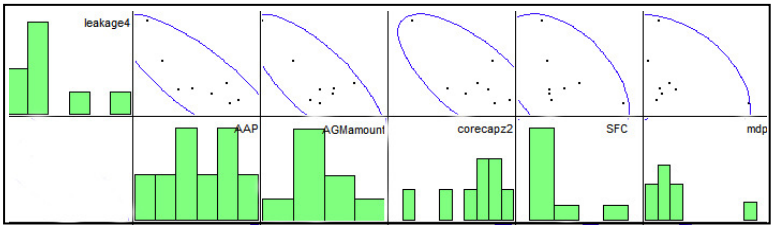


Fig 3.49: Correlation leakage 4 and important variables

This model has the highest explanation value in terms of urine leakage of all four urine leakage models ("R^2_x" = 81.9%; "R^2_y"= 84.6%). Nevertheless, the predictability of the model is not as good as expected with a "Q^2" of 50.4 percent. The high explanation ability of the model is connected to the measurements taken from fully saturated raw materials, which are related to the urine leakage data of the saturated diapers from the "Expert Panel". One reason for the low predictability is the small amount of products together with the deviation of product "F", which was probably caused by the chassis. The important parameters are all capacity-related. "AAP" is negatively-correlated to "Leakage 4" which means that the more liquid one gram of "AGM" absorbs under pressure, the less the diaper leaks. Additionally, the same negative correlation holds for "AGM amount" and "Core Capacity Zone 2". The negative correlation of "SFC" is no longer explainable with the "pulp amount", but due to the permeability of the swollen "AGM" gel bed. In a fully swollen diaper the "SFC" (permeability of the "AGM") becomes more and more important especially in combination with a bad "AGM" and pulp mixture, because the more liquid that travels through the gel bed, the less leakage occurs. The last important factor is the "Medium Desorption Pressure" of the "AQS" ("MDP2 AOS"), the lower it is, the more liquid is transferred into the "AGM and pulp" layer and the less leakage occurs. "MAP2 AQS" is an indication how easily liquid is released out of the "AQS" layer at a saturation of 50 percent. As easier the liquid leaves

the layer as higher the probability of having an empty “AQS” as intermediate storage system for the next gush arrival, as lower the probability of leakage.

Product	Δ	Δ in % from Obs	Pred	Obs
G	4.74	40	16.59	11.85
C	6.06	42	20.62	14.56
E	7.71	52	22.64	14.93
F	11.64	63	6.74	18.38
D	0.89	11	9.15	8.26
A	0.58	9	7.14	6.56
B	-	-	-	Excludes basen on Theor. Cap.
K	-	-	-	Excludes basen on Theor. Cap.
Q	2.69	9	28.37	31.06
P	4.93	9	49.97	54.90

Fig 3.50: Leakage 4: predicted versus observed leakage

Only 10.5 percent of the urine changes included in “BIG 3” are accomplished in this load cluster. As in the models for “Leakage 1”, “Leakage 2” and “Leakage 3” this model for “Leakage 4” is good at providing an estimation of the area of urine leakage probability for the single products, but not for predicting the exact value

3.1.2.6.3.5 Overall Leakage (61 - 300ml)

The single leakage models are built to provide, firstly, information about the different influencing raw material variables in the respective load clusters and secondly, they are intended to provide urine leakage predictions. The outcomes of the single models show that they can classify the products by the probability of urine leakage occurrence, but they do not predict the exact leakage value. To achieve a more exact predictability, the overall urine leakage model is built (load cluster: 61-300 milliliters). The model predicts the probability of total urine leakage based on the sum of the single probabilities of having a urine change, multiplied with the probability of having a urine leaked change in the respective load cluster (chapter 3.1.2.6.).

To validate the resulting equation, the observed and predicted overall urine leakage probabilities are compared. For example, for product “A” the observed leakage values are leak 1: 1.18; leak 2: 1.55; leak 3: 2.25; leak 4: 6.56. The sum of these single leakage values, multiplied with the urine change base of the respective load cluster lead to the overall observed leakage value for the load range of 61-300 mililiters:

Overall obs. leakage = 1.18*0.2868 + 1.55*0.3048 + 2.25* 0.1803 + 6.56*0.1045= 1.9

For the predicted total urine leakage value, the same multiplication as above is accomplished, but, for urine leakage values the single predictions of the respective load clusters are inserted into the equation to give urine leakage values. The same total urine leakage results are achieved by multiplying the single coefficients of each of the four equations with the probability of having a urine change in the respective load cluster. This leads to the total urine leakage equation (fig. 3.51). To achieve the predicted leakage values, the single values for each product are inserted and multiplied with the suiting coefficient – below, product A is used as an example. Finally, the results are subtracted from the constant.´

Input	Unstandardized Coeff.	Product "A" measured variables	Product "A" variable impact on overall leakage
$constant	22.1678		22.17
AAP	-0.0928	21.6	-2.00
AAP^2	-0.0019	466.56	-0.89
AGM amount	-0.3383	12.21	-4.13
$(AGM\ amount)^2$	-0.0074	149.08	-1.10
AQS caliper	-0.0502	3.15	-0.16
$(AQS\ caliper)^2$	-0.0305	9.94	-0.30
Core Cap. Z 2	-0.0322	102.44	-3.30
$(Core\ Cap\ .\ Z\ 2)^2$	-0.0001	10493.95	-1.28
CC time	0.2978	0.35	0.10
$(CC\ time)^2$	0.2228	0.12	0.03
Core Time Z 2	0.0179	41.94	0.75
$(Core\ Time\ Z\ 2)^2$	0.0001	1758.96	0.21
CRC	0.0188	27	0.51
Maximum Uptake AQS	-0.5830	9.6	-5.60
$(Maximum\ Uptake\ AQS)^2$	-0.0268	92.16	-2.47
MDP	-0.0001	18	0.00
MDP^2	0.0001	324	0.04
SFC	0.0139	33	0.46
SFC^2	0.0003	1089	0.27
Sum = predicted overall leakage			3.30

Fig 3.51: Overall leakage equation; weighted influence variable for product "A"

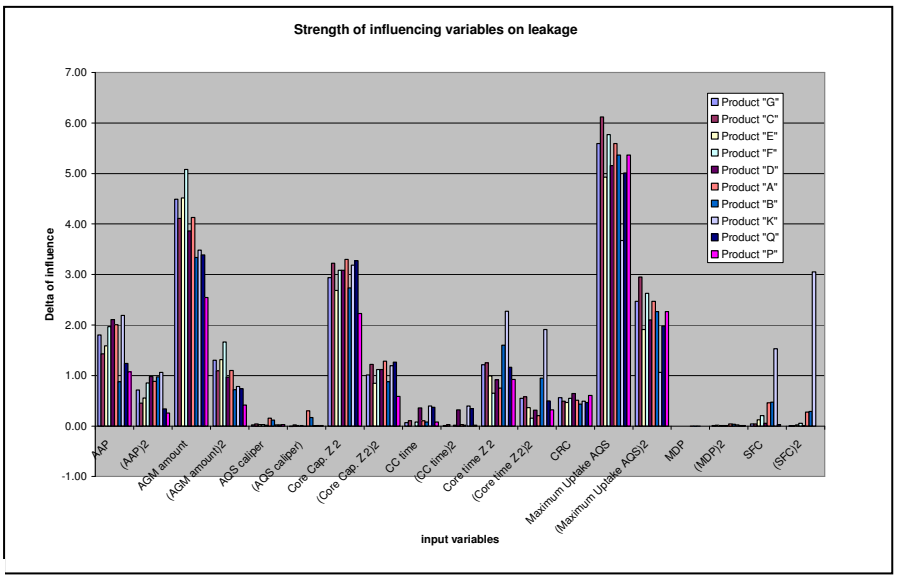


Fig 3.52: Overall urine leakage influencing variables

Fig. 3.52. gives an overview about all variables and their strength of influence per product. The predicted versus observed urine leakage percentages are compared (Fig. 3.53). The pink highlighted values indicate an over prediction of urine leakage and the yellow highlighted ones indicate an under prediction.

In terms of statistics, the model has a "R^2" of 80.4 percent and a "Q^2" of 70.4 percent.

Product	Δ	Δ in % from Obs	Predicted	Observed
G	0.9	17.4	4.28	5.18
C	2.02	101	4.02	2.00
E	1.77	44.3	5.77	4.00
F	3.49	67.2	1.70	5.19
D	1.9	69.1	4.65	2.75
A	1.4	73.7	3.30	1.90
B	3.89	111	7.39	3.50
K	5.97	27.7	15.57	21.54
Q	0.31	4	7.78	7.47
P	3.93	29.6	9.34	13.27

Fig 3.53: Overall urine leakage; predicted versus observed values

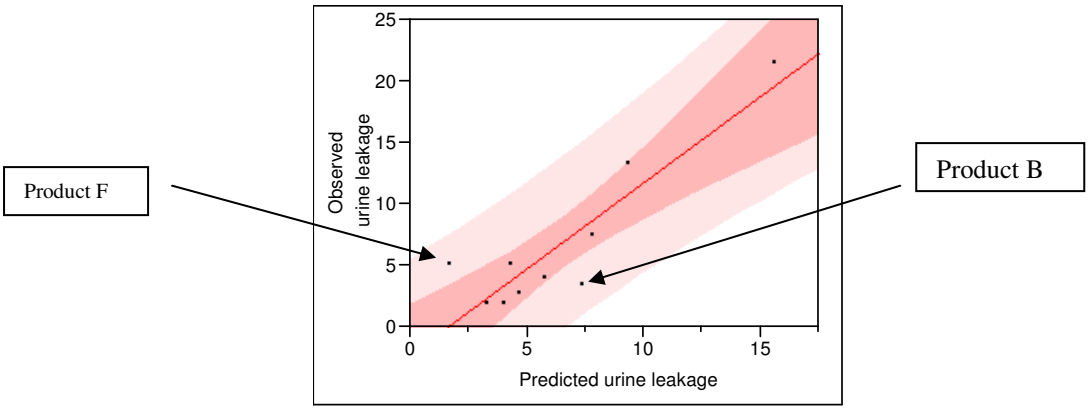


Fig 3.54: Observed versus predicted overall urine leakage

Referring to the "R^2" of 80.4 percent and the "Q^2" of 70.4 percent this model is a strong model which can be used for competitive analysis predictions. The dataset is strongly influenced from the products "K" and "F" (fig.3.54), but none of them are from a statistical side determined as an outlier. Without product "F" the "R square" increases to 90.4 percent and the "Q square" to 83.4 percent, the same without product "K" results in a "R square" of 45.4 percent and a "Q square" of 27.0 percent. Removing both products the "R square" yields to 68.6 percent and the "Q square" to 48.6 percent.

The difference of the predicted versus observed urine leakage percentage products is in five out of ten cases over 50 percent, which makes it impossible to use only the actual predicted numbers without considering the remaining dataset. In four out of ten cases the predicted leakage value is lower than the observed leakage value. For the remaining ones the model results are higher than the real observed leakage values.

This states that the "BIG 3 raw material to consumers' perception model" is a meaningful model for clustered leakage prediction. Although the model is not strong enough to predict the exact urine leakage probability of the products, to strengthen the model more lower "Tier" products need to be included.

Possible reasons for the difference in observed versus real leakage values are:

- observed leakage values multiplied with the average percentage of urine changes
- chassis influence
- consumers equity

3.1.2.6.3.5.1.1 Observed leakage based on Average Percent of Urine Changes

One possible reason for the deviation of predicted versus real leakage value in terms of product "F" is a possible failure implementation by multiplying the single percentages of urine leakage changes with the average percentage, instead of the actual percentage of urine changes of the respective load cluster. The actual percentages of urine changes per load cluster per product is multiplied with the percentage of leaked urine changes in the respective load cluster and yield into the actual observed overall leakage. These values are compared to the overall leakage values deriving from the average urine leakage percentages per product. Fig.3.55 provides with product "A" an example of the real leakage value calculated on the actual amount of changes.

Product "A"	Load cluster	# urine changes	% leakage	% urine changes	Overall percent of urine changes between 61-300ml
	60	63	0.00	4.94	
leak1	61-120	338	1.18	**26.51**	
leak2	121-180	453	1.55	**35.53**	
leak3	181-240	267	2.25	**20.94**	
leak4	241-300	122	6.56	**9.57**	
	301-360	32	12.5	2.51	**1.96**

Fig 3.55: Real overall leakage based on actual product change base

In the following table (fig.3.56.) the observed overall urine leakage values based on the average urine change base per load cluster are compared to the real overall urine leakage values based on the actual urine change base. A two sample "T-test", assuming equal variances, identifies that the two overall leakage sets are not significantly different from each other.

Product	Δ	Δ in % from Reality	Predicted	Observed	Reality
A	0.06	3.1	3.30	1.90	1.96
D	0.06	2.2	4.67	2.75	2.69
C	0.08	4.2	4.34	2.00	1.92
E	0.14	3.4	5.52	4.00	4.14
G	0.01	0.2	3.95	5.18	5.19
F	0.13	2.4	1.81	5.19	5.32
Q	0.69	10	7.84	7.47	6.88
B	0.88	20	7.52	3.50	4.38
K	6.1	39.5	15.43	21.54	15.44
P	0.34	2.4	9.34	13.27	14.01

Fig 3.56: Real overall leakage based on actual product change base

Product “K” and product “B” show variances in observed versus real leakage compared to the other products. This is caused by the different urine change distributions that product “B” and product “K” have in the different load clusters compared to the average over all products (fig. 3.57.).

Load cluster	Product “B” % urine changes	Product “K” % urine changes	Average over all 10 products % urine changes
61-120ml	35	25	29
121-180ml	37	25	31
181-240ml	24	8	18

Fig 3.57: Percent urine changes

The observed versus real leakage data does not explain the reason for product “F” being different from the rest of the dataset, but it points out possibilities to improve the model. The difference in calculating the overall leakage by the average load cluster or by the single respective urine changes per load cluster is not significantly different for “Tier 2" products, but it seems that for lower “Tiers” the consumer follow another diaper change pattern. This leads to the conclusion that to improve the model the calculation of overall urine leakage should split in “Tier1,& Tier 2” products and lower “Tier” products, so that the overall leakage can be calculated by using different average percentages for urine changes in the different load clusters.

3.1.2.6.3.5.1.2 Chassis Influence

The chassis influence on the overall leakage can be driven by any of the following:

- a bad fit; the diaper moves from the right position on the baby, and thereby gaps emerge where the liquid can easily flow out.
- a wrong design of the "Barrier Leg Cuffs"; for example, they are designed too low and the amount of liquid flows over them,
- the liquid permeability of the "Topsheet"

As diapers are those chosen with a variation of more than 50 percent of predicted versus observed leakage value (fig. 3.53). The products are "C", "B", "A", "F" and "D". Product "B" and "A" have the same chassis, therefore the first one is chosen based on the higher deviation. The model over-predicts the urine leakage of product "C" by 101 percent; "D" by 69.1 percent and "B" by 111 percent. The leakage value of product "F" is under-predicted by 67.2 percent. Product "C" and "D" are the two products with stretch elements in the chassis. To prove the first assumption of sagging, normally technical fit studies on babies are accomplished. Due to the fact that too few products from the same lot were available, laboratory (instead of "on baby") technical measurements are accomplished. The laboratory measurement of choice is the "Mannequin Diaper Sagging Test with Free Fall" (fig 3.58). This test correlates to the technical fit studies, accomplished on babies.

A size four mannequin is put in the drop stand with the diaper on it. It is filled with 225 milliliters of 0.9 percent saline solution. Afterwards, the mannequin is dropped twice in a free fall of 0.2 meters. The difference in the front and rear delta diaper position before and after the drop is measured.

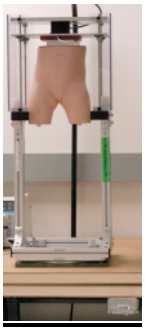


Fig 3.58: Mannequin Diaper Sagging Test with Free Fall

The middle of the squares in fig. 3.59 represents the area where 95 percent of the resulting values are located for one product. The upper and lower parts of the squares represent the area where the remaining five percent of the values are located. In fig. 3.59 product “C” (with only 1.5 cm of diaper shift from the start) is significantly better than product “D” (2.63cm shift) and “F” (with 2.52 cm shift). Product “B” performs significantly worse with a shift of 3.26 cm. The products “F” and “D” are both located in the medium field.

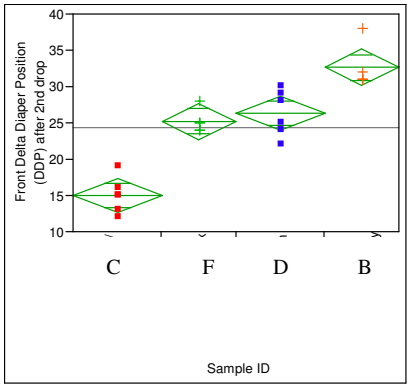


Fig 3.59: Analysis of Front Delta Diaper Position after 2nd drop by sample

In terms of rear delta diaper position after the second drop, the differences in stretched versus non-stretched products get clearer. Products “C” and “B” keep their first and fourth positions with a diaper shift of 1.27 cm and 3cm, respectively. Product “D” (diaper shift 2.02 cm) performs better than product “F” (2.74cm). The outcomes of the rear delta diaper position are also reflected in the rise measurement (fig. 3.60., fig. 3.61). The rise is from the top of the metal plate front to top of the metal plate rear, through the crotch. The metal plate holds the mannequin in place. These additional measurements are accomplished because a diaper can shift downwards from the original position on the baby, but the core can bunch in the crotch area and, based on that, be in the initial position.

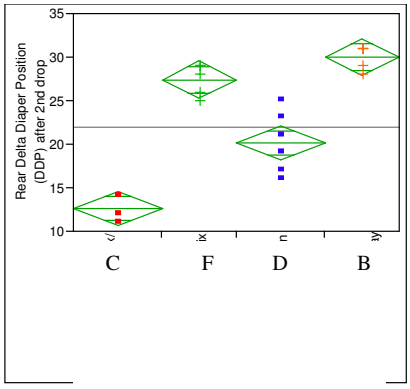


Fig 3.60: Rear Delta Diaper Position after 2nd drop

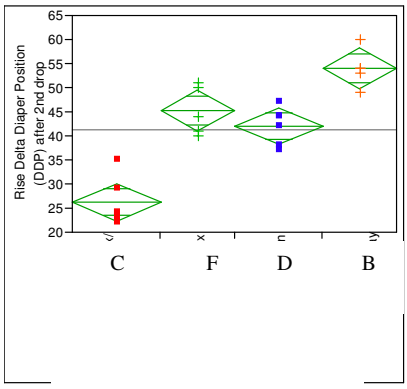


Fig 3.61: Rise Delta Diaper Position after 2nd drop

For product "C" the “BIG 3 raw material model” predicts a 4.02 percent leakage and 2.0 percent leakage is observed. Looking at the results of the drop down test, this implies that the good fit of the chassis holds the liquid in the core, which minimizes the percentage of observed leakage. For product “F”, the model predicts less leakage than actually observed. Looking at the sagging test, this diaper sags more than product “C", so the emerging gaps could be a reason for leakage occurrence. Product “D” behaves analogue to product “C". The model predicts more urine leakage than is observed in the “Expert Panel”. A reasonable explanation is that product “D” has a chassis with a good fastening system and therefore a good fit which helps to prevent leakage, even though the diaper is loaded with 225mls. The chassis of product “B” shows the highest impact on sagging. The model also predicts a much higher percentage of leakage occurrence than is observed. For this case, the explanation based on the chassis influence is not applicable.

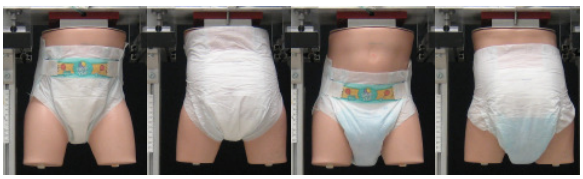


Fig 3.62: Product “B” unloaded front& back, loaded with 225ml front &back

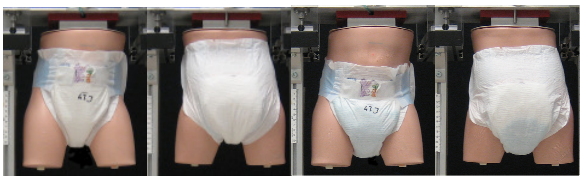


Fig 3.63: Product “C" unloaded front& back, loaded with 225ml front &back

The remaining parts which are chassis-related can be checked with different laboratory methods. One method is the “Topsheet run off” test, which measures how fast liquid is transferred through the “Topsheet”. The second laboratory method is based on the “Barrier Leg Cuffs”, which are tested to see if liquid can run out. Additionally, the height of the “Barrier Leg Cuffs” play a role, as the higher they are, the less leakage can occur, although the diaper sagging occurs.

Product “C" has the highest “Barrier Leg Cuffs” (3.8 mm) out of these four products, additionally, it shows no “Barrier Leg Cuff Run Off” and a low “Topsheet Run Off” which means that the liquid is led quickly through the “Topsheet”. Compared to product C, product “B” shows a high “Topsheet Run Off” and a cuff height of only 3.2 cm, which indicates, together with the high sagging chassis, a higher probability of leakage.

Product “F ” has, after product “B”, the second highest liquid run off from the “Topsheet”, but no “Barrier Leg Cuff Run Off” with a “Barrier Leg Cuff” height of 3.6 cm (the second highest). This explains the under-prediction of the model, because unbonded liquid is on the surface of the core longer and, together with the sagging identified in the “Mannequin Drop Test”, it results in more leakage.

Product	BLC run off left	BLC run off right	TS run off 1st gush	TS run off 2nd gush	TS run off 3rd gush	TS run off 4thgush	Liquid distribution [cm]
C	0	0	0	0	0	0.4	25.6
B	0	0.4	29.1	22.1	38.9	39.5	16.1
F	0	0	0.2	0	0.8	14.9	32.5
D	0	0.1	0	0	0	2.9	28.6

Fig 3.64: Laboratory measurements as indicators for the urine leakage of a diaper

The shift of the diaper based on the chassis, as well as the probability of liquid on the “Topsheet” and leaking “Barrier Leg Cuffs” and their height, fits in the overall picture and explains the over- and under-predictions of the “BIG 3 core-related raw material to consumer model”. The only product which has less observed leakage than predicted leakage and is not explained by any of the indicators is product “B”. This is possibly related to the consumers’ mindset. This means mothers can be influenced by the brand logo on the diaper and assess it better than it actually is, based on the fact that they get the diapers from this company. This hypothesis is not proven within this study, because it was based on time and costs not possible to place the diapers for this project in an external “Expert Panel”.

3.1.2.6.4 BIG 3 Raw Material to Consumer Summary

By using the “Partial Least Squares” method as a statistical technique combined with a quadratic correlation, a stable overall model results. The model identifies the maximum liquid uptake of the “AQS”, the “AGM amount”, the “Core Capacity Zone 2”, the “AAP” and the "Core Time Zone 2" as the main impacting raw material variables for urine overall leakage. Looking at the single load cluster models, leakage one and leakage three are weak models. This is due to the uneven product distribution over the loading areas and the low amount of products in general. Neither the single urine leakage models nor the overall urine leakage model can be used for exact value leakage predictions, only for prediction of the leakage area the product is in. This is due to the fact that consumers

have different diapering habits for lower “Tiers” and the sagging of the chassis has an additional influence on the probability of urine leakage. To stabilize the model in the future, further products need to be added, especially lower “Tier” products.

