Textile Product Design and Development
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Lecture – 24
Design and Development of Incontinent Products

We will discuss the design and development of incontinent products.

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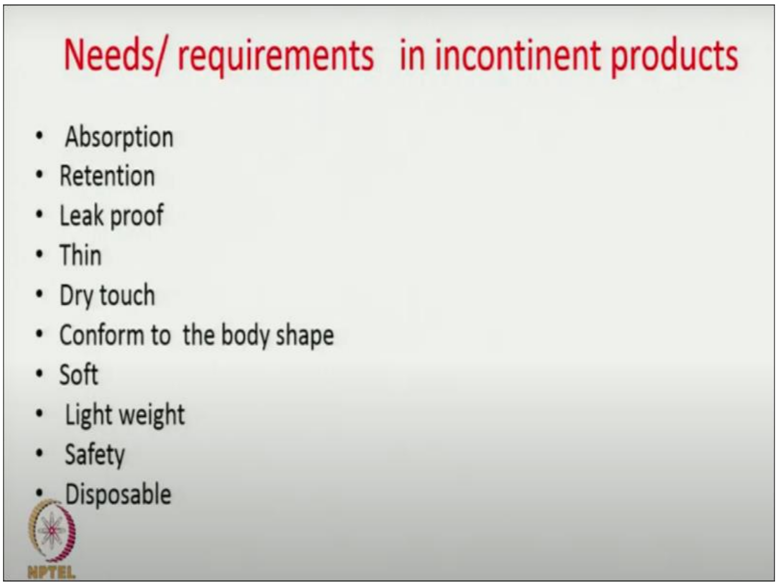

There are various needs and requirements for incontinent products. The primary need of all such products is absorption. Since these products are designed to absorb liquids, absorption is the most important property they must possess. Following absorption, retention is another key requirement for certain products.

Retention refers to the ability of the product to retain the liquid, preventing it from leaking when subjected to external pressure. Hence, the retention property is also equally important. Next comes the leakproof design, which means the absorbed liquid must remain within with no leakage during actual use.

Additionally, the product should be thin. A thinner product offers more flexibility, allowing it to conform better to the contours of the human body. Moreover, thin products are better and easier to store, requiring less space.

Another important requirement is a dry touch. Even when the product is wet, it should prevent the wet sensation from reaching the skin, as this would cause discomfort to the person. The product should maintain a dry feel while holding liquid within its structure. It should also conform to the body shape to avoid looking bulky or unattractive, ensuring it follows the contour of the body. It must be soft in nature.

If the material is too hard and remains in contact with the skin for a long time, it can irritate. Hence, softness is another important requirement. The product should also be lightweight; the less weight there is, the better the product is. Safety is also a key consideration. The safety aspect is also important, especially for products used by humans. When designed for children, it must be ensured from a safety point of view. The product should be safe to use.

It is essential to ensure that the product does not create environmental pollution, which is an important aspect of any product design. This is where disposability becomes important. The product should be easily disposable and degrade quickly in nature without clogging drains, and it should not create problems by any means with the environment. These are the key requirements for any incontinence product, and these things must be taken into consideration during the process of product design.

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Reasons for different Needs

	Needs	Reason
1	Absorption	To hold the liquid
2	Retention	Not to allow the liquid to escape under pressure
3	Thin	Easy packing, flexibility, conformation to body shape, look descent
4	Leak proof	Avoidance of leaking leading discomfort
5	Comfortable	For prolonged use,
6	Safety	Avoid rash formation
7	Disposable	Pollution control

In this slide, the needs in one column and the corresponding reasons are listed in the adjacent column. This format provides a clearer understanding of the points and a more concise summary in table form. For example, absorption refers to the product's ability to hold liquid, the higher the absorption capacity, the better the product.

The second point is the retention, which ensures that the liquid does not escape under pressure. The product should be thin. The reasons are ease of packing, flexibility, and conformation to the body shape, which should look decent and leakproof. To make the product comfortable, there are two key aspects: one is softness, and the other one is a dry feel.

Since these products are often used for extended periods, especially by the elderly, bedridden patients, or children, they may last for 4, 5, or even 6 hours. For such a long period, the product must be comfortable on the skin. Another important consideration is preventing rash formation. To address this, the product should be breathable to some extent.

The product has to be breathable so that moisture vapour generated by the skin has to escape. Otherwise, moisture will accumulate, leading to sweating, which can cause rashes or itchiness. Disposability, as previously mentioned, is essential to ensure that it does not affect the environment. These are the reasons which are stated.

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