3.1.2.6.5 Development of the BIG 3 Holistic Measurement Model

Besides the “raw material properties to consumer” model, a model between “holistic measurements and consumers” is developed. For this model, the same basic approach (fig. 3.25) as for the raw material overall leakage model is applied. This implies firstly, the model building of the four 60 milliliters urine leakage clusters and afterwards, their combination to the overall urine leakage model. In “Copy Claim Support” the diaper performance is based on holistic diaper measurements. The advantage of measurements on the complete diaper is the consideration of interactions between the single layers of the core. The disadvantage is that the reason for a good or bad diaper performance is not known exactly. The holistic measurements are also split into time and capacity. The time measurements are accomplished by the “Speed of Acquisition with Balloon Applied Pressure” (“SABAP”) test. For capacity measurements, the “Capacity 2.07 kPa” and the “Dunktest” are used. The differences between these capacity methods are that “Dunktest” is used to determine the maximum capacity of the diaper without pressure, whereas “Capacity 2.07 kPa” provides data for the maximum capacity under pressure. The “Absorption Before Leakage +” (“ABL+”) test combines time and capacity in one method. The diaper is put on a baby doll (mannequin) and different pressures, caused by the lying mannequin, are applied to different diaper zones. Additionally, the influence of the chassis on the baby is considered in this method. Furthermore, the two semi-holistic methods “Core Time Zone 2” and “Core Capacity Zone 2” are used as for the raw material performance determination.

The whole dataset is used as input variables, because of the unknown strength of influence of the single variables on overall urine leakage in the load area (61-300 ml). The model-building process is accomplished in exactly the same way as for the “raw material properties to consumer methods”, which connotes the determination of linear and quadratic correlations amongst the holistic methods (chapter 3.1.2.6.2.2.). For the holistic measurements, the correlations are determined for each load cluster, because “SABAP” measures the time after the first, second, third and fourth gush. For leakage cluster four the “SABAP” time of the fifth gush is extrapolated. This yields, through the

accomplished variable substitution, the following reduced input variable set per load cluster:

- Leakage 1 (61-120ml):
  "SABAP2"; "Core Capacity Zone 2"; "Dunktest"; "Capacity 2.07kPa"
- Leakage 2 (121-180ml):
  "SABAP3"; "Core Capacity Zone 2"; "Dunktest"; "Capacity 2.07kPa"
- Leakage 3 (181-240ml):
  "SABAP4"; "Core Capacity Zone 2"; "Dunktest"; "Capacity 2.07kPa"
- Leakage 4 (241-300ml):
  "SABAP5"; "Core Capacity Zone 2"; "Dunktest"; "Capacity 2.07kPa"

As a next step a "Partial Least Squares" model is built. The single model-building steps are exactly the same as for the raw material properties (chapter 3.1.2.6.3.) and will therefore not be explained in detail here. The threshold for excluding a variable is 0.8 for the "VIP" and for the standardized coefficient +/- 0.1. In general, the "VIP" value indicates how large the influence of a variable is on the overall urine leakage model, as the higher the "VIP" value is, the higher the influence of the variable is on overall urine leakage.

3.1.2.6.5.1 Leakage 1 (61-120ml)

In leakage area one, 26.7 percent of all urine changes are accomplished. The prediction power of the model ("Q^2") is very low at 12.5 percent. The input variables ("R_x^2") are explained to 62.9 percent and leakage ("R_y^2") to 64.4 percent. The strength of the urine leakage predicting measurements "SABAP 2", "Core Capacity Zone 2" and "Capacity 2.07kPa", including their quadratic terms, is similar. The capacity measurement method "Dunktest" has no influence on this load cluster.

Input	Standardised Coefficient	Unstandardised Coefficient	VIP
$constant	0.991802	4.44241	-
Core Cap. Z 2	-0.168434	-0.01872	0.99
(Core Cap. Z 2)^2	-0.158553	-0.00010	0.93
Capacity 2.07kPa	-0.175844	-0.00417	1.03
(Capacity 2.07kPa)^2	-0.170353	-0.00001	1.00
SABAP2	0.167126	0.02504	0.98
(SABAP2)^2	0.178497	0.00026	1.05

Fig 3.65: Important variables for leakage 1

For this model, product "K" needed to be removed from the dataset otherwise it resulted in negative leakage predictions. The final predicted versus observed urine leakage chart is shown in fig. 3.66.

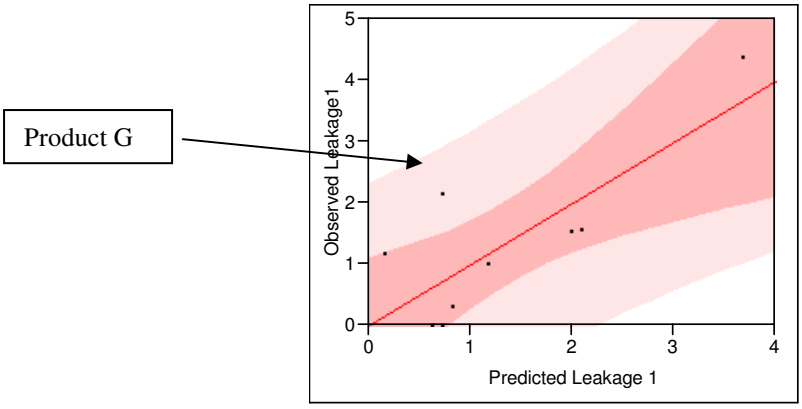


Fig 3.66: Leakage 1 predicted versus observed leakage

The model shows a medium to good ability to explain the input variables and urine leakage values ("R_x^2"= 62.9%; "R_y^2"= 64.4%), but a very low predictability ("Q^2"=12.5%), which is based on the fact that all capacity methods are based on fully-saturated cores. At such low levels, all products, apart from product "K", are similar in leakage occurrence, which makes it hard to model. Product "K" needed to be excluded to

construct a stable model. The product "G" seems to be different from the dataset, although it is not an outlier. The reason for the deviation is not explainable. In terms of prediction, the model predicts five out of ten leakage values with a deviation of more than 50 percent of the actual observed leakage value. Additionally, if accomplishing a ranking scale, and just looking at the area of urine leakage prediction as good to bad, the model still predicts differently to the observed urine leakage areas. This makes it, together with the low predictability, a model which cannot be used for predictions without increasing the base size of the products or improving the capacity measurement methods.

Product	Δ	Δ in % from Obs	Prediced	Observed
G	1.4	66	0.73	2.13
C	0.64	64	0.64	0.00
E	0.52	168	0.83	0.31
F	0.74	74	0.74	0.00
D	0.18	18	1.19	1.01
A	1.02	86	0.16	1.18
B	0.47	31	2.00	1.53
Q	0.54	35	2.10	1.56
P	0.68	16	3.69	4.37

Fig 3.67: Leakage 1 predicted versus observed leakage

3.1.2.6.5.2 Leakage 2 (121-180ml)

The model of experienced urine leakage load cluster two has an increased predictability, which is about 63.5 percent. The model, with a "R_x^2" of 60.1 percent, does not explain the input variables as well as model "Leakage 1", but the urine leakage explanation is quite high with a "R_y^2" of 86.2 percent. The main influence on the model is "SABAP 3" time, followed by the "Core Capacity Zone 2", including their respective quadratic terms. The lowest influence is the "Capacity 2.07kPa", which is reasonable because this is a measurement accomplished to determine the capacity of the whole diaper under pressure.

Input	Standardised Coefficient	Unstandardised Coefficient	VIP
$constant	1.12038	12.90900	-
Core Cap. Z 2	-0.214968	-0.06216	1.07
(Core Cap. Z 2)²	-0.205466	-0.00033	1.02
Cap 2.07kPa	-0.161461	-0.00996	0.80
(Cap 2.07kPa)²	-0.152769	-0.00001	0.76
(SABAP3)	0.221993	0.03334	1.17
(SABAP3)²	0.234233	0.00016	1.17

Fig 3.68: Main influencing variables on leakage2

The dataset “Leakage 2” also does not include product “K” based on the negative prediction urine leakage values - the same reason as in “Leakage 1”-. The chart (fig. 3.69) highlights product “P” as an influencing point towards which the remaining products are stretched.

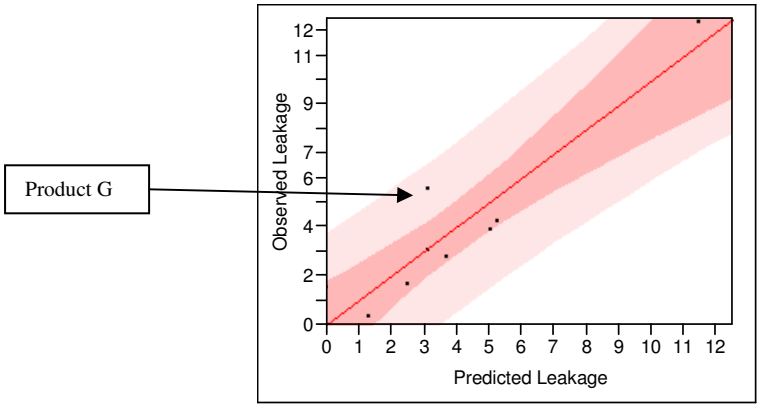


Fig 3.69: Predicted versus observed leakage 2

“Leakage 2” is much more predictable than “Leakage 1”, with a “Q^2” of 63.5 percent. Also, the ability of the model to explain urine leakage is, at 86.2 percent, quite strong.
The point in the blue circle, product “G”, is not an outlier but it deviates from the remaining dataset. As in “Leakage model 1”, the reason for the deviation is unknown. Two out of ten leakage predictions have more than 50 percent variance. This means product “C” has an observed leakage of 0.38 percent and the model predicts 1.31 percent. The same is true for product “A”, the model predicts no leakage, but 1.55 percent of leakage is observed.

Product	Δ	Δ in % from Obs	Predicted	Observed
G	2.41	44	3.13	5.54
C	0.93	239	1.31	0.38
E	0.07	2	3.13	3.06
F	0.8	47	2.49	1.69
D	0.91	33	3.68	2.77
A	1.55	155	0.00	1.55
B	1.17	30	5.07	3.9
K	9.34	46	11.09	20.43
Q	0.99	23	5.26	4.27
P	0.9	7	11.47	12.37

Fig 3.70: Leakage2 predicted versus observed leakage

3.1.2.6.5.3 Leakage 3 (181-240mls)

For “Leakage 3” the holistic measurements “Core Time Zone 2” and “Dunktest” are quadratic correlated (3.1.2.6.2.2.) and therefore only the variable “Dunktest” is used as an input variable. The strength of influence on urine leakage prediction of the variables are in decreasing order: “Capacity 2.07kPa”, “ABL+”, “SABAP 4” and “Dunktest”. The predictability (“Q^2”) of the resulting model is 83.5 percent and the “R_x^2” is 85.1 percent, urine leakage is explained by 97.9 percent. The small 95 percentage confidence interval of this model indicates the well prediction of the model.

Input	Standardised Coefficient	Unstandardised Coefficient	VIP
$constant	1.12153	26.23550	-
ABL	-0.30997	-0.07381	1.00
(ABL)^2	-0.27065	-0.00010	0.95
Capacity 2.07kPa	0.32158	0.05218	1.09
(Capacity 2.07kPa)^2	0.38367	0.00008	1.14
Dunktest	-0.26821	-0.02053	0.93
(Dunktest)^2	-0.20028	-0.00001	0.85
SABAP4	0.28212	0.03132	0.97
(SABAP4)^2	0.33365	0.00007	1.03

Fig 3.71: Leakage 3 impacting variables

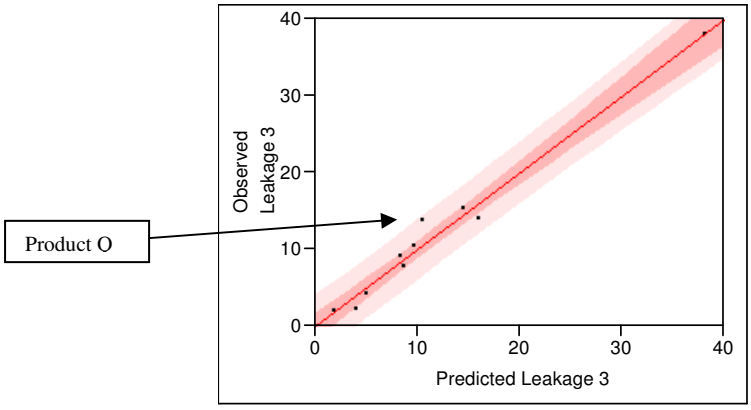


Fig 3.72: Leakage 3

The model is very strong in terms of input and output variable explanation as well as urine leakage prediction. Therefore, in fig. 3.72, the dots are closer to a line than to a cloud, product “K” is still the influencing point of the dataset. Product “Q” has a high deviation from the remaining dataset, which is not explainable. In terms of predicted versus observed leakage values, product “A”, as the only product, shows more than a 50 percent difference between the predicted versus observed leakage value. The reason for

that is not completely related to the diaper core, because otherwise the remaining diapers would also need to show effects which are bigger than 50 percent. A hypothesis is that the consumers, who test the diapers in the "Expert Panel", identify the brand logo on the diapers and automatically rate less leakage. Considering this fact the "Leakage 3" model can be used to predict the leakage values.

Product	Δ	Δ in % from Obs	Predicted	Observed
G	0.8	9	8.29	9.09
C	0.11	6	1.89	2.00
E	0.82	10	8.70	7.88
F	0.8	5	14.46	15.26
D	0.89	21	5.08	4.19
A	1.68	75	3.93	2.25
B	0.69	7	9.69	10.38
K	0.22	0.6	38.15	37.93
Q	3.24	24	10.46	13.70
P	2.02	15	15.92	13.90

Fig 3.73: Leakage 3 predicted versus observed

3.1.2.6.5.4 Leakage 4 (241-300ml)

Like "Leakage 3", the "Leakage 4" model is a very strong model ("$R_x^{2"}$ = 81.8%; "R_y^{2}" = 96.6% and a "Q^{2}" of 88.3%). The main influencing variable is "SABAP 5" with its quadratic term, followed by the quadratic term of "Core Capacity Zone 2" and "Capacity 2.07kPa" and "Dunktest" including their quadratic terms. For this model, the products "B" and "K" are excluded based on the limit of the "Theoretical Capacity" of the core.

Input	Standardised Coefficient	Unstandardised Coefficient	VIP
$constant	1.25703	66.15480	-
(Core Cap.Z 2)²	-0.35664	-0.00254	1.05
Capacity 2.07kPa	-0.05348	-0.01444	0.92
(Capacity 2.07kPa)²	-0.03661	-0.00001	0.89
Dunktest	-0.17658	-0.02977	0.91
(Dunktest)²	-0.16540	-0.00002	0.88
SABAP5	0.23121	0.04265	1.13
(SABAP5)²	0.24045	0.00008	1.17

Fig 3.74: Influencing variables on leakage 4

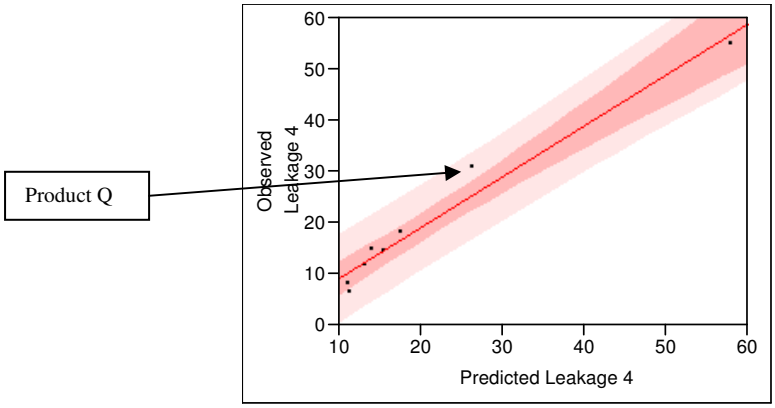


Fig 3.75: Predicted versus observed leakage 4

The model for the load cluster "Leakage 4" is the strongest model of all four urine leakage prediction models. The products "P" and "Q" are the influencing points of the model. This indicates that for the future more low-performing products need to be added in order to strengthen the model. The products still show deviations in terms of the 95 percent confidence interval of the model.

For almost all products the predictions are close to the observed values. Product "A" is the only product with a difference in predicted versus observed urine leakage higher than 50 percent. The difference in percentage of observed versus predicted urine leakage deviation is so much higher than for the other products, without any recognizable difference in "Barrier Leg Cuff" or "Topsheet" issues, that the hypothesis that the consumer detects the brand name and therefore rates in another way, is strengthened.

Product	Δ	Δ in % from Obs	Predicted	Observed
G	1.85	15.61	13.17	11.85
C	0.86	5.9	15.42	14.56
E	0.87	5.83	14.06	14.93
F	0.95	5.2	17.43	18.38
D	2.73	33	10.99	8.26
A	4.79	73	11.35	6.56
B		-	-	-
K		-	-	-
Q	4.82	15.5	26.24	31.06
P	3.02	5.5	57.92	54.90

Fig 3.76: Leakage 4 predicted versus observed leakage

3.1.2.6.5.5 Overall Leakage – Holistic Measurements

The overall leakage model is built in the same way as the raw material one. The non-standardized coefficients of the single important variables are multiplied with the average percentage of urine changes in the respective load cluster. Afterwards, all the weighted non-standardized coefficients of one variable are added together resulting in one non-standardized coefficient for overall urine leakage. These coefficients are multiplied with the respective variables for one product to achieve the predicted overall leakage equation. This approach is proven by predicting the single leakage per load cluster and multiplying each predicted leakage value with the average amount of urine changes for the respective load cluster. The average urine changes in load cluster one (61-120ml) are 28.7 percent, in load cluster two (121-180ml) 30.5 percent, in load cluster three (181-240ml) 18.03 percent and in load cluster four (241-300ml) 10.46 percent.[82]

Input	Leakage 1	0.287	Leakage 2	0.305	Leakage 3	0.180	Leakage 4	0.105	Overall
$constant	4.442	1.274	12.909	3.935	26.236	4.730	66.155	6.920	**16.859**
Core Capz. Z 2	-0.019	-0.01	-0.062	-0.019					**-0.024**
(Core Cap. Z 2)^2	-0.000	0.000	-0.000	-0.000			-0.003	-0.000	**-0.000**
Cap 2.07kPa	-0.004	-0.001	-0.01	-0.003	0.052	0.009	-0.014	-0.002	**0.004**
(Cap. 2.07kPa)	-0.000	0.000	-0.0000	0.000	0.000	0.000	-0.000	0.000	**0.00**
SABAP 2	0.025	0.007							**0.007**
(SABAP 2)^2	0.000	0.000							**0.000**
SABAP 3			0.033	0.010					**0.010**
(SABAP 3)^2			0.000	0.000					**0.000**
SABAP 4					0.031	0.006			**0.006**
(SABAP 4)^2					0.0000	0.000			**0.000**
SABAP 5							0.043	0.005	**0.005**
(SABAP 5)^2							0.000	0.000	**0.000**
ABL					-0.074	-0.01331			**-0.0133**
(ABL)^2					-0.000	0.000			**0.000**
Dunktest					-0.021	-0.004	-0.030	-0.003	**-0.007**
(Dunktest)^2					-0.0000	0.000	-0.000	0.000	**0.000**

Fig 3.77: Construction of the overall urine leakage model

For three out of ten products, the deviation of predicted versus observed leakage is more than 50 percent. In contradiction to the raw material model, the holistic model constantly over-predicts urine leakage for all products, especially for product “A”, product “D”, product “C” and product “E”. The same products “C” and “D” which were already outliers in the raw material model are also outliers here, the reason for this is attributed to their stretchy chassis. The high deviation in urine prediction of product “A” can be explained by the consumers’ mindset. Calculating only the first three clusters for product

"A", the model results in 0.75 percent of urine leakage, whereas the observed urine leakage values are higher with 1.2 percent. This leads to the conclusion, as also seen in the single model, that, only in the higher load clusters, product "A" appears as the only product with a high deviation between observed and predicted leakage value. As proven in the "mannequin drop down test" (chapter 3.1.2.6.3.5.1.2.) the chassis, when loaded, does not fit on the baby as well as the diaper chassis of product "C". This leads to the fact that something else, such as consumers' mindset, is the key driver for the good observed leakage performance, which is not related to the core or the chassis design.

Product	Δ	Δ in % from Obs	Predicted	Observed
G	0.95	18.3	6.13	5.18
C	3.09	155	5.09	2.00
E	1.97	49.3	5.97	4.00
F	2.53	48.8	7.72	5.19
D	3.81	139	6.56	2.75
A	2.74	144	4.64	1.90
B	0.37	10.6	3.87*	3.50*
K	9.42	43.7	12.12*	21.54*
Q	2.02	27	9.49	7.47
P	1.37	10.3	14.64	13.27

*Fig 3.78: Overall leakage predicted versus observed leakage(*only leakage area 1-3)*

Under predicted

Over predicted

Plotting all the products in a predicted versus observed urine leakage chart (fig. 3.79) results in an "R square" of 71 percent. This is based on the fact that the two products "K" and "P" are included even though they are only included in leakage model one to three (61- 240ml).

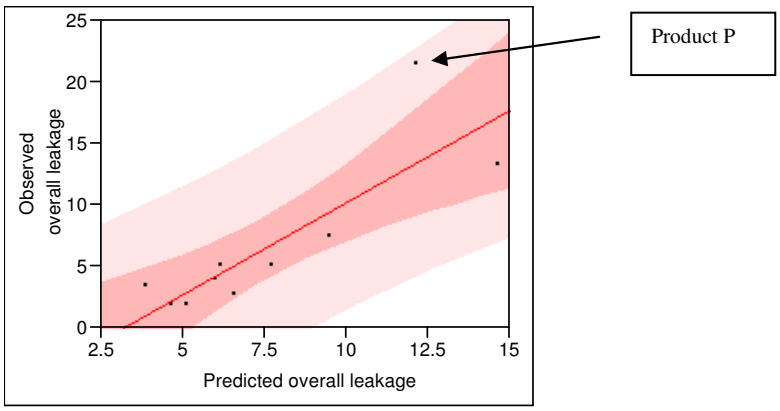


Fig 3.79: Overall predicted leakage versus observed leakage (all products)

Removing these two products gives an “R square” of 95.1 percent and a “Q square” of 97.12 percent result (fig. 3.80.). To ensure the outcomes, a higher number of lower performing products needs to be incorporated in the model.

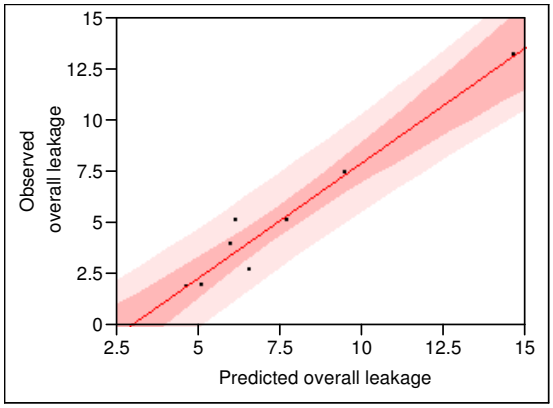


Fig 3.80: Overall predicted leakage versus observed leakage (without product “K” and “P”)

3.1.2.6.5.6 Summary BIG 3 Holistic Measurements - Consumer

The overall urine leakage model based on the holistic measurements has a high predictability of urine leakage (“Q^2”= 95.1%) and explains urine leakage to 97.12 percent. The model consistently over-predicts urine leakage in all the products included from leakage one to four. For three out of eight products, the over-prediction is more than 50 percent. For two of them this can be explained by their chassis influence, tested by the mannequin drop down test. For product “A” this explanation does not apply. A possible reason could be the consumers’ influence. This hypothesis cannot be verified, due to the fact that the products are not placed in the same way in an external panel.

3.1.2.7 BIG 3- Raw Material to Consumer Model Application

This chapter provides information about the key drivers of urine leakage occurrence and their strength of influence per product. This provides the basis for a core performance ranking and an explanation of the different core performances. The "AQS" and the "AGM and pulp" layer derive from the "BIG 3 raw material to consumer" model (chapter 3.1.2.6.3.) as the main influencing layers in terms of core performance. Therefore, the physical and chemical properties of their performance are discussed in detail.
The performance of the important layers as well as the whole core is compared to the raw material costs via a ranking.

3.1.2.7.1 Identifying Influence Factors of Observed Leakage Values

The "BIG 3 raw material to urine leakage model" provides the urine leakage influencing variables and their strength for each product. This is acquired by the overall leakage equation deriving from the "BIG 3 raw material to consumer model" (fig. 3.81). The coefficient of each single variable is multiplied with the value of this variable for each single product. The resulting numbers reflect the impact of the single variables on leakage for the related product.

Input	Unstandardized Coeff.	Product "A" measured variables	Product "A" variable impact on overall leakage
$constant	22.1678		22.17
AAP	-0.0928	21.6	-2.00
AAP^2	-0.0019	466.56	-0.89
AGM amount	-0.3383	12.21	-4.13
(AGM amount)^2	-0.0074	149.08	-1.10
AQS caliper	-0.0502	3.15	-0.16
(AQS caliper)^2	-0.0305	9.94	-0.30
Core Cap. Z 2	-0.0322	102.44	-3.30
(Core Cap . Z 2)^2	-0.0001	10493.95	-1.28
CC time	0.2978	0.35	0.10
(CC time)^2	0.2228	0.12	0.03
Core Time Z 2	0.0179	41.94	0.75
(Core Time Z 2)^2	0.0001	1758.96	0.21
CRC	0.0188	27	0.51
Maximum Uptake AQS	-0.5830	9.6	-5.60
(Maximum Uptake AQS)^2	-0.0268	92.16	-2.47
MDP	-0.0001	18	0.00
MDP^2	0.0001	324	0.04
SFC	0.0139	33	0.46
SFC^2	0.0003	1089	0.27

Fig 3.81: Percentage of influencing variables on overall prediction of product "A"

Product “A” is used as an example in the chart below (fig. 3.82.) and the strength of influence of the variables are given in percentages to allow a better comparability.

The following variables impact on urine leakage. They are arranged from high to low influence: “Maximum Uptake AQS” (23%), “AGM amount” (18%), “Core Capacity Zone 2” (14%); the quadratic term of “Maximum Uptake AQS” (10%), “AAP” (9%), the quadratic term of “Core Capacity Zone 2” (6%); the quadratic term of “AGM amount” (5%) and of less importance the quadratic term of “AAP” (4%); “Core Time Z 2” (3%); “CRC” (2%); “AQS caliper” (1%) and the quadratic terms of “AQS caliper” and “Core Time Zone 2”.

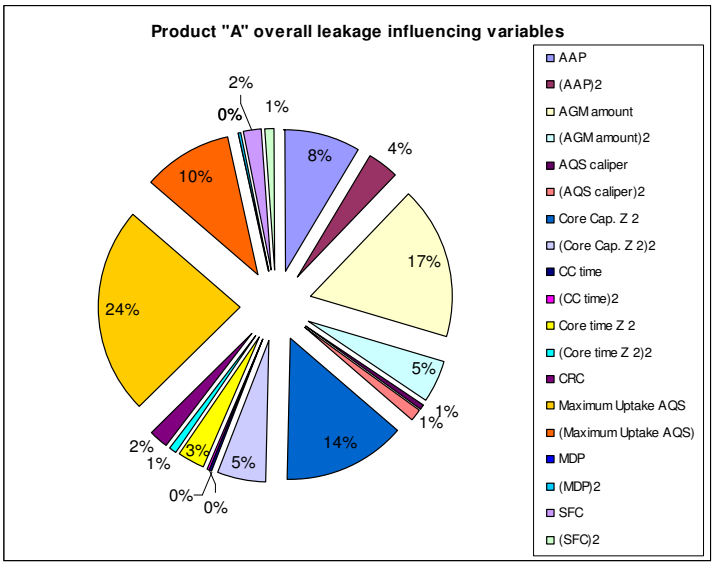


Fig 3.82: Percentage of influencing variables on overall prediction of product “A”

3.1.2.7.2 Performance Ranking of the Different Cores

Different possibilities exist to evaluate the performance of products, such as holistic measurements in the laboratory and the “Expert Panel” ratings of mothers – the latter are marked here as observed leakage or the predicted leakage of the model. In general, the “Expert Panel” is the method of choice, because the products are tested by consumers under real life conditions. The additional advantage is that influence factors like the market price of the product have no effect on performance, as in consumers’ normal lives, because the panellists do not pay for these products. As proven in chapter 3.1.2.1. the percentage of urine leakage cannot be compared between different regions due to consumers’ diapering habits and mindsets and babies’ dimensions. Therefore, this product estimation will concentrate on only the ten products tested in the “STC Expert Panel”. As the model is built in the loading area, where nearly 88 percent of all urine changes take place (61-300 milliliters), the performance estimation of the product is also

accomplished in this area. The performance explanation is given based on the **predicted leakage** of the developed "BIG 3 Raw Material to Consumer" model, as the reasons for the deviation between predicted versus observed leakage are already explained. The products are ranked as follows: 25 percent of all products are in the upper and lower categories and 50 percent are placed in the medium area.

Product	Observed leakage	Predicted leakage
A	1.90	4.33
C	2.00	5.08
D	2.75	5.57
B	3.50	8.27
E	4.00	6.77
G	5.18	5.31
F	5.19	2.81
Q	7.47	8.64
P	13.27	10.33
K	21.54	15.90

Fig 3.83: Performance ranking in the load range of 61-300ml

Table (fig. 3.83) highlights the observed leakage occurrence in the "Expert Panel" by a ranking. Products "A", "C" and "D" are the best products in the group, followed by products "B", "E", "G", "F", and "Q" in the medium field. Product "P" and "K" are the worst products in terms of overall urine leakage within the predicted set of diapers.

All explanations for the different predicted core performances are based on the performances of the single variables (fig. 3.84-3.86). The following tables provide an overview about the important variables, determined by the "BIG 3" model, in terms of urine leakage. To get a quick overview about the performance of the single product cores on specific variables the same kind of ranking, as used in fig. 3.83., is used again

Product	Maximum Uptake AQS [g/g]	Product	AQS time [s/60ml]	Product	AGM amount [g]
P	11.2	K	16	P	7.52
C	10.5	A	21.29	B	9.86
F	9.9	B	23.14	Q	10.01
A	9.6	F	35.25	K	10.3
G	9.6	C	37.97	D	11.43
B	9.2	E	38.66	C	12.16
D	8.85	Q	41.53	A	12.21
Q	8.6	P	43.08	G	13.28
E	8.45	G	43.48	E	13.34
K	6.3	D	111.99	F	15.01

Fig 3.84: Urine leakage prediction influencing raw material variables

Product	Core Cap.Z2 [g]	Product	Core Time Z 2 [sec/60ml]	Product	AAP [g/g]
P	69.25	F	36.49	P	11.6
E	83.31	A	41.94	Q	13.4
B	84.85	D	51.39	C	15.4
G	91.03	P	51.72	E	17.1
F	95.58	E	55.52	G	19.4
K	98.92	Q	65.05	F	21.2
C	99.97	G	67.92	A	21.6
Q	101.63	C	70.14	B	22.6
A	102.44	B	89.57	D	22.68
D	108.52	K	127.14	K	23.6

Fig 3.85: Urine leakage prediction influencing raw material variables

Product	CRC [g/g]	Product	SFC[cm3*g/g*E-7]	Product	Pulp amount [g]
B	23	P	0	K	0
Q	25	Q	2	B	3.01
E	25	C	3	A	5.15
K	26	G	3	F	12.4
C	26	D	3.81	P	15.63
A	27	E	9	C	16.31
F	29	F	15	Q	17.26
G	30	A	33	G	18.1
P	32	B	34	E	18.6
D	34	K	110	D	19.91

Fig 3.86: Urine leakage prediction influencing raw material variables

In the following core performance explanation, the percentage of influence of the variable on overall urine leakage is the sum of the linear and quadratic term of the variable.

3.1.2.7.2.1 BIG 3 – Good Performance Ranking

The three cores, which show the lowest predicted urine leakage occurrence (fig. 3.83), belong to products “F”, “A” and “C”. All three cores include the same ranking order of important variables. Including the quadratic terms of these variables, 90 percent of the overall predicted leakage is explained by “Maximum Uptake AQS”, “AGM amount”, “Core Capacity Zone 2”and “AAP”. The remaining ten percent is composed of “Core Time Zone 2”; “SFC”, “CRC” and “AQS caliper”. The “BIG 3 – raw material properties to Consumers’ perception of urine leakage” model delivers the core of product “F” as the one with the lowest percentage of overall urine leakage in the loading area of 61-300 milliliters. The two key parameters of urine leakage prediction are “Maximum Uptake of the AQS” with an influence of 36 percent and “AGM amount” with an importance of 29 percent (fig. 3.87.). For both key parameters, product core “F” shows the highest performance values (fig. 3.83.). Product “F” uses an average advanced “AGM”, visible in the medium “AAP” value, combined with no core profiling technology (tested via the “Bromocresol Green Test”). This states that the proportion of “AGM” and pulp in each zone of the diaper is the same. The result is a medium performance level on “Core Capacity Zone 2” - the third leakage-influencing factor - with 18 percent. On the other hand, the “Core Time Zone 2” has a high performance, which plays, only to four percent, a role in overall urine leakage.

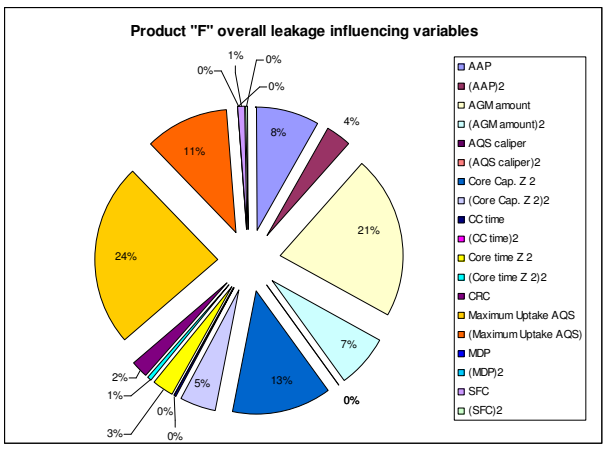


Fig 3.87: Product ”F”; influence of variable on leakage

Product “A” 's core performance for leakage is dependant to 33 percent on “AQS” to and to 23 percent on the “AGM” amount. The “AQS” of core “A” has a medium to high liquid uptake and a strong ability to distribute liquid over the storage core. This core uses a profiling technology to achieve maximum “Core Capacity Zone 2” by using a medium

amount of sophisticated “AGM”. The technology of the core uses a good proportion of pulp to advanced “AGM” which leads to a good liquid distribution in zone two even though a higher “AGM” concentration exists in this area.

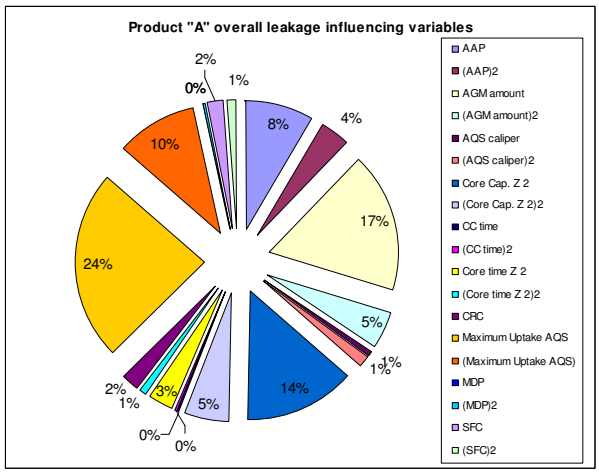


Fig 3.88: Product “A”; influence of variable on leakage

Product “C” has a different design approach compared to product “A”. In terms of core “C”, the high ability of the “AQS” to uptake liquid is reflected in a five percent higher influence on overall urine leakage in the “Maximum Uptake of the AQS”, compared to core “A”. From a technical design point of view the “AQS” of core “C” has a mid-ability to distribute the liquid horizontally. Therefore, more liquid arrives in zone two of the storage core. This means, from a technical point of view, a high capacity must be available, which is the case with the medium to high “Core Capacity” in this zone, influencing the overall leakage percentage to 19 percent. The sparsely-developed “AGM” with a medium to low “AAP” and “SFC” performance, is blended with three times more pulp than in the case of product “A”. Based on the low permeability of the “AGM” and the profiling, a worse performance in “Core Capacity Zone 2” is yielded, which accounts for the overall urine leakage at seven percent.

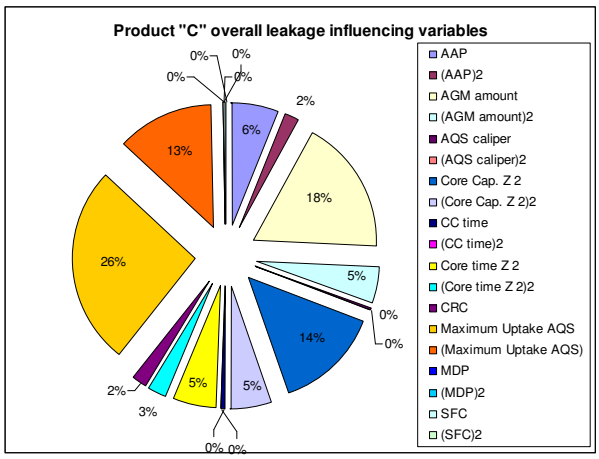


Fig 3.89: Product "C"; influence of variable on leakage

3.1.2.7.2.2 Medium Performance Ranking

In this category product cores "G", "D", "E", "B" and "Q" are presented.

The core of product "G" has the same overall core design as the one of "F", but contains a smaller amount of raw material which is noticeable, for example, in the lower basis weight of the "AQS", which succumbs to the wet collapse of the fiber structure and hence leads to a lower liquid uptake and a worse ability to distribute liquid over the core. This is mirrored in the 3 percent less influence of the "Maximum Uptake of the AQS" and "AGM amount" on overall urine leakage compared to product "F". The liquid impinges in zone two, which needs to have a high storage core capacity and a good liquid distribution ability. The high non-profiled "AGM amount" blended with a high cellulose proportion, results in a medium "Core Capacity" and "Core Time" in zone two. The "AGM" itself is, as in the case of product "F", only of a medium developed "AGM" generation.

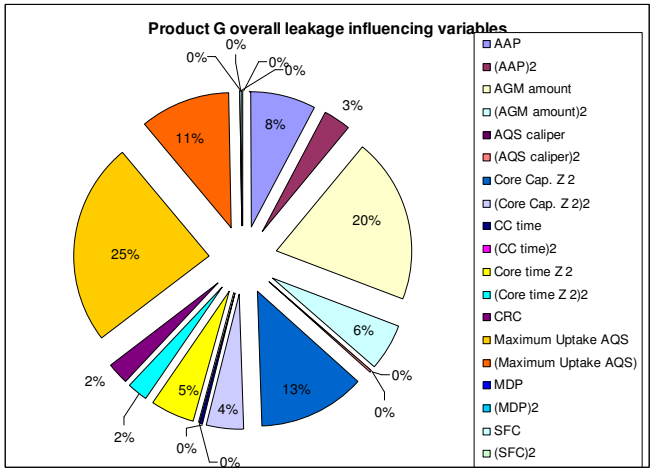


Fig 3.90: Product "G"; influence of variables on leakage

The core of “D” has the advantage of a highly-developed “AGM” technology combined with a profiled “AGM” distribution in the core. The “AAP” has an influence of 14 percent and the “AGM amount” has an influence of 21 percent on overall urine leakage prediction. The profiling and the high capacity value of the “AGM” leads to the best “Core Capacity” in the second core zone out of all the products. Product “D” uses the highest amount of pulp - four times as high as product “A”. It achieves only a medium “Core Time” in zone two, driven by the non-homogenous blending of the core. The weakness of this product is a combination of the low-performing “AQS” and the slow liquid distribution in zone two. In terms of product “D”, the medium liquid uptake of the “AQS” constitutes 31 percent to the overall urine leakage value. The variable “AQS time”, correlated to the “AGM amount”, shows the worst performance of all products based on the low resilience caused by the fiber type and bonding technology.

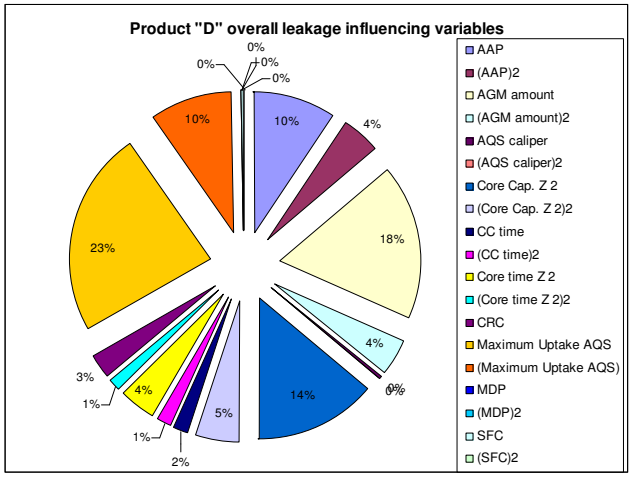


Fig 3.91: Product “D” influence of variables on leakage

In terms of product “E”, the “Maximum Uptake of the AQS” has an impact on the overall urine leakage to 33 percent as in the case of product “A”. The leakage influence of the “AGM amount” is very high at 28 percent. The “AQS Maximum Uptake”, the “AQS time” as well as the physical properties of the “AGM” and its quantity are in the medium range. This yields, combined with the non-profiled core system, in a worse “Core Capacity” and a medium “Core Time” in zone two.

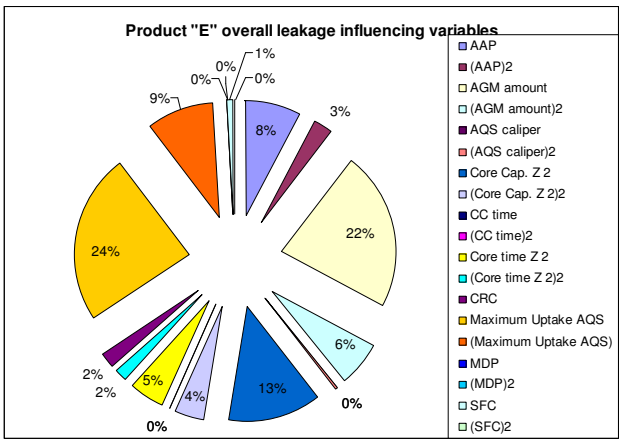


Fig 3.92: .Product "E"; influence of variables on leakage

Product "B" and product "A" have an identical core technology. The core of "B" contains less "AQS" and "AGM" material compared to the core of product "A", but both use a similarly-developed "AGM" generation. The influence of input variables on leakage is 33 percent for liquid uptake of the "AQS", which is as much as for product "A". The influence strength of the single variable on leakage differs for product "B" and product "A" in terms of "AGM amount" (18 percent for B instead of 23 percent for A), "Core Capacity" (17% for B instead of 20% for A) and "Core Time" (11 percent for B instead of 4 percent for A). The medium "AGM amount" blended with the low pulp amount results in a bad "Core Capacity" and a bad "Core Time" in zone two, even though core profiling is used.

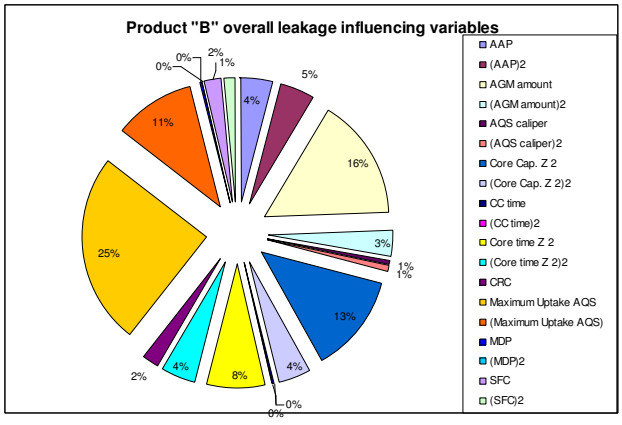


Fig 3.93: Product "B"; influence of variables on leakage

Product "Q" and "C" both have the same core technology. The two products differ in that product "Q" has a smaller amount of "AGM" and a lower basis weight of the "AQS". Additionally, its "Maximum Uptake of the AQS" influences the urine leakage perception to 34 percent, "AGM amount" to 21 percent and "Core Capacity Zone 2" to 23 percent.

Product “Q” has a medium “AQS” liquid uptake and “AQS Time” performance; additionally, it contains a medium quantity of “AGM amount”. The “AGM” performance is located in the lower area with less capacity under pressure (“AAP”). The “Core Time” in zone two is also located in the medium performance level, probably caused by a high “AGM amount” in zone two which is, on the other hand, responsible for the good “Core Capacity” in this zone.

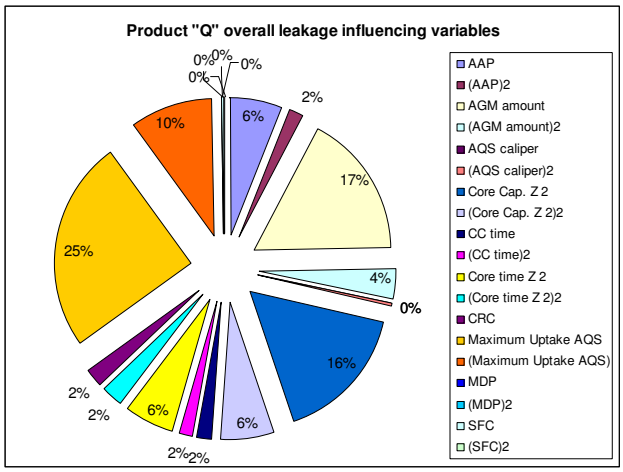


Fig 3.94: Product “Q”; influence of variables on leakage

3.1.2.7.2.3 Low Performance Ranking

The two low Tier products “P” (“Tier 3.5”) and “K” (“Tier 4”) are located in this category. The fragmentations of the single variables differ from those in the high and medium performance area. In terms of product “P”, the variable “Maximum Uptake AQS” owns 44 percent of the proportion of urine leakage perception, eight percent more than the highest value of any of the other products. The core of this product is extremely split. On the one hand, it owns the best performance in “AQS” liquid uptake of all products, but, on the other hand, it performs badly in all remaining input variables, apart from a medium liquid distribution in the storage core, due to the low amount of undeveloped “AGM”.

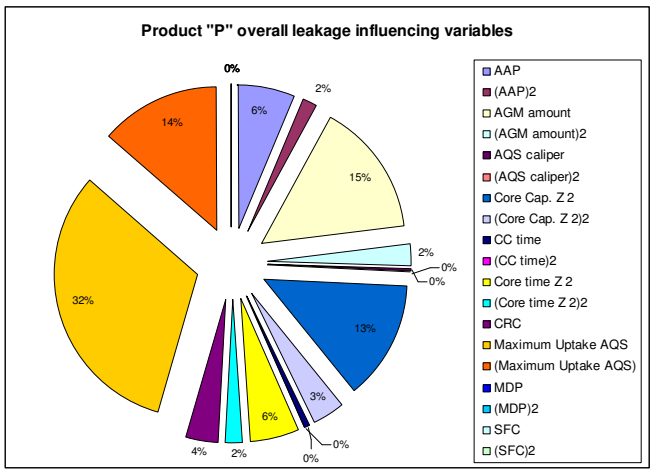


Fig 3.95: Product "P"; influence of variables on leakage

The last product in this dataset, product "K", has a completely different design, which is perceivable in the more evenly-distributed fragmentation of the influence of the different variables. Maximum liquid uptake of the "AQS" only has an influence of 18 percent, which is 15 percent less than that of the other products. The low influence of the "AGM amount" is based on the low amount of "AGM" within the product. The superior "AGM" technology has an influence due to the high "SFC" value of 16 percent, 14 percent more than for every other product. Additionally, the "Core Time" has a seven percent higher influence compared to other products. Produkt "K" is badly performing in "Core Time" and "Maximum Uptake" of the "AQS", because of the missing cellulose. The "AAP" value is very high, which helps, together with the core profiling, to achieve a medium capacity, despite the low "AGM amount" in zone two.

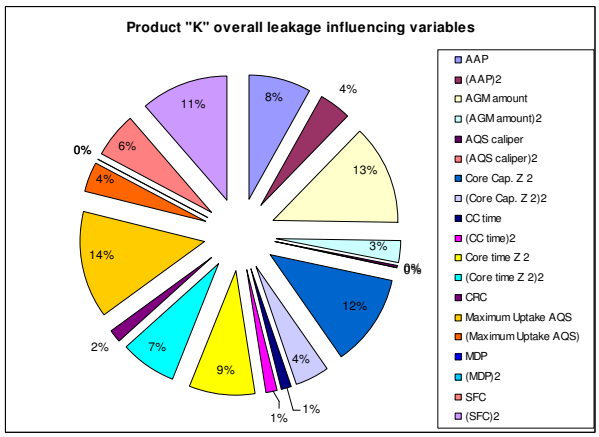


Fig 3.96: Product "K"; influence of variables on leakage

3.1.2.7.2.4 Summary Performance Ranking of the Core

The good performing product cores show three different designs to achieve an overall good performance. Product “F” uses a high amount of medium advanced “AGM” in a non profiled core in combination with a high “AQS” liquid uptake. This combination achieves in the model the lowest urine leakage influence. The high uptake of the “AQS” shows a medium ability to distribute liquid horizontally, which means that a high amount of liquid enters zone two and only because of the high pulp amount a good horizontal liquid distribution is accomplished. Product “A”, the second best performing product, has a medium liquid absorbing “AQS” and a medium amount of “AGM”, which is balanced by the “AGM” profiling. This system has a high ability to distribute liquid not only in the “AQS” but also in the core which is pointed out by the good “Core Time”. Additional through the profiling of the high advanced “AGM” the liquid can be absorbed. Product “C” achieves it good urine leakage prevention by the combination of the high liquid uptake of the “AQS” and the good capacity of core zone two, caused by the good profiling of the medium amount of “AGM”. In terms of liquid distribution this product is in the medium performance area for the “AQS” and in the bad performance area in terms of “Core Time”.

In the medium performance area a on the one hand products having the same core design than product in the high performance area, but contain less raw material, which lead consequently to a higher urine leakage occurrence. This applies for product “B”, which mirrors the core technology of product “A” and product “G” which reflects the core design of product “F”. The remaining product have a medium to worse “Maximum Uptake” of the “AQS” in common. Product “D” has an excellent “AGM and pulp” layer performance, based on the high performances of “Core Capacity”, “Core Time”, driven by the mixture of advanced “AGM” and high pulp amount. The diaper performance is restricted by the low “Maximum Uptake AQS” and the low “AQS time”, which leads to the fact that the liquid from a gush is not absorbed in an intermediate storage system to get there distributed, but it is absorbed directly by the high pulp amount of the core and needs then to be distributed.

Product “E” offers a better ability of liquid distribution in the “AQS”, but the “AQS” provides also a bad intermediate storage system. Additionally is the capacity in the second zone of the diaper low, which leads to the fact that the liquid can not be absorbed there in higher gushes, combined with the medium “Core Time” this leads to higher urine leakage occurrence. The “AQS” of product “Q” as the last product in this performance

category has a worse ability to store liquid intermediately and distribute it over the core. The medium “Core Time” in zone two combined with the good “Core Capacity” in this zone is not able to balance this, which leads to a medium to worse urine leakage occurrence.

In the worse performance category are the product “P” and “K”. Both designed as low “Tier” products and therefore they contain fewer raw materials in all areas. Product “P” has the advantage of the high “Maximum Uptake” of the “AQS”, although it performs worse for all remaining variables. In terms of product “K” the “Maximum Uptake AQS” is worse, but the “AQS” has a medium ability to distribute the liquid. The “AGM and pulp” layer contributes worse to further liquid distribution and works based on its medium ability of “Core Capacity” in zone two, which is based on the low “AGM amount”.

3.1.2.7.3 Performance of Raw Materials

Based on the outcomes of the “Big 3 raw material to consumer” model and the product performance ranking the importance of the “AQS” and the “AGM and pulp” layer on overall urine leakage occurrence is highlighted. Therefore the two raw materials “AQS” and “AGM” are determined closer for the ten products to identify the properties, which lead to the different performances.

Like in the case of the product performance ranking for the variables the green/yellow and red performance ranking is accomplished. This implies that for each variable 25 percent of the products are located in the upper and lower performing area (green and red highlighted) and 50 percent of the products are located in the medium performance area.

To achieve an overall performance ranking of the holistic raw material per product, the red, yellow and green performance scale of the important raw material variables are used. The green marked fields are provided with a one, the yellow marked ones with a two and the red ones with a three. The different numbers are multiplied with the average influence of the variable on urine leakage, like for example for “Maximum Uptake AQS” 34.5 percent (fig.3.97.). This average influence number is calculated, as mentioned above, on all ten products. As lower the resulting sum of multiplied performance numbers (1, 2, 3) as better the performance of the raw material of this product is. For each product a concluding explanation is given based on the physical and chemical properties of the raw material.

3.1.2.7.3.1 Performance Acquisition System

The “AQS” of a diaper is designed to absorb liquid fast and build an intermediate storage system, which distributes liquid horizontally over the diaper core. The “BIG 3 Partial Least Squares Raw Material Model” identifies the “Maximum Uptake” of the “AQS” and the “AQS time” as the variables with a high input on leakage. “AQS time” is highly negative quadratic correlated (69.3 percent) with “AGM amount”, which derives from the factor substitution (chapter 3.1.2.6.2.1.), therefore it is not directly mentioned in the model. “AQS time” reveals to the ability of the “AQS” to distribute 60 milliliter of 0.9 percent saline solution horizontally through a standardized piece of AQS (35mm).

The overall performance ranking is given based on the outcome of the “BIG 3 raw material to consumer model” on the one hand and on the other hand on the physical performance parameters.

Product	Maximum UptakeAQS [g/g]	AQS time [s/60ml]	number*average influence	Ranking Performance
K	3	1	1.257	**5**
A	2	1	0.912	**2**
B	2	2	1.134	**4**
F	1	2	0.789	**1**
C	1	2	0.789	**1**
E	3	2	1.479	**7**
Q	2	2	1.134	**4**
P	1	3	1.011	**3**
G	2	3	1.356	**6**
D	2	3	1.356	**6**
average % influence	0.345	0.222		

Fig 3.97: Ranking of the “AQS” of the different products

The “Maximum Uptake” of the “AQS” is given in capacity uptake (in gram) of 0.9 percent saline solution per gram “AQS” (“Maximum Uptake AQS”). The quantity of liquid uptake depends on the void volume of the “AQS” and thereby on the available space between the fibers, the fiber/liquid contact angle, the surface tension of the liquid and the medium pore radius. Considering the “Young-Laplace” equation, the medium pore radius (r) corresponds to the “Medium Absorption Pressure” (“MAP”) in the equation p, at the same surface tension (γ) and the advancing contact angle (Θ) of the liquid.

$$p = \frac{2\gamma * \cos\Theta}{r}$$

Fig 3.98: Young-Laplace Equation

The “MAP2” of the “AQS” is the suction power of the “AQS” after the first gush. This value is used because the whole model is based on the assumption of saturated media (chapter 3.1.2.2.). Based on this, an “AQS” made of a non-resilient web underlies a wet collapse after the first gush, which reduces the amount of void volume in the layer and thus results in a lower “MAP” value for the following gushes.

Product	Maximum Uptake AQS [g/g]	Product	AQS time [s/60ml]	Product	MDP2 AQS [cm hydro head]	product	MAP2 AQS [cm hydro head)]
P	11.2	K	16	Q	7.8	A	6
C	10.5	A	21.29	D	8.68	C	4.9
F	9.9	B	23.14	P	8.87	D	4.9
A	9.6	F	35.25	E	9	K	3.8
G	9.6	C	37.97	G	9.2	P	3.4
B	9.2	E	38.66	F	10	B	3.2
D	8.85	Q	41.53	C	10.6	E	3.2
Q	8.6	P	43.08	K	12.4	G	2.8
E	8.45	G	43.48	B	16.2	Q	2.13
K	6.3	D	111.99	A	18	F	1.1

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Product	AQS BW (s/sqm)	Product	AQS caliper [mm]	Product	AQS caliper/BW
C	67	A	3.15	A	0.05
A	65	B	2.34	B	0.04
B	65	C	0.84	P	0.02
E	55.5	F	0.58	C	0.01
F	52	E	0.54	G	0.01
Q	48	P	0.53	F	0.01
K	45	Q	0.52	C	0.01
G	34	K	0.42	E	0.01
D	34	G	0.4	D	0.01
P	31	D	0.32	K	0.01

Fig 3.99: Ranking of the main raw material performances by products.

The “AQS time” depends on the medium pore size, as the smaller the pores, the less liquid can travel through within the same time period. The pore size depends on the basis weight of the “AQS” as well as the resilience.

The resilience of the web is dependent on:

- The faser type, for example “PET” is very resilient.
- The fiber diameter; the thicker it is, the more resiliency it has.
- The number of crimps per fiber; the higher the number of crimps, the more stable the fiber is.
- The crimping angle; the larger it is, the more stable the web is.[68,69]

Due to the fact that within this project only finished “AQS”s are examined, the number of crimps per fiber and the crimping angle could not be determined. Only the fiber titer (thickness of the fiber) is determined by the “Environmental Scanning Electron Microscopy” (“ESEM”) pictures.
Additional measurements, which are accomplished to explain the liquid performance properties, are the fiber type and determination of web consolidation technology. The different polymers are determined by their melting points (“PET” ~ 260 °C; “PP”~165 °C and “PE” ~120°C) using “Differential Scanning Calorimetry” (“DSC”). The exact fiber morphology, for example, “Linear Low Density PE” cannot be determined. This does not allow for the determination of the exact proportion of the different fibres, because the necessary input of the specific molar mass of the molecule, which is needed to convert the heat of fusion from J/g in kJ/mol, is unknown. Hence, the proportion is assumed roughly by using the J/g information.

3.1.2.7.3.1.1 Best Performing Acquisition Systems

As shown in the performance ranking (fig. 3.97.) the best performing “AQS”s are contained in the diaper cores of product “C”, “F” and “A”. Two main different design approaches exist between these three products. Product “C” and “F” are both designed to have a high liquid uptake, “F” with 9.9 g/g and “C” with 10.6 g/g. Both have a medium ability to distribute liquid horizontally (“F” = 35.32 sec/ 60ml and “C” = 37.97 sec/ 60ml). Product “A” is designed the other way round, that means for a fast liquid distribution (“A” = 21.29 sec/60ml) and medium “AQS uptake” (“A” 9.6 g/g).
Product “C” is made of three types of fibres “PP”, “PE”, “PET” in the proportion 2.5:5:1. This implies the use of bicomponent fibres, “PET” and “PP”, both sheathed with “PE”. “PET” is used to achieve a highly-resilient web and, probably due to a supply shortage of

[68] **Froehlich,U.:**Determination of contact angle of current AQL 3; 2006

[69] **Siemons,M.:**How Fiber Thickness and Crinp Influence AQL Performance, 2007

"PET", a part of it is substituted by "PP" fibres. Different bicomponent fibers do not essentially differ in their price and the "PP" bicomponent fibres have the disadvantage of not being as resilient as "PET" bicomponent fibers. To achieve a bulky web, carding in combination with air-through bonding is used to form the nonwoven. The medium thickness of product "C" combined with the high basis weight of 67g/m^2 leads to the assumption of medium high void volume. The high "MAP" (4.9cm H_2O) and medium "MDP" (10.6cm H_2O) indicate small pores and an even surfactant distribution on the fibers (dots visible in fig. 3.100.) This observation corresponds well with the medium "AQS time" (37.97 s/60ml). With a smaller pore size and weaker resilience the web does not have a high permeability, and thus has a medium "AQS time".

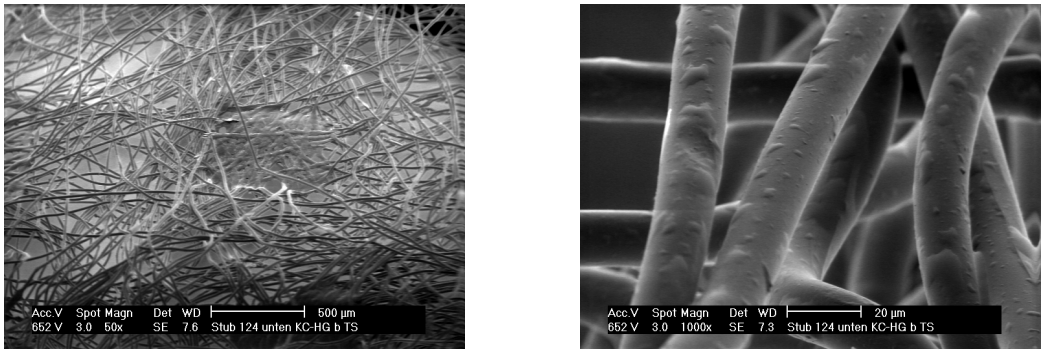


Fig 3.100: Product "C" AQS

The "AQS" of product "F", in contrast to product "C", is made only of "PET" fibers, and also uses a carding and air-through bonding to achieve a highly fluffy web. The "AQS" of product "F" performs slightly worse in all physical properties than product "C". Its "AQS" has a thinner basis weight (52g/m^2) and a lower caliper (0.58mm). The medium "AQS time" (35.25 s/60ml) is caused by the small pores on the one hand and the fact that "PET" fibers have the property of breaking under pressure, which again reduces the pore size and leads to less void volume and lower permeability. The "AQS" of "F" has a worse "MAP2" (1.1 cm H_2O) which is caused by the low level and uneven distribution of surfactant, visible on the "SEM" pictures (fig. 3.101).

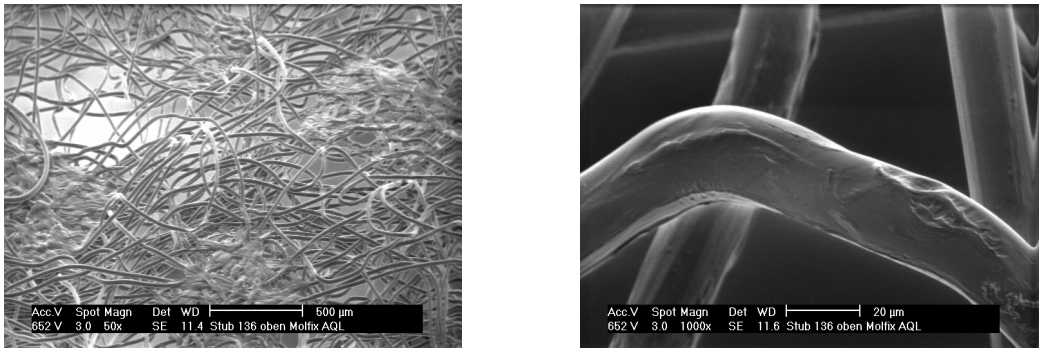


Fig 3.101: Product "F", "AQS"

The dual "AQS" of product "A" consists of a carded resin bonded nonwoven exclusively based on "PET" fibers for the upper layer, followed by a citric acid treated cellulose layer. The citric acid leads to a higher resilience of the cellulose fibers. The slightly worse liquid uptake compared to products "C" and "F", is caused by cellulose fibers sticking in the open pores of the "AQS" and clogging the pore space. In terms of horizontal liquid distribution, this system is stronger than the "AQS"s of product "F" and "C". This is due to increased web resiliency achieved by: a) highly resilient "PET" fibers and b) by the resin, which is less brittle and thus avoids "PET" fiber breakage at crossover points. "Pampers Baby Dry" has the thickest "AQS" (3.15mm) of all products, combined with a high basis weight (55g/m^2). Additionally, it has the best "MAP2" (6 cm H_2O), which is related to pore size and hydrophilic resin, even though the resin is not evenly-distributed over the fibers. The "MDP2" is worse (18 cm H_2O), because the thicker the "AQS", the lower the "MDP2". In addition, the bonded water molecules (hydrogen bonds) of the cellulose decrease the "MDP2".

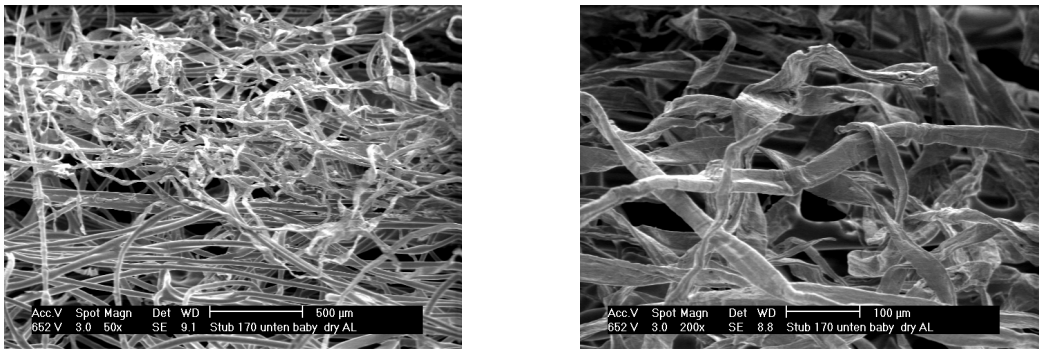


Fig 3.102: "AQS" of product "A"

3.1.2.7.3.1.2 Medium performing Acquisition Systems

The “AQS” performance of the products “P”, “B”, “Q” and “K” are categorized in the medium performance area. All four products are in the medium caliper range and have a medium to low base weight. The products in this category range show either a good void volume or a good liquid distribution. The “AQS” of the product “P” is designed to achieve a good liquid uptake (11.2 g/g) but has a poor ability to distribute liquid horizontally (37.97 s/60ml). By using “Differential Scanning Calorimetry” “PE”, “PP” and “PET” are detected in the ratio of 1.4:1:1. This means “PET/PE” bicomponent fibers and “PP” fibers are used. The “PET” bicomponent fiber is responsible for good web resiliency, meaning the nonwoven structure does not collapse upon liquid absorption. “PP” as a cheap material is used for this product to fill in the expensive “PET” bicomponent fiber structure. “PP” does not have the resilience of “PET” under pressure and therefore, the medium pore size is reduced, which leads to a bad “AQS time” (43.06 sec/60ml). The web is formed by carding and air-through bonding. The “AQS” caliper is 0.514 mm, which is in the medium range of thickness. The basis weight of 31 g/m^2 is, however, the lowest of all “AQS” measured, which enhances nonwoven collapse under pressure and hence leads to bad “AQS times”. The medium to bad “MAP2” (3.34 cm H_2O) is caused by low and unequal distribution of the surfactants, caused by a reduced fiber/liquid contact angle. The good “MDP2” (8.87g/g) is achieved by surfactants (fig.3.103.)

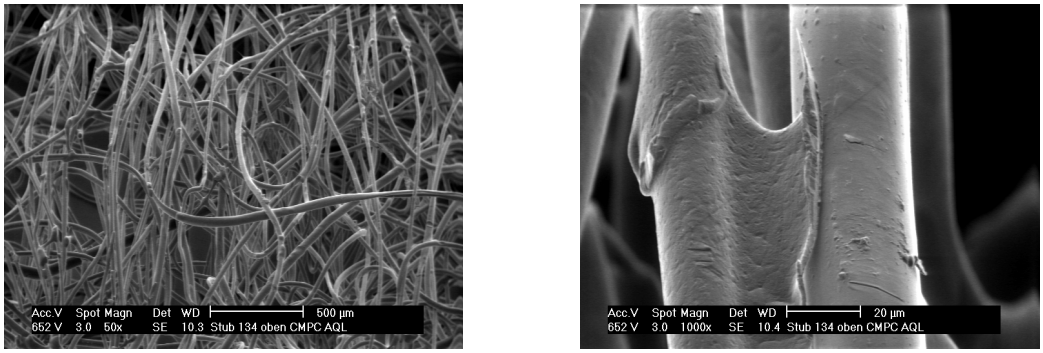


Fig3.103: “AQS” of the product “P”

The “AQS” of “Q” is a similar composition to the one of product “C”. The one of product “B” is analogous to product “A” but, in both cases, less material is used. The product “Q” uses bicomponent fibers (“PET” covered with “PE”) formed using a carded air-through technology to achieve a lofty web. Due to the 0.3mm lower caliper, the maximum liquid uptake is medium to bad, although the basis weight is reduced by 20g/sqm. Due to the

low basis weight the “AQS” has a lower resilience against pressure, which reduces the pore size and leads to a medium to bad “AQS time”. The “MAP2” performs poorly and “MDP2” is the best performing over all products, because of the greater pore size based on the lower basis weight.

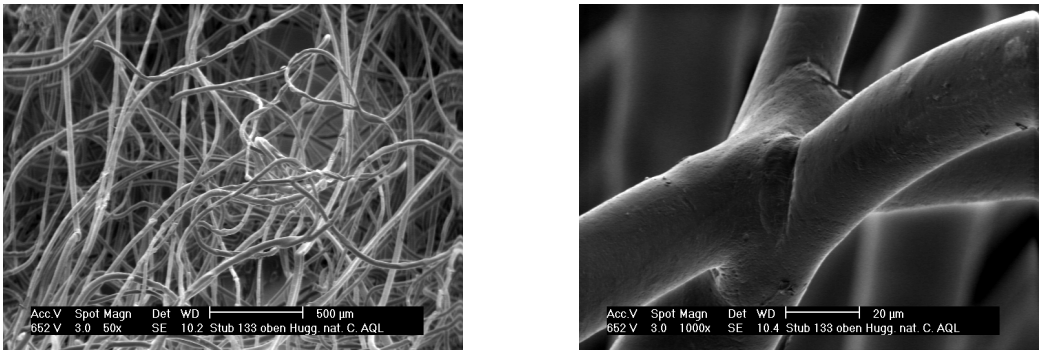


Fig 3.104: “AQS” of the product “Q”

The pictures show, as in the case of “A”, the crosslinked cellulose fibers sticking into the carded, resin bonded “AQS” (fig. 3.104.). This prevents liquid absorption in these areas. Therefore the maximum liquid uptake of the “AQS” (9.2g/g) is in the middle range of the ranking scale. Product “B” has, like product “A”, a dual “AQS” (2.13mm) and the same basis weight as "A" of 65 g/m^2. In terms of “AQS time” (23.14 s/60ml) the “AQS” of product “B” is better as those of product “A”. “MAP2” (3.2 cm H_2O) is higher than expected, probably caused by the presence of less hydrophilic material (citric acid cellulose layer) and smaller pores (fig. 3.105.). The “MDP2” follows the one of “A” directly, as expected, based on the thickness of the “AQS” and the cellulose- water hydrogen bonds.

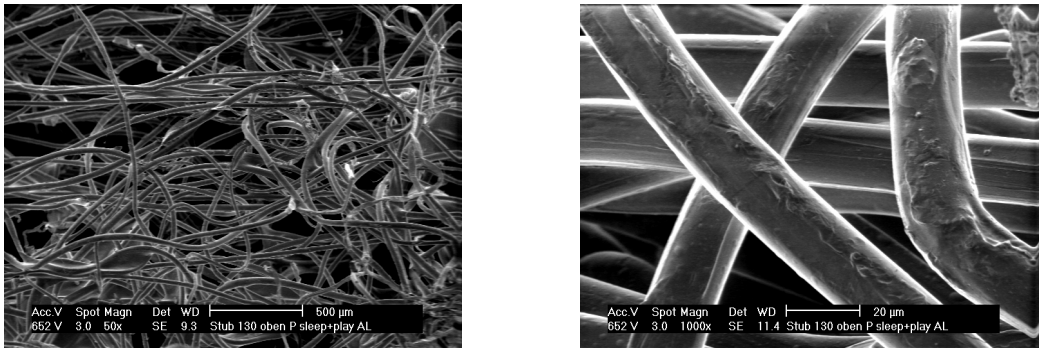


Fig 3.105: “AQS” of product“B”

Product “K” also uses in its “AQS” resin-bonded “PET” fibers, and offers less void volume (6.3g/g) due to a low basis weight web (45g/m^2) and a thin caliper (0.42mm). The resin-bonded “PET” fibers provide high resilience, which lead liquid easily through in

cross-direction (15sec/60ml). “Pampers Liberty” has a medium to bad “MDP2” (12.4cm H_2O) caused by the hydrophilic resin, which is simultaneously responsible for the good “MAP2” (3.8cm H_2O).

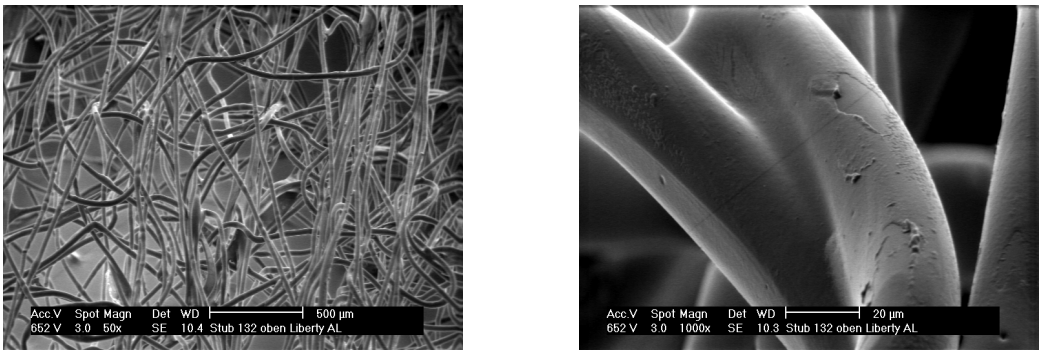


Fig 3.106: “AQS“ of product “K”

3.1.2.7.3.1.3 Worst Performing Acquisition System

The product “D”, “G” and “E” fall in this worst category in terms of “AQS” performance. Within this category the “AQS” of “G” and “D” have lower caliper and basis weight, which offer neither a good “Maximum Uptake of the AQS” nor a good “AQS time”. In general, less surfactant is visible on all products.

The “AQS” of product “E” has a high basis weight at equal caliper and by that a less void volume. The “AQS”s of “D” and “G” show a medium performance in liquid uptake and a bad performance in liquid distribution. For the one of “E”, it is the other way round. This can be explained by the fact that the “AQS” of “E” has a medium to high caliper and basis weight, while the two others have a low caliper and a low basis weight. The “AQS” of “G” contains only weakly-thermobonded “PET” fibers. The fibers themselves are very thick to ensure a high resiliency. The “AQS” is critically thin (0.4mm) and has a low basis weight (34g/m^2). Based on its thinness, the physical property values need to be treated in a critical way. The medium pore size and the little amount of surfactant, visible in the pictures as dots, lead to a medium “Maximum Uptake AQS” (9.6g/g) and the low “MAP2” (2.8cm H_2O). The “MDP2” (9.2cm H_2O) is located in the medium performance area. The liquid distribution horizontally is very slow (43.8 s/60ml), which is related to a low web resilience leading to a smaller pore size under pressure. so liquid needs longer to travel through.

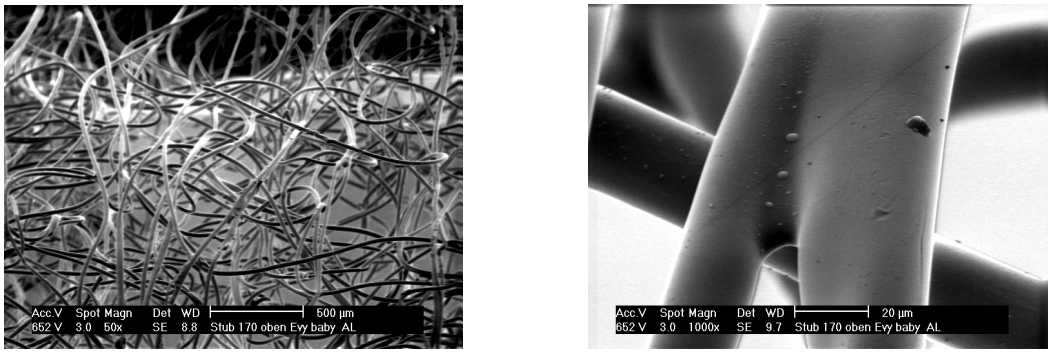


Fig 3.107:"AQS" of product "G"

The "AQS" of "D" is produced by calender bonding technology by using only "PP" fibers. The "PP" fiber is a cheap material, with a low melting point (~165 °C) and low resilience compared to "PET". The fibers are spunlaid and calender bonded, which yields high web strength. The elliptical bonding pattern achieves smoother webs compared to other bonding patterns. Product "D" has the thinnest "AQS" (0.32mm) within the test series and the second lowest basis weight (34 g/m^2). Due to the bad resiliency and the small pores, the "AQS time" is, at 111.99 s/60ml, the highest in this project. The caliper of the "AQS" is below the specified level of the measurement instrument. Therefore, the values for "Maximum Uptake AQS", "MAP2" and "MDP2" are not taken into account.

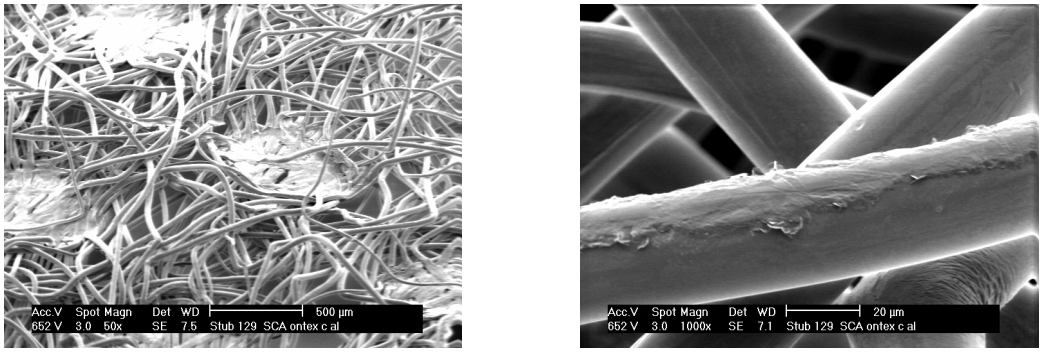


Fig 3.108:"AQS" of product "D"

For the "AQS" of product "E" an air-through bonding process is used with a "PET/PE" bicomponent fiber. In combination with this bicomponent fiber, the technology leads to a bulky and resilient web. The medium "AQS" caliper of 0.54mm and the high basis weight of 55.5 g/m^2 indicate small pores and low void volume. The low void volume, combined with a low surfactant add-on level, is responsible for the extremely small "Maximum Uptake" of the "AQS" (8.45 g/g). The "AQS" of product "E" is located in the medium area for all remaining physical measurements. The "AQS time" of 38.66s/60ml is based on the small pores of the web. The fibers do not seem to be treated with a high

amount of surfactant. This is responsible for the “MAP2” of 3.2 (cm H_2O) and “MDP2” of 9.0 (cm H_2O).

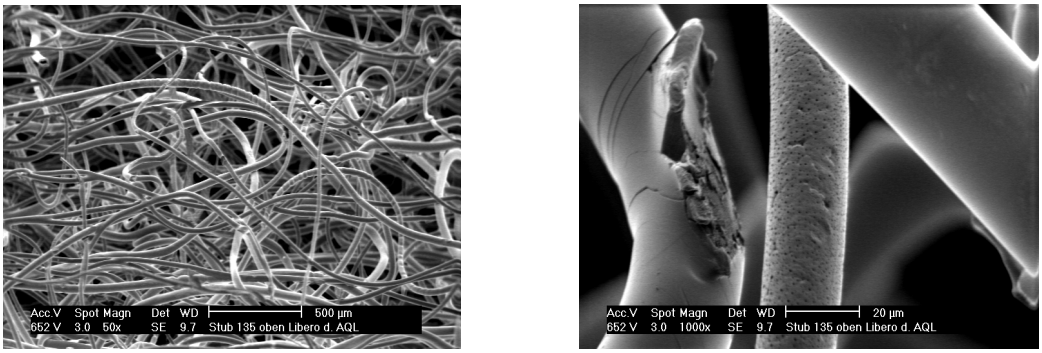


Fig 3.109: “AQS” of “E”

3.1.2.7.3.1.4 Summary

It seems that all “AQS” have either a high liquid uptake or a fast liquid distribution, but none of the products perform well in both areas. The well performing products either use “PET” fibers alone or bicocomponent fibers with “PET” as core. The combination of carded, resin bonded “PET” fibres and carded, airthrough bonded bicocomponent fibers have been found to be the best combinations in terms of raw material performance. Especially important for a carded airthrough technology is an evenly distributed surfactant. The “AQS” performs the better the thicker it is within a special range. If the “AQS” is too thick the desorption rate of the liquid is too high, which has a negative influence on the overall leakage performance, because less void volume is available for further gushes. Furthermore the “AQS” data indicate that a high basis weight combined with a thicker “AQS” lead to better results.

In the medium performance area the same carded airthrough and carded resin bonding technology is used as in the good performance area. The reason for the different performance is not based on the “AQS” design, but on the thinner caliper and lower basis weight of the “AQS”. This yields to less void space in case of the same basis weight or a lower “AQS time” based on the lower resilience of the fewer fibres per square meter “AQS”.

In the low performance area the “AQS” are either critical thin and made of thermobonded “PET” fibers or in case of product “D” they are more comparable to a “Topsheet”. This means they are thin and a calender bonding technique is used, which reduces further the void space due to the bonding pattern. For three products less to no surfactant (product “E”) is visible on the fibres, which reduces further their performance.

3.1.2.7.3.2 Performance of the "AGM and Pulp Layer"

The "BIG 3 raw material to consumer model" identifies the "AGM and pulp layer" next to the "AQS" as important in terms of urine leakage prevention. The important urine leakage based variables, which are related to the "AGM and pulp layer", are: "AGM amount", "Core Capacity Zone 2", "AAP" and "Core Time Zone 2". The performance of the "AGM" is directly measurable in the "AAP" value and indirect in the "Core Capacity Zone 2" and "Core Time Zone 2". The last two variables, besides the "AGM" performance are driven by the amount of "AGM" and pulp in the different zones of the diaper. An "AGM & Pulp layer" performance rating between the different competitive products is provided by using the red, yellow and green classification of the four main important AGM related properties. Like in the case of the "AQS" all green fields are provided with a one, the yellow ones with two and the red ones with three. This product related values are then multiplied with the average influence of the single variables of urine leakage. The sum of single product related outcomes yields in the final performance indices (fig.3.112.). As lower the index is, as better is performance of the storage layer. To determine the "AGM" performance the physical measurements of the permeability ("SFC"), the capacity without pressure ("CRC"), the free swell rate ("FSC") as well as the information about the roundness of the particles and the particle size distribution are necessary. To explain the physical performance of the "AGM" a chemical analyzes is accomplished to determine the quantity of the following different elements in the "AGM": silicon, calcium, magnesium, aluminium, sodium, sulfur and nitrogen.

Product	AGMamount [g]	Core Cap. Z.2. [g]	AAP [g/g]	Core Time Z 2 [sec/60ml]	Performances Indices	Ranking
K	2	2	1	3	1.163	**6**
E	1	3	2	2	1.169	**7**
Q	2	1	3	2	1.121	**5**
D	2	1	1	2	0.897	**1**
B	3	3	1	3	1.576	**9**
A	2	1	2	1	0.934	**3**
G	1	2	2	2	0.978	**4**
F	1	2	2	1	0.903	**2**
C	2	2	2	3	1.275	**8**
P	3	3	3	1	1.65	**10**
Average variable influence [%] on urin eleakage	22.2	19.1	11.2	7.5		

Fig 3.110: AGM performance ranking

As explained in the theoretical part (chapter 2.4.2), the “AGM” is made of partially neutralized sodium polyacrylate. The sodium is responsible for the suction power of the osmotic pressure of the “AGM” particles. Magnesium and calcium can also be used as counterions in the polyacrylate matrix. The amount of nitrogen indicates the degree of crosslinking of an “AGM” particle when combined with the data of the stained surface crosslinked pictures. Less surface crosslinking (bright color) and a high degree of nitrogen indicate a high inner crosslinking of the AGM particle. The silicon occupies a spacing function as “AGM” surface coating. The detection of aluminium and sulfur amount indicates aluminium sulphate as coating agent

The different “AGM and pulp” layer related input variables for urine leakage (on the blue colored background below) are ranked for the “AGM” performance in the same way than for the “AQS” performance. This means 25 percent of all products are respectively located at the top (green) and low (red) performance end. The remaining 50 percent are located in the medium (yellow) performance level.

Product	Core Cap. Z.2. [g]	Product	Core Tme Z 2 [sec/60ml]	Product	AGM amount [g]
P	69.25	F	36.49	P	7.52
E	83.31	A	41.94	B	9.86
B	84.85	D	51.39	Q	10.01
G	91.03	P	51.72	K	10.3
F	95.58	E	55.52	D	11.43
K	98.92	Q	65.05	C	12.16
C	99.97	G	67.92	A	12.21
Q	101.63	C	70.14	G	13.28
A	102.44	B	89.57	E	13.34
D	108.52	K	127.14	F	15.01

Product	SFC[cm3*g/g*E-7]	Product	AAP [g/g]	Product	CRC [g/g]	Product	PSD<150µm [%]
P	0	P	11.6	B	23	A	5.68
Q	2	Q	13.4	Q	25	F	11.86
C	3	C	15.4	E	25	B	12.69
G	3	E	17.1	K	26	D	17.06
D	3.81	G	19.4	C	26	G	18.16
E	9	F	21.2	A	27	P	26.7
F	15	A	21.6	F	29	E	37.06
A	33	B	22.6	G	30	Q	39.45
B	34	D	22.68	P	32	C	48.23
K	110	K	23.6	D	34	K	Incapable to measure

Product	AGM/PULP ratio	Product	FSR [g/g{sec]	Product	Roudness [%]	Product	AGM/PULP ratio
B	0.48	C	0.48	D	58.6	B	0.48
C	0.57	Q	0.43	A	59.6	C	0.57
E	0.58	P	0.37	F	61.8	E	0.58
P	0.72	E	0.28	P	62.5	P	0.72
G	0.73	F	0.23	B	64.4	G	0.73
A	0.75	K	0.23	G	67.7	A	0.75
D	1.21	D	0.21	E	72.4	D	1.21
F	2.37	A	0.2	Q	72.4	F	2.37
Q	3.28	G	0.2	C	75.7	Q	3.28
K	10.3	B	0.15	K	incapable to measure	K	10.3

Fig 3.111: AGM performance properties

3.1.2.7.3.2.1 Best performing AGM and Pulp Layers

The diaper with the best storage core performance is “D”. The storage core is based on a profiling technology. This implies that in zone two a higher “AGM” concentration exists, compared to the other zones. This leads, combined with the advanced “AGM” technology, to a high capacity in this zone although the overall “AGM” amount is in the medium range. The high proportion of pulp in the storage core is responsible for the medium liquid distribution in zone two (“Core Time Z 2”). As the higher the pulp amount, the more open channels exist and the faster the liquid can travel though. This is especially important for “AGM” with a low “SFC” performance.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
<0.05 %	<0.05 %	26.8 %	0.07 %	34 mg/kg

Fig 3.112: Element analysis of product “D”

The “AAP” (22.68g/g) is very high and the “SFC” (3.81 cm3*g/g*E-7) is in the medium range, therefore the pulp is needed to avoid gel blocking. The high “Core Time” (51.38 sec/60ml) is the result of the pulp amount, based on the fact that the “SFC” is only in the medium range and the liquid travels through the pores provided by the cellulose fibers.
The medium “SFC” is caused by the low percentage of roundness of the particles, because the rounder the particles are, the more open space exists between them (when they are in the medium size range). The medium-thick and evenly-distributed surface crosslinking (fig. 3.115.) is responsible for the “SFC” not being too low. The “Free Swell Rate” (“FSR”) is in the medium area (0.21g/g[sec]). This is caused by the smaller amount of pores in the particle (fig. 3.116.). The more pores, the faster the liquid enters the “AGM” particle and the faster it swells. The “FSR” is also influenced by the coating and the roundness of particles. The rounder the particle is, the less available surface it provides leading to a slower “FSR”. The highest impact has the sodium concentration (26.8%); the more counterions are inside the particle, the higher the osmotic pressure and the faster the “FSR”. The “CRC” and “AAP” value is high, which is based, on the one hand, on the amount of sodium ions and, on the other hand, the good not-too-strong surface crosslinking. Since, the coating on the surface (fig. 3.114) is not detectable, in this case, it is probably an inorganic compound.

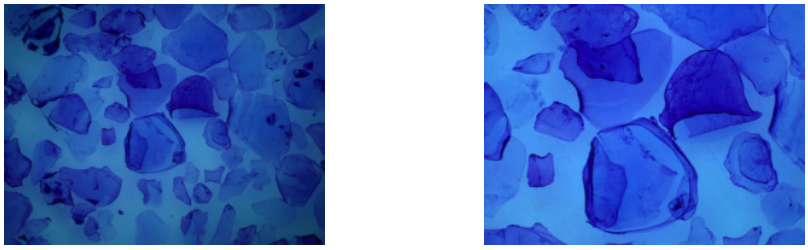


Fig 3.113: Surface crosslinking of the AGM of product "D"

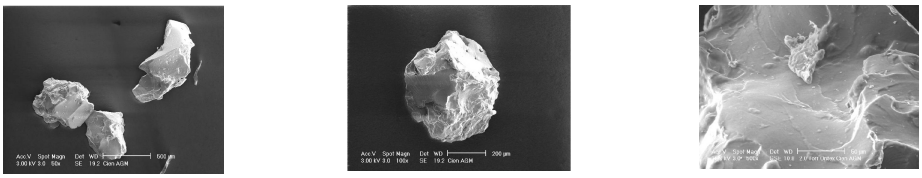


Fig 3.114: ESEM Pictures of the AGM of product "D"

The "AGM and pulp layer" of product "A", ranked as number three in the performance scale, offers the same physical performances as product "D" apart from the permeability of the swollen gel bed ("SFC"). Product "A" has the more advanced "AGM" with a greater "SFC" (33 cm3*g/g*E-7) value, which yields to a core with a medium amount of fluff pulp (5.15g). The profiling in zone two is detectable by the combination of the high "Core Capacity" in this zone and the average amount of "AGM" (12.21g) in the diaper. Product "A" has a medium to high "AAP" (21.6g/g), "CRC" (27g/g) and a high "SFC". One reason for this is the high sodium counterion concentration within the "AGM" particle, and the second reason is the small amount of aluminium sulphate, which builds complexes with the extractables of the polymer and reduces the liquid viscosity based on this reaction. The surface crosslinking, as well as the intramolecular crosslinks, are responsible for the swelling capacity of the "AGM". The more crosslinks that exist within the "AGM" and the shorter they are, the less liquid can be taken up by the "AGM". Also, the higher the density of the surface crosslink of the "AGM" particle, the lower is the capacity. This is based on the equilibrium of "AGM" affecting forces (chapter 2.4.2.4.2). The good "Core Time" (41.94 sec/ 60ml) of product "A" is caused, on the one hand, by the high "SFC" and, on the other hand, by the homogenous blending of "AGM" with cellulose fibers. The cellulose fibers create channels through the "AGM" layer, which allow the liquid to travel quickly through it.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
<0.05 %	0.11 %	26.1 %	0.64 %	20 mg/kg

Fig 3.115: Element analysis of product "A"

The high "SFC" again is caused by the high amount of pores based on the manufacturing process, the medium to high surface crosslinking and the higher amount of larger particles. The greater the particles are, the lower is the probability of the gel blocking appearance, because the liquid channels are not blocked by small particles. The "FSR" (0.2 g/g[sec])) is low, which is a disadvantage of large particles in general, because the smaller the particles are, the higher the surface area compared to the inner space and the higher the possibility of liquid channelling in the "AGM" particle and hence the faster it swells.

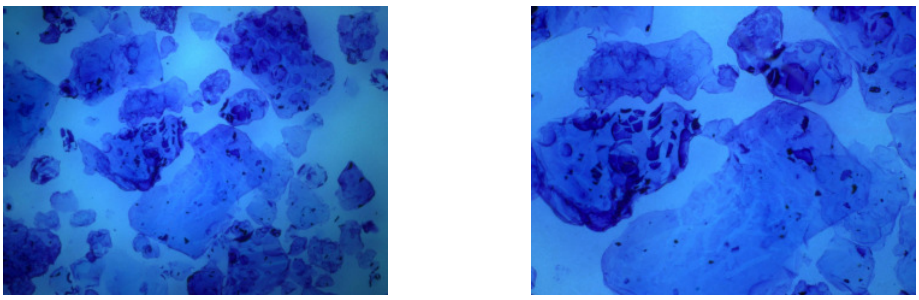


Fig 3.116: Surface crosslinking of the AGM of product "A"

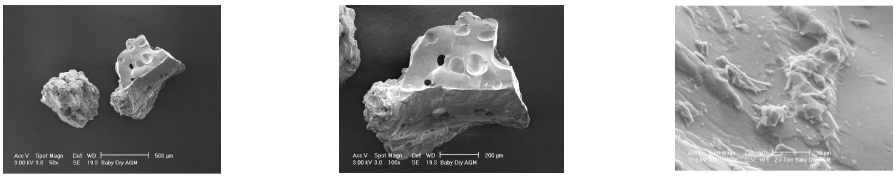


Fig 3.117: ESEM pictures of the AGM of product "A"

The "AGM and pulp" layer of product "F" differs from the discussed two technologies. It gains overall capacity based on its high amount of "AGM" (15g) and the medium amount of pulp (12.4g), but makes no use of the advantage of a profiled "AGM" system. The medium "Core Capacity" in zone two (95.98g) is an argument for the non profiled core. The "AGM" itself is not highly technical advanced which is expressed by the medium physical performance of all variables.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
< 0.05 %	0.11 %	12.4 %	0.11 %	9 mg/kg

Fig 3.118: Element analysis of the AGM of product "F"

The high "Core Time" in zone two (36.49 sec/60ml) confirms that the "AGM" and pulp mixture are perfectly-mixed and designed to distribute liquid fast horizontally. The "SFC" (15 cm3*g/g*E-7) is in the medium to high range due to the large amount of large particles covered with a very thin surface crosslinking. The "AGM" of product "F" has a medium to high "CRC" (29g/g) value and a medium "AAP" (21.2g/g) value. The "FSR" (0.23g/g[sec]) is also in the medium area which derives from the large, not round, particles. Also here, a surface coating made of aluminium sulphate is used to bind the extractables.

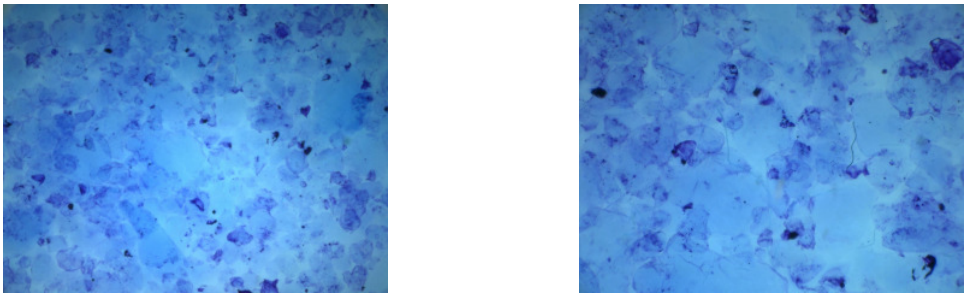


Fig 3.119: Surface crosslinking of the AGM of product "F"

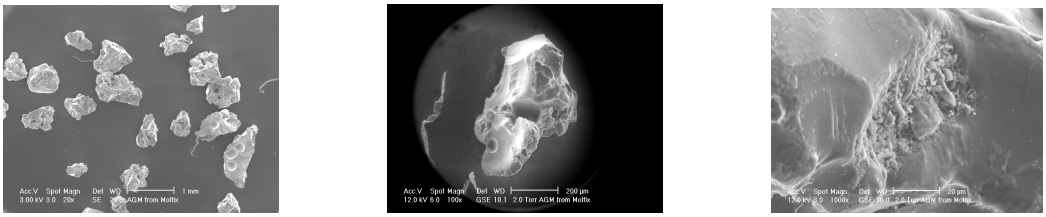


Fig 3.120: ESEM pictures of the AGM of F

3.1.2.7.3.2.2 Medium performing "AGM and Pulp" Layers

The "AGM and pulp" layer of product "G", "Q", "K" and "E" are located in this category. The storage core of product "G" is, from a technical point of view, identical to the one of product "F". These two "AGM and pulp" layers differ only in the amount of raw materials in the core. Product "G" contains less "AGM" (13.28g) but more pulp amount (18.1g), which is reflected in the overall medium physical performances. Its "Core Capacity Zone 2" (91.03 g/g) is in the medium area pointing to a non-profiled core

structure. The “Core Time” (67.92 sec/60ml) is also in the medium category, although the pulp amount is very high, which indicates a poor blending of the core with cellulose fibers and medium “AGM” properties. The “SFC” (3 cm3*g/g*E-7) and “AAP” performance is in the medium area, and the “CRC” (30g/g) in the high area. The “FSR” (0.2g/g[sec]) is in the low area as would be expected with the amount of large particles and the high roundness. The percentage of sodium as counterion is quite low, which explains the medium “AAP” (19.4g/g), also the crosslinking is low. The surface crosslinking is very thin, which also explains the “SFC” performance in the medium range. Silicon is used as a spacer and aluminium sulphate as the extractable complexing agent.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
0.06 %	0.02 %	12.4 %	0.14 %	20 mg/kg

Fig 3.121: Element analysis of the AGM of “G”

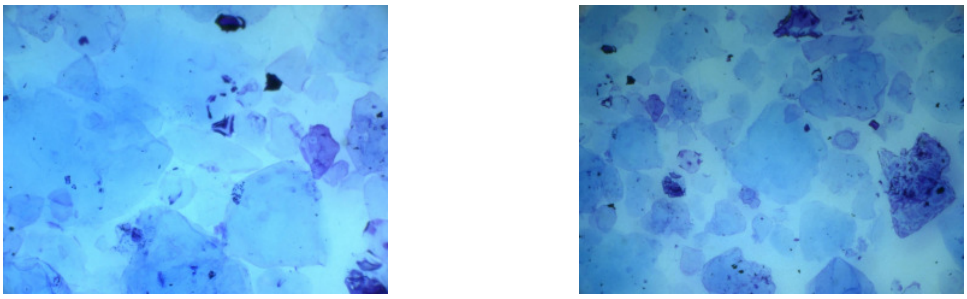


Fig 3.122: Surface crosslinking of the AGM of of product “G”

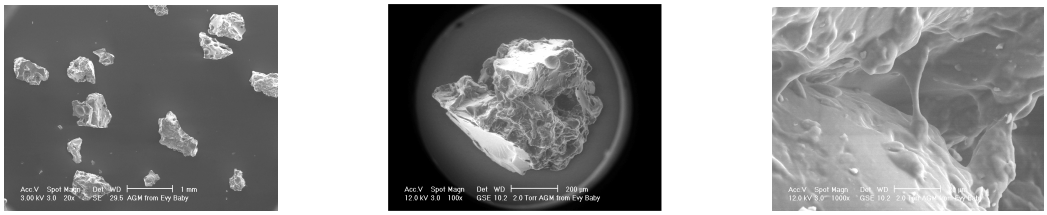


Fig 3.123: ESEM pictures of the AGM of “G”

The product “Q” uses the technical approach of a profiled core with a medium amount of non-advanced “AGM” (10.01g). This solution results in a high “Core Capacity in Zone 2” (101.63g) and, although the “AGM” is well-blended by cellulose fibers, the liquid distribution (“Core Time Zone 2”) (65.05sec/60ml) is located in the medium category. This resulting ability of liquid distribution is based on the large amount of small particles which greatly reduces the “SFC” and the homogenous blended core, which helps the liquid to easily travel horizontally.

The “AGM” particle size distribution is comparable to product “C”, but the “AGM” is not as highly-crosslinked as those from product “C”. Therefore, the “AAP” (13.4g/g), “CRC” (25g/g) and “SFC” (2 cm3*g/g*E-7) and “FSR” (0.43g/g[sec]) values are slightly worse than the storage core of product “C”.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
0.73 %	0.02 %	11.3 %	0.22 %	12 mg/kg

Fig 3.124: Element analysis of the AGM of product “Q”

The amount of sodium counterions is the same for both products, but the product “Q” differs in the larger amount of sulfur and the smaller amount of nitrogen compared to product “C”. Probably is the sulfur used as a surface crosslinking. The surface crosslinking is irregular; it seems that the smaller particles have a larger amount of surface crosslinker than the larger particles. The silicon coating is used as spacer, and aluminium sulphate coating acts as complexion agent.

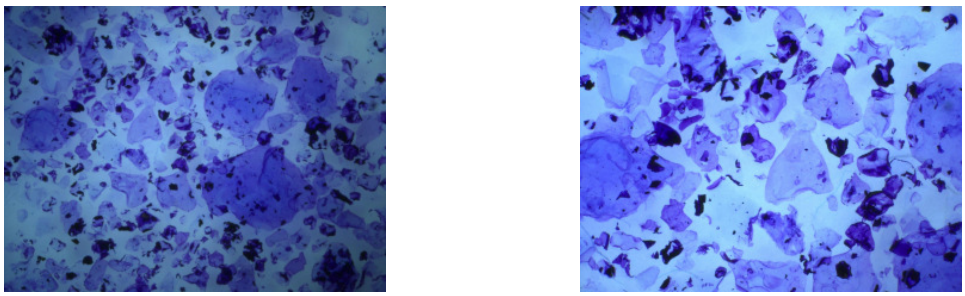


Fig 3.125: Surface crosslinking of the AGM of product “Q”

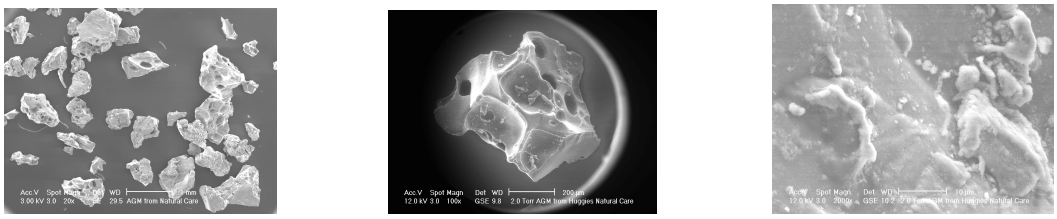


Fig 3.126: ESEM pictures of the AGM of product “Q”

The storage core of product “K”, the “Tier 4” diaper uses a new core technology. The storage core of this diaper contains no pulp. A superior “AGM” technology, which is detectable in the physical performance properties (fig.3.111.) allows the elimination of cellulose fibers. The storage core of “K” contains a medium amount of profiled “AGM” (10.3g), which leads only to a medium capacity (98.92g) (“Core Capacity in Zone 2”). In terms of liquid distribution this diaper is slower than the remaining products (“Core Time” = 127.14 sec/60ml), because no additional channels created by the cellulose fibers

exist and therefore the liquid needs to travel through the swollen gel bed. The “Core Time” can therefore directly be correlated to the “SFC” (110 cm3*g/g*E-7).

Product “K” has the highest “SFC” based on the low amount of small particles and the even surface crosslinking. The pictures (fig.3.130.) highlight the intact core shells. In terms of capacity the “AGM” of product “K” has the highest “AAP” (23.6g/g) and a medium “CRC” (26g/g) value.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
< 0.05 %	0.11 %	13.5 %	0.12 %	8 mg/kg

Fig 3.127: Element analysis of the AGM of the product “K”

The elastic force is lower compared to other “AGM”s, because the surface crosslinking is very thin. The high capacity against pressure is caused by the smaller amount of inner crosslinks and surface crosslinking. The sodium counterion amount is in the medium range and a low amount of aluminium sulphate coating is used to bind the extractables and keep the viscosity of the liquid stable. The “FSR” is in the medium range, based on the roundness and the large particle sizes.

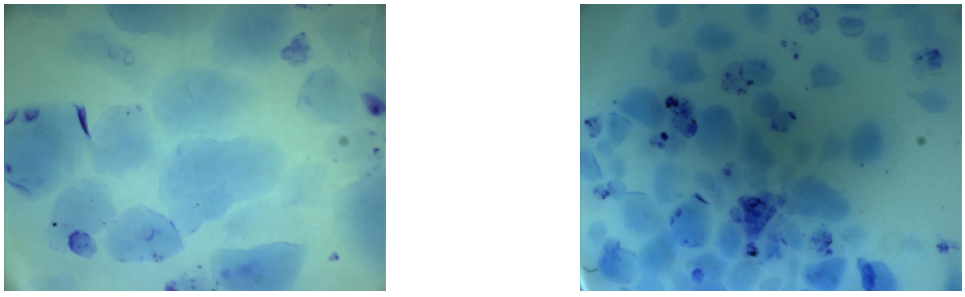


Fig 3.128: Surface crosslinking of the AGM of the product “K”

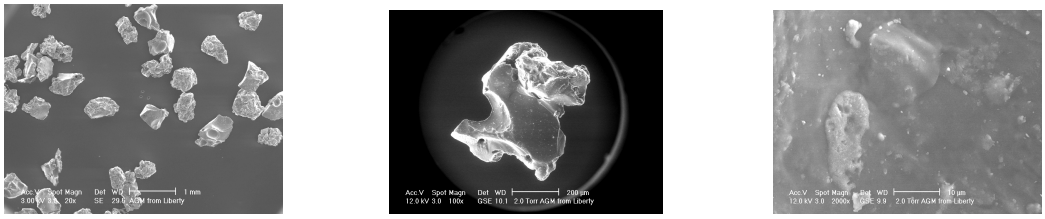


Fig 3.129: ESEM pictures of the AGM of the product “K”

The “AGM and pulp” layer of product “E” is the last one in this category. The storage core system is conceived in the same way as those of product “F” and “G”, but with less “AGM amount” than them. The product has a medium “AGM” efficiency and no profiling; therefore, the technical weaknesses are compensated with a larger “AGM amount” (13.34g). The poor performance in terms of “Core Capacity Zone 2” (83.31g) emerges from the technical disadvantages of this core. The high pulp proportion (18.6g)

yields to the medium liquid distribution (55.52 sec/60ml). The “AAP” (17.1g/g) and “CRC” (25 g/g) are located in the medium area. The medium “FSR” (0.28) is explainable by the small amount of sodium counterions and the round, small particles. Aluminium sulphate, is also used as the extractable binder in this product.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
< 0.05 %	0.17 %	11.9 %	0.14 %	21 mg/kg

Fig 3.130: Element analysis of the AGM of product “ E”

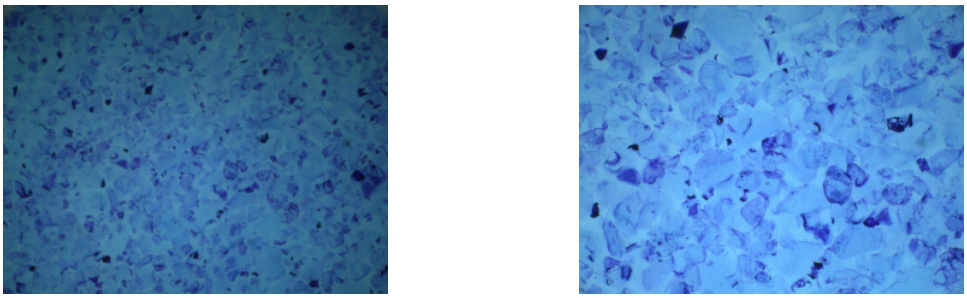


Fig 3.131: Surface crosslinking of the AGM of product “ E”

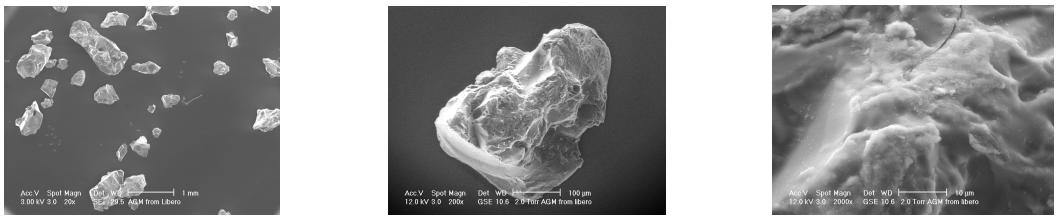


Fig 3.132: ESEM pictures of the AGM of product “E”

3.1.2.7.3.2.3 Worst performing “AGM and Pulp" Layers

The product “C”, “B” and “P” are included in this classification. Product “C” is the only “Tier 2” product in this category, which is driven by the combination of the average amount (12.16g) of medium developed “AGM” in a badly-profiled core system. This leads to a poor performance in horizontal liquid distribution of the core in zone 2 (70.14 sec/60ml). The low “SFC” is also responsible for the “Core Time”. The “SFC” is caused by the large amount of small particles, also detectable by the high “FSR”. The high percentage of round particles plays no role for the “FSR” (0.45g/g[sec]), because the “AGM” consists of a large amount of very small particles and a only a few large particles. The huge surfaces of the small particles drive the “FSR”. To achieve a high "SFC" with such small-sized particles, the particles are covered with silicon to keep spaces open for the liquid.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
0.62 %	0.02 %	11.3 %	0.06 %	69 mg/kg

Fig 3.133: .Element analysis of the AGM of product "C"

In addition, the surface crosslinking is uneven, very strong (dark blue) and medium to weak (bright blue). The small amount of sodium counterions and the large amount of nitrogen (surface crosslining) explains the medium to bad "CRC" and "AAP" values. As the larger the amount of crosslinking, the less the "AGM" swells. Additionally, slight traces of the aluminium sulphate coating are detectable.

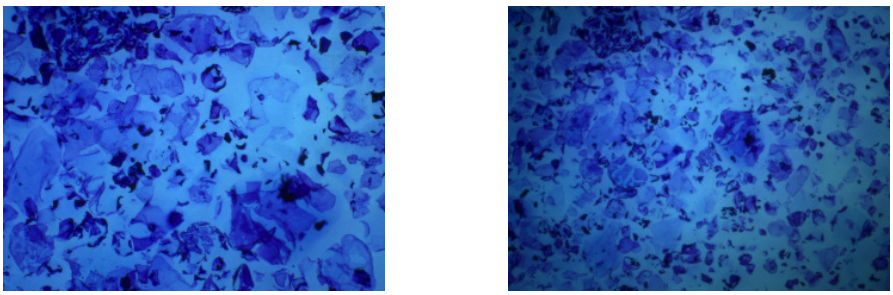


Fig 3.134: Surface crosslinking of the AGM of product "C"

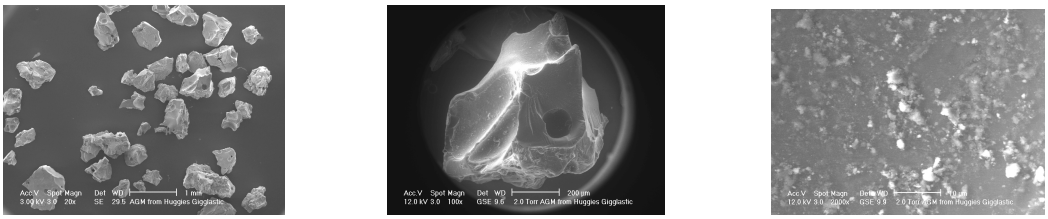


Fig 3.135: ***ESEM pictures of the AGM of product "C"***

The products "B" and "P" are both designed as low "Tier" products for low income markets. Therefore they contain only a low amount of expensive "AGM". Both products offer a low "Core Capacity" in zone two, although in both cases a profiling exists. The higher advanced "AGM" technology of product "B" leads a higher "AAP" value. The storage core system of product "P" contains a higher pulp proportion, which results in a faster liquid distribution of the core ("Core Time Zone 2").

Product "B" as a Tier 3 product contains a very low amount of "AGM" (9.86g) and in this case also of pulp (3.01g). The medium "Core Capacity" (84.85g/g) is therefore caused by more "AGM" in the second zone of the diaper. The "Core Time" in zone two (89.57 sec/60ml) is worse based on the high "AGM" and low pulp concentration. The time the liquid needs to travel horizontally through this layer is based on the high "SFC" (34 cm3*g/g*E-7) of the "AGM". The "CRC" (23g/g) value is worse, but the "AAP" (22.6g/g) value is high compared to the other products, which is based on the high

surface crosslinking and the medium amount of sodium counterions. The counterion concentration as well as the sharpened particles combined with the medium roundness and the high surface crosslinking result in a medium “FSR”. The amount of aluninum and sulphur suggest that very low to no surface coating is used, which has also an influence on the “FSR”. The nitrogen amount is extremely high indicating a strong surface crosslinking.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
< 0.05 %	< 0.05 %	12.8 %	0.02 %	91 mg/kg

Fig 3.136: Element analysis of the AGM of product “B”

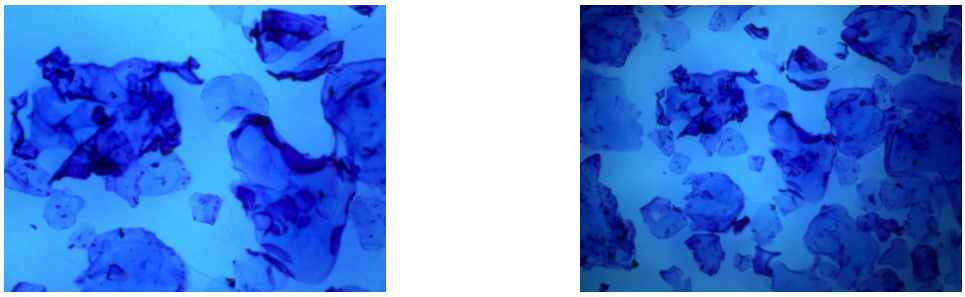


Fig 3.137: Surface crosslinking of the AGM of product B”

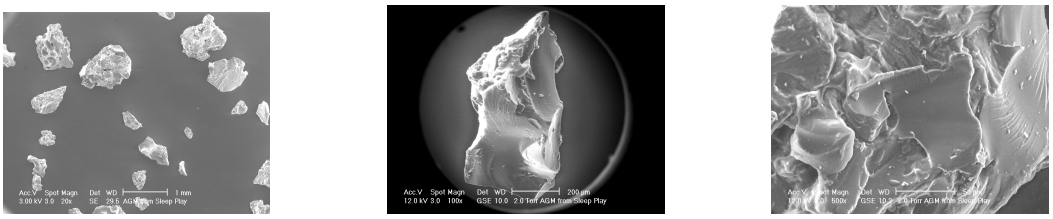


Fig 3.138: .ESEM pictures of the AGM of product “B”

Product “P” has the smallest amount of “AGM” (7.52g). It also has the lowest “Core Capacity” in zone two (69.25g), which indicates a non-profiled core. The medium “Core Time” (51.75 sec/60ml) derives from the small amount of “AGM”, combined with the medium amount of pulp (15.63g) where liquid can travel through very quickly. The extremely-poor “SFC” (0 cm3*g/g*E-7) does contribute in a negative way to the “Core Time”, meaning that when a lot of swollen “AGM” particles are together, gel blocking appears and no liquid can travel through this area.

Silicon	Aluminum	Sodium	Sulfur	Nitrogen
0.71 %	0.33 %	12.1 %	0.17 %	19 mg/kg

Fig 3.139: Element analysis of the AGM of CMPC BabySec Ultra

The “AGM” of product “P” has a high “CRC” (32g/g) but a very low “AAP” (11.6g/g). This leads to a bad absorption during pressure application, which is caused by a poor inner crosslinking and a weak outer surface crosslinking, as well as the small amount of sodium counterions. The high numbers of small particles, as well as their medium roundness, explain the high “FSR” (0.32 g/g*sec), but at the same time they are, together with the bad crosslinking, responsible for the non-existing “SFC”. The particles have two types of coatings. The “SFC” of zero identifies that the silicion coating does mot fulfil its function as a spacer. In addition, the aluminium sulphate bonds the extractables and keeps the liquid viscosity low so that liquid can travel easily within the particles.

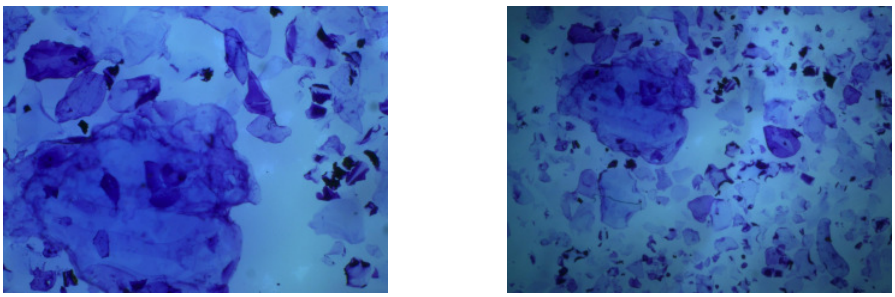


Fig 3.140: Surface crosslinking of the AGM of product “P”

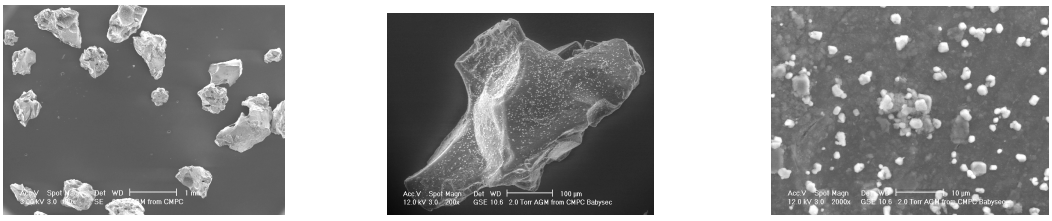


Fig 3.141: ESEM pictures of the AGM of product “P”

3.1.2.7.3.2.4 Summary

The highest performing products within this test design offer two storage core designs. The first one includes a profiled “AGM” system and therefore achieves a good “Core Capacity Z 2” by using a medium amount of “AGM”. Deviations in the design are based on the degree of development of the “AGM” generation. This leads to the fact that by using a more highly-advanced “AGM”, less pulp is needed in the core technology to achieve the same results. The other core design is not based on a profiled core system. To achieve the same overall performance more “AGM” is used in the diaper. In terms of “Core Capacity Z 2”, these products do not achieve the same high performance that the products with a profiled core system achieve. In this case, the “AGM” is not highly-advanced and therefore a medium amount of pulp is needed to ensure acceptable “Core Times”.

In the medium performance cluster, the core designs are the same as in the good performance area, the difference exists in the smaller amounts of raw materials, particularly “AGM”. Products “G” and “E”, for example, have the same core design as product “F”. The core design of product “Q” is in principle similar to the one of product “D”, the only deviation is based on the smaller “AGM" amount and less-advanced “AGM” technology.

A completely different design for this area is used by product “K”, which has a medium amount of highly-advanced “AGM” technology, which enables the complete exclusion of cellulose fibres in the storage core. This pure, profiled “AGM” layer leads to a medium capacity of the core in the second zone, but a poor time for liquid distribution compared to the other products.

In the worst performance area, two products use a profiled storage core system. The storage core of product “C” is analogue to the one of product “Q”. Looking on the actual performances of the single variables it becomes clear that the product performance do not differ so much from each other as it seems in the introduced ranking system. The performance deviation between these two products is based on the fact that product “C” has more “AGM" amount, which normally leads to a higher performance, but, due to a bad blending in combination with the small particles, this storage core performs badly in “Core Time”. The storage core design of product “B” is similar to the one of product “A”, the difference in performance occurs because of the smaller raw material proportion of product “B”. Product “P” closes this product category by having the same non-profiled core design as product “F”, “G” and “E” combined with the smallest amount of “AGM”, which leads to the performance result.

3.1.3 Performance versus Cost Estimation

After identifying the different reasons for a specific core design performance, a cost versus performance estimation is accomplished. The focus is set on the diaper core and therefore, first, the two important layers, the “AQS” and “AGM and pulp” layer are covered. Afterwards, the cost versus performance estimation is expanded to the diaper core and the whole product. The performance versus cost estimation is accomplished in the same way as for the single performances. This includes, firstly, the categorization of the products concerning urine leakage perception of mothers. For the categorization 25

percent of the products are located at the top and 25 percent at the bottom end of the rating scale and 50 percent in the medium field.

3.1.3.1 Raw Material Costs

In general, two aspects need to be considered for the cost versus performance estimation of the raw materials. The raw materials are designed to fulfil their function of urine leakage prevention in combination with the remaining core components, meaning an "AQS" can be low-performing but, together with the remaining core components, the overall performance of the core is good. Additionally, the leakage area which the diaper is designed for needs to be considered. This means a product can be designed to be lower performing to achieve a low price for the consumer.

The costs of all the raw materials of competitive products are determined yearly for a competitive benchmarking overview by the different finance functions. For the raw material price estimations, assumptions are made based on the base price of the raw material, the assumed negotiated price, and the ex work price and the freight for the raw materials. These input data of the raw materials are used to build the basis for the cost indices comparison of competitive products. The whole raw material product costs can be split into the core-, chassis- and fastening-system raw material costs.

The storage core includes “AGM”, pulp, “AQS”, a tissue or non-woven “Core Cover” and “Dusting Layer”, a “Topsheet” and lotion – if it is used. .

The chassis contains the “Backsheet” film, the “Backsheet” non-woven, the “Backsheet” glue, the “Back Ear” non-woven, the “Back Ear” film, the “Front Ears”, the “Leg Elastics”, the “Barrier Leg Cuff” fabric and the “Barrier Leg Cuffs”.

The fastening system consists of the “Tape”, the “Hooks”, the “Landing Zone” and the “Release Tape”.

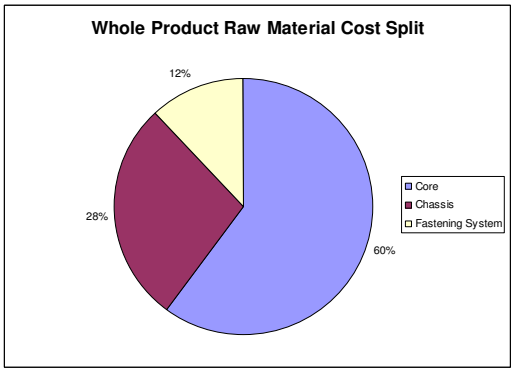


Fig 3.142: Whole product raw material cost split

The main contributor to the overall raw material costs is the core and within the core the “AGM”, as visible in fig. 3.143.

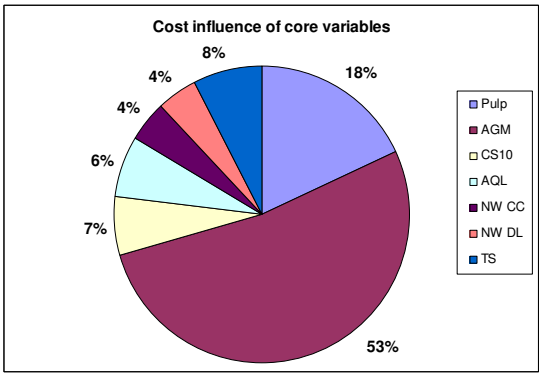


Fig 3.143: Percentage of single raw material costs on the overall core raw material costs

3.1.3.1.1 Cost versus Performance Ranking of the “AGM and Pulp Layer”

To accomplish the ranking the raw material costs of the “AGM and pulp” layer of product “A” is arbitrarily set to one and the “AGM and pulp” raw material costs of the remaining products are set in relation to product “A”. The lower the resulting cost ranking numbers the cheaper the “AQGM and pulp” layer is.

The different landed price indices are based on the "Procter & Gamble" finance estimation per region, which are calculated on the assumed base price, negotiated and ex work price of the material, including the freight.[86] The costs are presented as raw material indices converted in a cost ranking, which are compared to the performance ranking of this layer.

Product	AGM & Pulp Cost Indices	AGM & Pulp Cost Ranking	AGM & Pulp Performance Ranking
F	1.40	8	2
C	1.34	6	8
B	0.67	2	9
A	1.00	4	3
P	0.86	3	10
Q	1.02	5	5
K	0.50	1	6
D	1.35	7	1
G	1.41	9	4
E	1.34	6	7

Fig 3.144: Cost versus performance ranking AGM

The best "AGM and pulp" layer in the high performance area is "A", followed by "D" and "F". The storage cores of product "K" and product "Q" offer cheap alternatives in the medium performance area. Product "G" and "E", both located in the medium performance area, do not show a good cost versus performance pattern due to their high "AGM" amount of the non-profiled cores. Product "G" has a good medium performance, but very high raw material costs, whereas "E" shows a lower medium performance but is more cost effective. The medium performing storage core of "C" is the unbalanced one in terms of performance versus raw material costs. It shows a medium to bad performance by medium to high raw material costs. Product "B" is low down in the low performance ranking but it is cheap in terms of raw material costs, which is a basic requirement for a low "Tier" product. Product "P" is bottom of the performance- and cost ranking. This storage core has a lower performance and is more expensive than the one of product "B". This cost versus performance estimation highlights the fact that the manufacturer design the diaper cores according different consumer needs. This means for higher "Tier" products the raw material cost can be higher than for lower "Tier" products. The raw material cost of the storage core is mainly driven by the amount of "AGM". Therefore, profiled storage cores are highly cost-efficient, because they reduce the "AGM" amount by achieving the same overall diaper performance. Furthermore, the more highly-developed the "AGM" generation is, in terms of high capacity and permeability, the less pulp as spacer is needed, which further reduces the raw material costs of the storage core.

3.1.3.1.2 Costs versus Performance Ranking of the Acquisition System

The cost versus performance ranking of the “AQS” is accomplished in the same way as for those for the “AGM and pulp” layer. Product “A” is again marked with an index of one and the “AQS” raw material costs of the remaining products are put in relation to product “A”.

Product	Costs per product (Indices)	Costs per product (Ranking)	Performance ranking
F	0.4	3	1
C	0.45	4	1
B	0.77	6	4
A	1	8	2
P	0.45	4	3
Q	0.48	5	4
K	0.79	7	5
D	0.48	5	6
G	0.3	1	6
E	0.34	2	7

Fig 3.145: Cost versus performance ranking of “AQS”

Within the best performing “AQS”, product “F” has the best cost versus price efficiency. This “AQS” contains a smaller amount of expensive “PET” fibres, less basis weight and less “AQS caliper” than product “C”. Product “A” also has a good performance but at the highest raw material price of all the “AQS”, which in terms of the “AQS” alone, without the remaining core, is not efficient. In the medium performance area, the “AQS” performance, as well as costs, is located in the medium performance area. From these “AQS”, the one of product “P” is the most balanced one and that of product “K” has the lowest cost efficiency. The products “D”,”G” and “E” are the lowest performing ones. The "AQS" of product “G” is the cheapest one, although it uses expensive “PET” fibres, but it has a very low basis weight and is very thin. The “AQS” performance is normally dependent on the storage core design and by that also on the “Tier” the product is designed for. Product “F” has the optimum design in terms of “PET” fibres with a high resiliency based on the carded air-through bonding technology and a low basis weight and caliper. Other “AQS” designs which are not so cost versus performance effective use either cheap fibres like “PP” which do not offer the same resilience as “PET” fibres, or they are combined with medium to thick nonwoven webs with a higher caliper.

3.1.3.2 Costs versus Performance Ranking of the Product

First of all, a cost ranking of the whole product core is given, accomplished in the same way as for the “AGM and pulp” and “AQS” layers. This is followed by a cost versus performance ranking of the whole product. The core cost versus urine leakage performance estimation is given based on the urine leakage predictions of the “BIG 3 raw material model to consumer” model, because the chassis influence is neglected here.

Product “A” has the most cost versus performance efficient core, by an “AQS” based on “PET” resin-bonded fibres and citric acid-treated cellulose and a profiled highly-advanced “AGM and pulp” layer. The products “F” and “C” are much more expensive based on the larger amount of “AGM” and pulp. In the medium performance area, there are either products which perform well, but which are also expensive like product “G”, or, products which perform not as well but are cheap, based on the smaller amount of raw materials in the core. The low "Tier" products are located in the lowest performance area, in that core “K” is the cheapest core, but also has the worst performance.

Core	Cost Indices	Cost Ranking	Performance Ranking
K	0.606	1	10
B	0.751	2	7
Q	0.945	4	8
E	0.984	5	6
A	1.000	6	2
G	1.072	7	4
D	1.102	8	5
C	1.142	9	3
F	1.197	10	1
P	0.825	3	9

Fig 3.146: Material cost ranking core

The overall urine leakage performance (“Expert Panel”) versus raw material costs is provided (fig.3.150) including the chassis and fastening system of the product. Fig. 3.147 provides an overview about the cost proportion of these parts for all products.

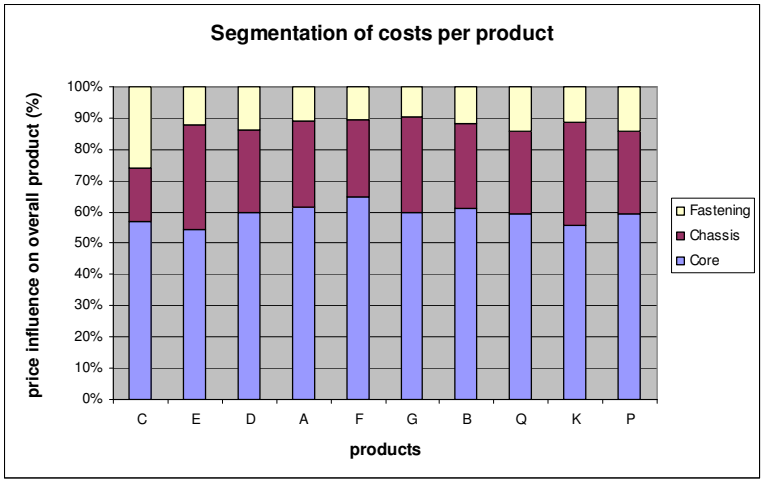


Fig 3.147: Raw Material Cost Split by chassis, fastening system, core per product

As shown in Fig. .3.148, the cost influence of the different materials on the chassis is as follows: “Backsheet–film”, 36 percent; “Backsheet nonwoven”, 29 percent; and the “Barrier Leg Cuff Fabric”, 26 percent. For the “Fastening System”: 42 percent of all raw material costs are caused by the “fastening tape”, 37 percent by the “landing zone” and 15 percent by the “hooks”.

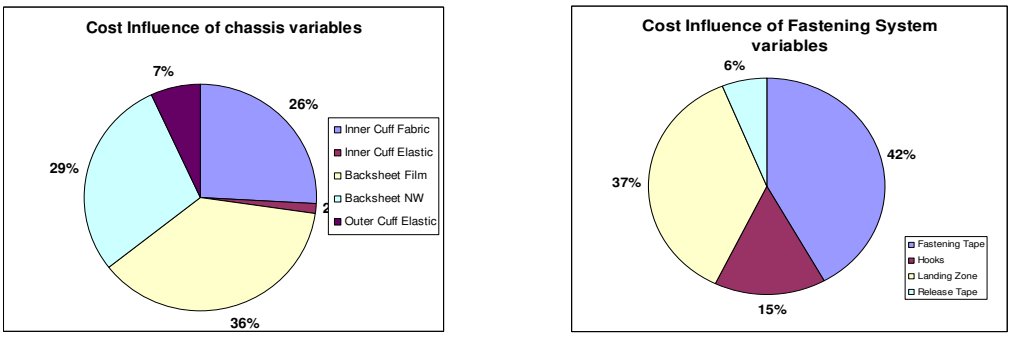


Fig 3.148: Raw Material Cost Portion on Chassis and Fastening System

The “overall product cost versus performance” ranking is accomplished based on the model prediction and afterwards a comparison with the observed leakage values is accomplished.

Product	Observed leakage	Predicted leakage
A	1.90	4.33
C	2.00	5.08
D	2.75	5.57
B	3.50	8.27
E	4.00	6.77
G	5.18	5.31
F	5.19	2.81
Q	7.47	8.64
P	13.27	10.33
K	21.54	15.90

Fig 3.149: Observed versus predicted leakage

3.1.3.2.1.1 Best Performing Products

In terms of performance, in the model product “F” is the best in terms of leakage, but it is also the second most expensive product based on the raw material price. This is mainly due to the expensive core, which has a high “AGM” amount. In addition, the fastening system and chassis are in the medium raw material cost level. In reality, the product performs only in the medium area. The second best product, according to the “BIG 3” model prediction, is product “A”. This product is located in the medium raw material cost range for the core, the chassis and the fastening system and therefore, the overall cost is placed in the medium level. The good performance from a medium raw material cost price in the core is related to the highly-sophisticated “AGM”, in combination with a core-profiling technology, which allows a high performance to be achieved with a smaller amount of “AGM”. Product “C” is the last product in this the category of well-performing products. This product has the highest raw material costs of all products. Looking at the individual components, product “C” has the second cheapest chassis of all products, the most expensive “Fastening System” and the second highest cost for the core. The high core price is driven by neither the “AGM” nor by the “AQS”, but by the tissue and the nonwoven “Dusting layer”. For the fastening system, the hooks are the drivers for the high raw material costs.

Whole Product	Cost Indices	Cost Ranking	Performance Ranking
K	0.723	1	10
B	0.753	2	7
Q	0.979	4	8
A	1.000	5	2
G	1.097	6	4
E	1.109	7	6
D	1.129	8	5
F	1.136	9	1
C	1.232	10	3
P	0.086	3	9

Fig 3.150: Cost versus performance ranking whole diaper

3.1.3.2.1.2 Medium Performing Products

In the medium performance, leakage predicted area is located product “G”, “D”, “E”, “B” and “Q”. Product “G” has the lowest percentage of leakage in this category and the raw material costs for the whole product are located in the medium area. The most expensive part is the high amount of “AGM” in the core. The fastening system is cheap and the chassis is located in the medium area.

Chassis	cost indices	Ranking
B	0.728	1
C	0.760	2
K	0.798	3
Q	0.979	4
A	1.000	5
F	1.011	6
D	1.070	7
G	1.195	8
E	1.332	9

Fastening System	cost indices	ranking
K	0.709	1
B	0.830	2
G	0.990	3
A	1.000	4
F	1.105	5
E	1.249	6
Q	1.309	7
D	1.435	8
C	2.959	9

Core	Cost indices	ranking
K	0.606	1
B	0.751	2
Q	0.945	3
E	0.984	4
A	1.000	5
G	1.072	6
D	1.102	7
C	1.142	8
F	1.197	9

Fig 3.151: Diaper components cost indices

Product “D” is the next product which is predicted in terms of percentage of leakage. This product has a high to medium price in terms of raw material costs. The fastening system is expensive and the core and chassis are in the medium to high raw material cost range. The raw material costs of the core (fig. 3.143) can be split by the “AQS”, which is in the medium cost range, the “AGM” (medium to high cost) and the nonwoven “Core Cover”(medium to low costs).

Product “E” offers a medium-performing diaper with a medium raw material cost combination. The core and fastening system are in the medium cost level and the chassis is the most expensive, based on the expensive “Backsheet film” (large amount of colors) and the outer cuffs elastics.

3.1.3.2.1.3 Worst Performing Products

Product “B” is at the lower end of the medium performance range for its core, chassis and fastening system and uses cheap raw materials. Product “Q” has the worst performance out of the medium performance area, but a cheap raw material price. The raw material price includes a cheap core, a medium-cost chassis and an expensive fastening system.

3.1.4 Business Related Application Examples of BIG 3

This chapter states examples for the use of the model in the daily business life. The first example illustrates an oil price increase. Hence, a supply shortfall takes place and the "AGM" raw material price increases by 20 percent. In the second case, a competitor wants to improve the cost-effectiveness of its leakage performance to become at least as good as the main competitor. The third example presents, for product "A", possible ways to reduce costs with the same overall leakage performance.

3.1.4.1 Price Increase of Absorbent Gelling Material

The assumption is that a crude oil price increase leads to an "AGM" price increase of 20 percent. As the market prices for diapers could not immediately follow immediately the price increase in the "AGM" market, the manufacturer needs to reduce the "AGM" amount in relation to the 20 percent price increase. The "BIG 3- raw material to consumer" model gives a forecast of the change in the overall leakage performance per product.

For the forecast, the assumption is made that the diaper manufacturers stay with their current core design and "AGM" technology. Furthermore, they will reduce the "AGM" amount evenly over all four diaper zones. This involves a "Core Capacity" decrease and "Core Time" increase of 25 percent of the percentage of the "AGM" amount reduction.

Price increase 20% of AGM		
product	AGM amount per diaper before price increase	AGM amount per diaper after price increase
F	15.01	12.51
C	12.16	10.13
B	9.86	8.22
A	12.21	10.18
P	7.52	6.27
Q	10.01	8.34
K	10.30	8.58
D	11.43	9.53
G	13.28	11.07
E	13.34	11.12

Fig 3.152: AGM amount per diaper after the price increase of 20%

The new calculated values for "AGM amount", "Core Capacity Zone 2" and "Core Time Zone 2" and their respective quadratic terms replaces the old values in the overall leakage equation.

Input	Overall
$constant	22.1678
AAP	-0.0928
(AAP)^2	-0.0019
AGM amount	-0.3383
(AGM amount)^2	-0.0074
AQS caliper	-0.0502
(AQS caliper)^2	-0.0305
Core Cap. Z 2	-0.0322
(Core Cap. Z 2)^2	-0.0001
CC time	0.2978
(CC time)^2	0.2228
Core time Z 2	0.0179
(Core time Z 2)^2	0.0001
CRC	0.0188
Maximum Uptake AQS	-0.5830
(Maximum Uptake AQS)^2	-0.0268
MDP	-0.0001
(MDP)^2	0.0001
SFC	0.0139
(SFC)^2	0.0003

Fig 3.153: Overall leakage equation

Fig. 3.152. shows the predicted urine leakage performance before and after the "AGM" reduction. The overall ranking does not change. The percentages on the right side present the leakage increase after the "AGM" reduction. The reduction of the "AGM" impacts strongly on the diaper with a large "AGM amount" or a large "AGM amount" in zone two.

incl. less AGM, core cap. Z2, coretime more			price increase	
Product	**Observed**	**Predicted**	**Predicted AGM, coretime,corecap incl.**	**Percent predicted leakage before/after AGM reduction**
F	5.19	1.7	3.31	95
A	1.9	3.3	4.62	40
C	2	4.02	5.37	34
G	5.18	4.28	5.73	34
D	2.75	4.65	5.92	27
E	4	5.77	7.18	24
B	3.5	7.39	8.5	15
Q	7.47	7.78	9.89	27
P	13.3	9.34	10.72	15
K	21.5	15.57	16.88	8

Fig 3.154: Predicted leakage after price increase of AGM

3.1.4.2 Performance Opportunities based on Product “E”

This example is based on the core of product “E”, which is in the medium performance area. The assumption is that the aim of the manufacturer is to increase the product performance which the lowest possible cost increases. Due to the fact that “BIG 3” is a model only focussing on the diaper core, the assumption is that the value the model predicts is the real observed urine leakage value. Therefore, the focus is aimed at the two main attributes “AGM and pulp” layer and “AQS”. Due to the fact that the “AGM” is more expensive, the "AQS" is considered first. The core of “E” performs worse in terms of “AQS”. It has a bad “Maximum Uptake”, combined with a medium “AQS time”, caliper and basis weight. In terms of “AGM”, product “E” contains a large “AGM" amount, a medium “Core time” in zone two combined with a bad “Core Capacity” in this zone.

From a “BIG 3 raw material to consumer model” point of view, first of all the “Maximum Uptake” of the “AQS” needs to be improved. To give a comprehensible example here, the assumption is made that a thicker caliper with the same basis weight shows no influence in “AQS time”. A 20 percent increase in the caliper (0.648mm) with the same basis weight results accordingly in 20 percent more void volume and hence, 20 percent more liquid uptake of the “AQS” (10.14g/g). When these two parameters are put in the model equation (Fig. 3.155.) the overall urine leakage decreases to 3.94 percent, which makes the product comparable to product “C”. In terms of cost increase, the assumption is made that 20 percent more volume results in a 20 percent higher raw material cost, which results in a cost index of 0.408 instead of 0.34. The 20 percent price increase results in a 1.44 percent cost increase of the core and in a 0.64 percent cost increase of the whole diaper, which yields to the fact that the core of product “E” stays with the same cost performance ranking, but an improved overall urine leakage performance ranking. A further “AQS” improvement would be the application of more surfactant on the fibres, which also leads to a further “Maximum Uptake” of the liquid. In terms of the “AGM & pulp” layer, the issue is that “AGM” is the most expensive part of the core (Fig. 3.134.) and product “E” already uses a large amount of it. To improve the performance continuously by having a higher capacity in zone two, a profiling need to be added here, this involves no raw material cost increase concerning the diaper, but a conversion of the manufacturing process. Due to the fact that this is a competitive product, the necessary input variables to calculate the costs are not given and the assumptions are so weak that this calculation cannot be accomplished.

Input	Overall	*Product "E" input*	Product "E" predicted urine leakage	*Product "E" 20% more AQS liquid uptake*	*Product "E" pred. 20% more AQS liquid uptake*
$constant	22.17		22.17		22.17
AAP	-0.09	17.10	-1.59	17.10	-1.59
(AAP)^2	0.00	292.41	-0.56	292.41	-0.56
AGM amount	-0.34	13.34	-4.51	13.34	-4.51
(AGM amount)^2	-0.01	177.96	-1.31	177.96	-1.31
AQS caliper	-0.05	0.54	-0.03	0.65	-0.03
(AQS caliper)^2	-0.03	0.29	-0.01	0.42	-0.01
Core Cap. Z 2	-0.03	83.31	-2.69	83.31	-2.69
(Core Cap. Z 2)^2	0.00	6940.56	-0.85	6940.56	-0.85
CC time	0.30	0.00	0.00	0.00	0.00
(CC time)^2	0.22	0.00	0.00	0.00	0.00
Core time Z 2	0.02	55.52	0.99	55.52	0.99
(Core time Z 2)^2	0.00	3082.47	0.36	3082.47	0.36
CRC	0.02	25.00	0.47	25.00	0.47
Maximum Uptake AQS	-0.58	8.45	-4.93	10.14	-5.91
(Maximum Uptake AQS)^2	-0.03	71.40	-1.91	102.82	-2.75
MDP	0.00	9.00	0.00	9.00	0.00
(MDP)^2	0.00	81.00	0.01	81.00	0.01
SFC	0.01	9.00	0.13	9.00	0.13
(SFC)^2	0.00	81.00	0.02	81.00	0.02
predicted leakage values			5.77		3.94

Fig 3.155: "BIG 3" model prediction for product "E" normal and with 20percent more void volume of the AQS

3.1.4.3 Cost Reduction of Core "A" by Minimal Performance Loss

The assumption for this scenario is that the manufacturer wants to achieve a cost saving on the core of product "A" of 10 percent with a minimal performance loss. The reduction is accomplished based on the different cost portions of the core components. One example in terms of cost reduction, is a material reduction of ten percent for all relevant materials. The assumption here is that this leads to a 10 percent performance loss yielding in 5.72 percent leakage instead of 3.3.

10% RM cost reduction core		10% less perform. On all rel materials	
Input	**Overall**	Product "A"input	Product "A" predicted
$constant	22.1678		22.1678
AAP	-0.0928	21.60	-2.00
$(AAP)^2$	-0.0019	466.56	-0.89
AGM amount	-0.3383	10.99	-3.72
$(AGM\ amount)^2$	-0.0074	120.76	-0.89
AQS caliper	-0.0502	2.84	-0.14
$(AQS\ caliper)^2$	-0.0305	8.04	-0.25
Core Cap. Z 2	-0.0322	92.20	-2.97
$(Core\ Cap.\ Z\ 2)^2$	-0.0001	8500.10	-1.04
CC time	0.2978	0.35	0.10
$(CC\ time)^2$	0.2228	0.12	0.03
Core time Z 2	0.0179	46.13	0.82
$(Core\ time\ Z\ 2)^2$	0.0001	2128.35	0.25
CRC	0.0188	27.00	0.51
Maximum Uptake AQS	-0.5830	8.64	-5.04
$(Maximum\ Uptake\ AQS)^2$	-0.0268	74.65	-2.00
MDP	-0.0001	18.00	0.00
$(MDP)^2$	0.0001	324.00	0.04
SFC	0.0139	33.00	0.46
$(SFC)^2$	0.0003	1089.00	0.27
			5.72

Fig 3.156: Model usage to predict urine leakage performance of product "A"

For the next step, the 10 percent cost saving of the core is accomplished by only the "AGM" amount. This leads to the fact that 10.15g of "AGM" is in the diaper core instead of 12.21g, which also leads to a reduction in "Core Capacity" and an increase in "Core time" in zone two. The reduction of the "Core Capacity" in zone two is based on the assumption of an even "AGM" reduction over all four zones of the diaper and, by that, the capacity in zone two is reduced by 25 percent and the time of liquid distribution increased by 25% of the "AGM" amount taken out. Changing all these "AGM"-related input variables in the model, results in the urine leakage prediction of 5.73 percent.

The 10 percent cost reduction can also be achieved by just reducing the "AQS" by 47.9 percent. The assumption again is that the performance will also be reduced by 47.6 percent. The model predicts urine leakage at 10.86 percent.

Input	Overall	Product "A" input	Product"A" predicted	Product "A" 10%leaa AGM		Product"A" 10%leaa AQS	
$constant	22.17		22.17		22.17		22.17
AAP	-0.09	21.60	-2.00	21.60	-2.00	21.60	-2.00
$(AAP)^2$	0.00	466.56	-0.89	466.56	-0.89	466.56	-0.89
AGM amount	-0.34	12.21	-4.13	10.15	-3.43	10.15	-3.43
$(AGM amount)^2$	-0.01	149.08	-1.10	103.02	-0.76	103.02	-0.76
AQS caliper	-0.05	3.15	-0.16	3.15	-0.16	1.51	-0.08
$(AQS caliper)^2$	-0.03	9.94	-0.30	9.94	-0.30	2.28	-0.07
Core Cap. Z 2	-0.03	102.44	-3.30	81.64	-2.63	81.64	-2.63
$(Core Cap. Z 2)^2$	0.00	10493.95	-1.28	6665.74	-0.81	6665.74	-0.81
CC time	0.30	0.35	0.10	0.35	0.10	0.35	0.10
$(CC time)^2$	0.22	0.12	0.03	0.12	0.03	0.12	0.03
Core time Z 2	0.02	41.94	0.75	50.50	0.90	50.50	0.90
$(Core time Z 2)^2$	0.00	1758.96	0.21	2550.25	0.30	2550.25	0.30
CRC	0.02	27.00	0.51	27.00	0.51	27.00	0.51
Maximum Uptake AQS	-0.58	9.60	-5.60	9.60	-5.60	4.60	-2.68
$(Maximum Uptake AQS)^2$	-0.03	92.16	-2.47	92.16	-2.47	21.16	-0.57
MDP	0.00	18.00	0.00	18.00	0.00	18.00	0.00
$(MDP)^2$	0.00	324.00	0.04	324.00	0.04	324.00	0.04
SFC	0.01	33.00	0.46	33.00	0.46	33.00	0.46
$(SFC)^2$	0.00	1089.00	0.27	1089.00	0.27	1089.00	0.27
predicted leakage values			**3.30**		**5.73**		**10.86**

Fig 3.157: Different approaches of cost reduction of core "A2

With the given core design and "AGM" generation, the best choice is to reduce the "AGM amount". This has the same impact on urine leakage increase as reducing respectively material from all core materials, which is in reality much more difficult. The "AGM" amount can be controlled within the diaper manufacturing process, in terms of a thinner "AQS", it is more complex to realize, because new specifications for the new nonwoven web need to be framed and the production process need to be converted to the thinner web with the new specifications.

Another possibility is to use a more advanced AGM generation, which makes the use of pulp unnecessary and hence leads to a cost reduction of 10 percent of the core.

A further possibility is the mixture of another "AQS", which has more liquid uptake by less caliper and therefore material and costs are saved and a smaller "AGM" amount used.

4 Summary of Results

The main objective of this PhD thesis is to build a model which predicts consumers' urine leakage experience for a wide range of different diaper core technologies. In addition, the determination of the key drivers of urine leakage in general and their proportion of influence on each product is required. These two key parameters build the basis for an in-depth understanding of competitive core technology.

The model is based on the following assumptions:

- The core is the main contributor to urine leakage, as it is responsible for liquid handling and storage.
- Urine leakage is a function of time and capacity.
- Laboratory measurements are only generated in fully-saturated media to exclude the changing kinetics of the core which is not measurable in a reliable way.

For this project, 18 products are selected based on volume share and the competitive interest of "P&G". All products are placed in consumer studies in their country of origin. The analyses of these datasets point out that only consumer data generated in one region can be incorporated in the model. This is due to the different mindsets and diapering habits of consumers between different regions, which lead to different urine leakage experiences for the same product. Furthermore, the analyses determine the specific load cluster (61-300ml) of the model. The model predicts consumers' urine leakage experience of a wide variety of diaper technologies for this load cluster.

The different raw material influencing-variables are identified (152 variables) and reduced via physical relations ("First Principle Based Model") and simplifications. The simplification is the incorporation of the second zone (11-22cm) of the diaper core only, because there the urine has the first contact with the diaper and should be accordingly, absorbed there quickly and distributed to the other diapers zones. This makes this part of the diaper the most important.

The remaining influencing-variables are further reduced by the identification of correlations amongst each other. In the case of correlations, only one of these correlated variables is used for the model-building, this assures a higher prediction capability of the model by fewer input variables.

The first model approach, using the holistic laboratory diaper measurements as an intermediate step between diaper raw material properties and consumers' urine leakage perception, does not work out. The reason is that no meaningful link between the raw material properties and the holistic measurements of the diaper can be accomplished. Therefore, a model is realized which links raw material properties directly to consumers' urine leakage experience. In addition, a second model between holistic diaper measurements and consumers' urine leakage perception is built to identify the important holistic diaper measurement methods.

Different model approaches point out that "Partial Least Squares" is the right statistical technique to link laboratory measurements and consumers' urine leakage experience. The focus for this thesis is concentrated on the "raw material to consumer model", which is able to explain the influence factors of urine leakage.

As mentioned above, the model is built for the load cluster of 61-300ml; within this area 86 percent of all urine diaper changes are accomplished. To be in line with the laboratory measurements and determine the changing influence of the input variables by diaper load, the whole load area (61-300ml) is divided into four 60ml load clusters. For each load cluster, a model is built and afterwards the single models are combined to give an overall urine leakage model incorporating the percentage of urine diaper changes per load cluster.

The developed models of the single load clusters assess the area of urine leakage experience, but need to improve, in terms of prediction, the exact urine leakage occurrence. The models identify that the urine leakage influencing-variables are capacity-related in load cluster one (61-120ml) and change to time- and capacity-based variables in the second cluster (121-180ml). Within load cluster three (181-240ml), time-related variables influence urine leakage of the diaper only. This can be explained by the fact that the second zone, which is already swollen (AGM) needs to distribute the liquid within the core in areas with free capacity. In the last load cluster (241-300ml), the capacity-relevant variables become important in terms of urine leakage, as most of the "AGM" is already fully-swollen.

The overall urine leakage model (load cluster 61-300ml), generated by the single models, identifies the following five variables and their quadratic terms as key influencing variables for urine leakage occurrence:

1) The capacity of the “Acquisition System” (“Maximum Uptake AQS”)
2) The amount of superabsorber (“AGM amount”)
3) The capacity of the core in zone two (“Core Capacity Zone 2”)
4) The capacity of the superabsorber under pressure (“AAP”)
5) The time the core in zone two needs to distribute 60 ml of liquid (“Core Time Zone 2)

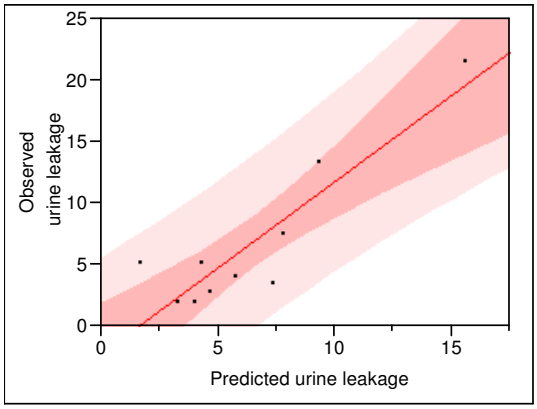


Fig 4.1: Predicted versus observed overall leakage

The model predicts leakage performance across all products by 70 percent and explains the influence of the input parameters on urine leakage by 80 percent, which is quite a strong model for consumer predictions. Fig. 4.1. illustrates the predicted versus real (observed) urine leakage occurrence. The dark pink area points out the 95 percent confidence interval of the model. Research highlights that the reason why two products deviate from the remaining dataset is chassis- related.

Accomplishing a similar model for the link between holistic measurements and consumers’ urine leakage experience, similar good results are yielded.

This overall urine leakage model, also predicting for the load cluster 61-300ml, determines two capacity variables (“ABL”, “Core Capacity Z 2”) and one time variable (“SABAP3”) as the main influencing holistic parameters on urine leakage prediction.

The main two layers determined by the overall "raw material to holistic model" are the “Acquisition System” and “AGM & pulp” layer. For both layers, a performance versus

cost ranking of the single products is accomplished. This ranking has been carried out by using the proportion of influence of the single variables, which derive from the model.

The ranking of the “Acquisition System” leads to the conclusion that the most efficient layers in terms of cost versus performance either use carded resin-bonded “PET” fibers or carded, air-through bonded bicomponent fibers (“PET” core, “PE” cover). In addition, these nonwoven webs own a medium to high basis weight and caliper to achieve a high capacity and resilience for urine distribution. The findings of the “AGM and pulp” layer ranking are that profiled storage cores with highly-advanced “AGM” generations (high “SFC” and “AAP”) perform best in terms of cost versus performance.

Nevertheless, the single layers achieve their best performance in combination with each other, because that is what they are designed for. The performance comparison of the diaper core, including all layers, identifies two 'best in class' approaches to diaper core design.
The first one is based on an “Acquisition System” which distributes the liquid quickly over the profiled storage core, and that also has a strong ability to distribute the urine further within the different zones of the diaper.
This core design is cheap from a cost point of view, because it uses the most expensive raw material for the core - the “AGM” in a profiled design. This means that, overall, a medium amount of “AGM” is used in the diaper core, but more of the “AGM” is allocated in zone two compared to the other zones. This leads to a high performance in this zone with lower costs.
The second approach of the diaper core design is highly-expensive and designed for liquid absorption only. This includes a greater ability of the “Acquisition System” to store the liquid intermediately than to distribute it. The storage core underneath the “Acquisition System” is not profiled, which leads to higher raw material costs based on the higher “AGM” amount, which is needed to achieve good urine leakage prevention.

For overall raw material cost estimation, the chassis and fastening system are also included in the analysis. The outcomes point out that the manufacturers which own a lower-performing core invest more in the chassis to assure a good fit of the diaper on the baby and thereby also achieve a slightly better urine leakage prevention.

The three business-relevant examples for the overall “raw material to consumers’ urine leakage experience ” model application, state that the model can be used in terms of competitive product assessment. This leads, alongside time and cost savings for the company, to a more exact understanding of the competitive market and a better forecast in terms of consumers’ satisfaction.

However, to achieve a higher prediction ability of the model, more low-performing products and parameters related to the chassis need to be incorporated in the model. Additionally, the model needs to be updated concerning completely new diaper core designs and technologies, e.g. no pulp or a new fiber technology. Only this progress will ensure that the model delivers accurate urine leakage prediction probabilities in the future and delivers the proportion of the key raw material drivers.

5 Literature

Abdi, H.: Partial Least Squares (PLS) Regression, Encylopedia of Social Sciencies Research Methods, .Thousand Oaks, Sage, USA: 2003.

Albrecht, W.& Fuchs, & Kittelmann, H.: Nonwoven Fabrics, Wiley-VCH Verlag,, Weinheim: 2003.

Atterby, A.: A-two-Pronged Attack on the Global Diaper Market, Nonwoven Industry-World Diaper Market: Jan. 2007.

Bamberg, B. & Baur, F: Korrelationsrechnung, Statistik, Oldenbourg Verlag, München: 2002,

Bamberg, B. & Baur, F: Regressionsrechnung, Statistik, Oldenbourg Verlag, München: 2002.

Barker, R.: Comments Submitted By The American Fiber Manufacturers Association On The Reach Proposal. European Comission.

Bhat, G.S.& Malkan,S.R.: Polymer-Laid Web Formation, Handbook of Nonwovens, Woodhead Publishing Limited, Camebridge: 2006.

Booz et al: Baby Care Sourcing & Manufacturing, Competitive Cost Analysis, P&G Internal Source: October 2003

Brünner, A.: Lineare Regression-Methode der kleinen Fehlerquadrate, Mathematik. As at 2002. URL:http://www.arndt-bruenner.de/mathe/scripts/regr.htm (called up July 2007)

Brydon, A.: "Polymer –Laid Web Formation – Polyolefin Resins", Handbook of Nonwovens, Woodhead Publishing Limited, Camebridge:2006.

Buchholz, F.L., Graham, A. T.: Modern Superabsorbent Polymer Technology, Wiley-VCH, Weinheim: 1997.

Cain, L.W.: Polyolefin Polymers and Fibers, Fibers and Binders from Nonwovens, San Francisco: 1992, Issue 2.

Chapman, R.A.: Chemical Bonding; Handbook of Nonwovens, Woodhead Publishing Limited, Camebridge: 2006.

Cheng,C.Y.: Tappi Nonwovens Conference; Orlando Florida Feb.14-16,1994.

Christianus, D.: Interne Kundenbeziehung, Management von Kundenzufriedenheit und Kundenbindung, Expert Verlag, Renningen-Malmsheim: 1999.

Courtray Consulting Labservice: Absorption Before Leakage –Return, Baby Hygiene; Douai: January 2005.

Dichtl E., Dr. & Issing, O. : Preis, Vahlens Großes Wirtschaftlexikon; Franz Vahlen Verlag Verlag GmbH, München:1993, Issue 2.

Edana: Absorption Against Pressure, EDANA ERT. 442.2-02, l.

Edana: Absorbent Hygiene Products Training Course, 2006, Issue 2 1998, 1.16-1.21

Edana: AGM PartAn, EDANA ERT. 420,

Edana: Centrifuge Retention Capacity, EDANA ERT. 424,

Edana: Making Nonwovens, Edana Nonwovens. As at August 2007. URL: http://www.edana.org/story.cfm?section=|edana_nonwovens&story=making.xml (called up August 2007)

Edana: Nonwoven Market Overview**,** Edana Conference, 2001.

Edana: Raw Materials For Nonwovens, Nonwovens Training Course, January 2006, Module 2.1.

Edana: Strikethrough, EDANA ERT. 150.5-02.

Ehrnsperger, B.: A First Principles Model to Predict Diaper Leakage, SLR, P&G Internal: July 2005

Ehrnsperger, B.: Urine Leakage und SABAP Correlations, SLR, P&G Internal: February 2007

Erlbeck, K.: Kundenorientierung als Primat der Unternehmensführung, Kundenorientierte Unternehmensführung- Kundenzufriedenheit und –loyalität, Deutscher Universitäts Verlag, Wiesbaden: 1999.

Fahrmeir, L. et al: Multivariate Deskription und Exploration, Statistik- Der Weg zur Datenanalyse, Springer Verlag, Heidelberg: 2007.

Froehlich, U.: Determination of Contact Angle of Current AQL 3; SLR, P&G Internal: December 2006.

FU Berlin: Kunstoffe zum Kennenlernen: Polyethylene. As at 2001. URL: http://www.chemie.fu-berlin.de/chemistry/kunststoffe/polyethylen.htm (called up August 2007)

FU Berlin: Kunstoffe zum Kennenlernen: Polyester. As at 2001. URL: http://www.chemie.fu-berlin.de/chemistry/kunststoffe/ester.htm (called up August 2007))

Garson, D.: Partial-Least-Squares-Regression, Statistics Solution Inc.. As at 2006. URL: http://www.statisticssolutions.com/Partial-Least-Squares-Regression.htm (called up July 2007)

Hinterhuber, H. & Matzler, K.: Das Kano-Modell der Kundenzufriedenheit, Kundenorientierte Unternehmensführung; Gabler Verlag, Wiesbaden:2002.

Heskett, J.L. et al: Putting the Service Project Chain to Work, Havard University Review, Issue 2: 1994.

Homburg, C., Dr.: Preisbezogene Auswirkungen von Kundenzufriedenheit, Kundenzufriedenheit, Gabler Verlag, Wiesbaden: 2006.

Horie, K. & Braun, M.: Definitions of Terms Relating to Reactions of Polymers and to Functional Polymeric Materials, IUPAC Recommendations, 2003,

IUPAC: Compendium of Chemical Terminology, 1997, Issue 2

Janssen, J.: Korrelation und Distanzen, Statistische Datenanalyse mit SPSS für Windows; Springer Verlag, Berlin: 2003.

Jarke, T.: Evaluation of diapers to meet consumer needs, P&G Internal Presentation: 2003.

Kamath, M.G. et al.: How Binder Works, Chemical Bonding. As at April 2004. URL: http:// www.engr.utk.edu/mse/pages/textiles/chemical%bonding.htm (called up March 2006)

Kloock, J. et al: Grundlagen der Kosten-und Leistungrechnung, Kosten-und Leistungsrechnung; Lucius&Lucius; Stuttgart:2005.

Lebhardt, G. & Münz R.: Fertilitäts und Geburtenentwicklung, Humboldt- Universität Berlin. As at: April 2002. URL: http://www.berlininstitut.org/pages/buehne/buehne_beventw_muenz_fertilitaet.html (called up August 2007)

Liedtke, C.: Has Mothers' perception influence on leakage occurrence?; SLR, P&G Internal: January 2007

Loebel, P.: P&G; Laboratory Methods for Competition Monitoring - Dunktest, Baby Care Test Method Diapers; P&G Internal: January 2006

Lohninger,H.: Grundlagen der Statistik. As at 2006. URL: http://www.statistics4u.info (called up July 2007)

Matzler, K. & Pramhas,N.: Preiszufriedenheit-Prospect Theory, Kundenorientierte Unternehmensführung, Gabler Verlag, Wiesbaden: 2006.

Mlymor, M. Et al: Chemical Binders, INTC 2003: Sept. 15-18.

Mueller: Metallocen Polymerisation, Koordinationschemie Geschichte und Zukunft, Universität Bayreuth, Anorganische Chemie 2 WS0506. As at 2005. URL: www.ac2.uni-byreuth.de/teaching/hs/vortraege/ws0506-13-mueller.pdf (called up July 2006)

Nagasuna, K. et al.: Eur. Patent Appl.1994, 605,150

Nakamura, M. et al : US Patent 5, 1993,180,798.

Nielson, AC: Volume Shares Baby Diapers- National Retail Index, Source One,P&G Internal database. As at 2005. URL: http://sourceone.internal.pg.com/global/s1/main.htm (called up March 2005).

Osborne, J.W.: Prediction in Multiple Regression, Practical Assessment Research & Evaluation. As at 2000. URL:http://pareonline.net/getvn.asp?v=7&n=2 (called up July 2007)

P&G: AGM Titration, Baby Care Test Method Raw Materials, P&G Internal, GCAS 60051628.002.

P&G: Barrier Leg Cuffs, Baby Care Test Method Raw Materials, P&G Internal, GCAS 95282695.

P&G: Bromocresol Staining, Baby Care Test Method Raw Materials, P&G Internal, GCAS 95004733.002

P&G: Free Swelling Rate, Baby Care Test Method Raw Materials, P&G Internal, GCAS 64015188.002.

P&G: Global Competitive Claims Database. URL: http://www.pg.internal.gcna.com (called up July 2005)

P&G: In Plane Radial Permeanility, Baby Care Test Method Raw Materials, P&G Internal, GCAS 95364041.001,

[1]**P&G:** Saline Flow Conductivity, Baby Care Test Method Raw Materials, P&G Internal, GCAS 58007040.003.

P&G: Speed of Acquisition with Balloon Applied Pressure, Baby Care Test Method Raw Materials, P&G Internal, GCAS 95292975.001.

P&G: Topsheet Run Off, Baby Care Test Method Raw Materials, P&G Internal, GCAS 95018059.003.

P&G Finance: Germany- Retail Brands Share Tracking; P&G Internal database, As at 2005. P&G Intranet : URL: http:// rabbit.pg.com/stdapps/EASYWeb/weretailer/design.nsf/vHTML/Welcome (called up June 2006)

P&G Internal Source; Maslow's Hierachy of Diaper Needs, P&G Internal: 2004

Ponomarenko, K.: Capsorption- TRI: Developmental Method, Baby Care Test Method Raw Material; P&G Internal, As at 2006.

Pusko Jezic ,Z.: Polyethylene Fiber Development, Fibers and Binders from Nonwovens, Miller Freeman, San Francisco: 1992.

Ramachandran, T. et al: Antimicrobial Textiles – an Overview. 2004, IE (I) Journal – TX, 84.

Richer, C.: 50 years of evolution, Diaper History. As at 2004. URL: www.disposablediaper.net (called up October 2004),

Rosati, R. & Schmidt, M.: Capillary Liquid Training, P&G Internal Training. March 2006, Version 10.

Siemons,M.: How Fiber Thickness and Crimp Influence AQL Performance, SLR, P&G Internal. June 2007.

StatSoft: Multiple Regression, Statistika. As at 2006.
URL: Internet:www.statsoft.com/textbook/stmureg.html (called up July 2007)

Thommen, J.-P.,Dr. & Achtleitner, A.-K., Dr.,Dr. : Deckungsbeitragäge, Allgemeine Betriebswirtschaftslehre : Gabler- Verlag, Wiesbaden: 2006, p.242

Turbak, A. F.: Introduction to Nonwovens, Atlanta (GA), Tappi Press. 1998.

Turbak, A. F.: Nonwovens: Theory, Process, Performance and Testing,
Tappi Press, Atlanta (GA): 1993.

Tsubakimoto,T & Shimomura,Y. Irie: U.S. Patent 4, 1987, 666,983

Ullman, D.G.: The Mechanical Design Process, McGraw Hill Inc, U.S.A.: 1997

Vejaux, L.: Total Delivered Costs, Costed Formula Card CBA 2006 1216,
P&G. August 2006

Verband Deutscher Kunststoffindustrie: Kunstoffproduktion-Umsatz-Außenhandel.
As at 2007. URL:
http://www.vke.de/de/markt/produktion/index.php?PHPSESSID=c1f07f2d2acf55d79c96cd51fd7a467c (called up November 2007)

Weinmüller, S. et al : Finance for non finance people, P&G Training: November 2006

Wilson, A.: Development of the Nonwovens Industry, Nonwovens Report International. 2006

Wold, H.: Partial Least Squares, Encyclopedia of Satatistical Sciences,
WileyVerlag, New York: 1985, Issue 6.

Wöhe, G. Dr. Dr.h.c. & Döring, U., Dr: Die Producktions- und Kostentheorie;
Einführung in die Allgemeine Betriebswirtschaftslehre;
Verlag Franz Vahlen GmbH, München: 2005.

Zhand, C.: Finance Knowledge, P&G Training: October 2006.

Zimmermann, W., Dr. & Fries, H.-P.,Dr.:Grundbergriffe und Gliederung des industriellen Rechnungswesens, Betriebliches Rechnungswesen; R. Oldenbourg Verlag, München: 1998.

6 Declaration

Die vorliegende Arbeit wurde erstellt von Claudia S. Liedtke, geboren am 06.12.1979 in Ulm.

Ich erkläre hiermit an Eides Statt, dass ich die vorliegende Arbeit selbständig angefertigt habe. Die aus fremden Quellen direkt oder indirekt übernommenen Gedangen wurden als solche kenntlich gemacht.

Diese Arbeit wurde bisher weder in gleicher noch in ähnlicher Form einer anderen Prüfungsbehörde vorgelegt oder veröffentlicht.

Schwalbach a.T., den 20.12.2007



(Claudia S. Liedtke)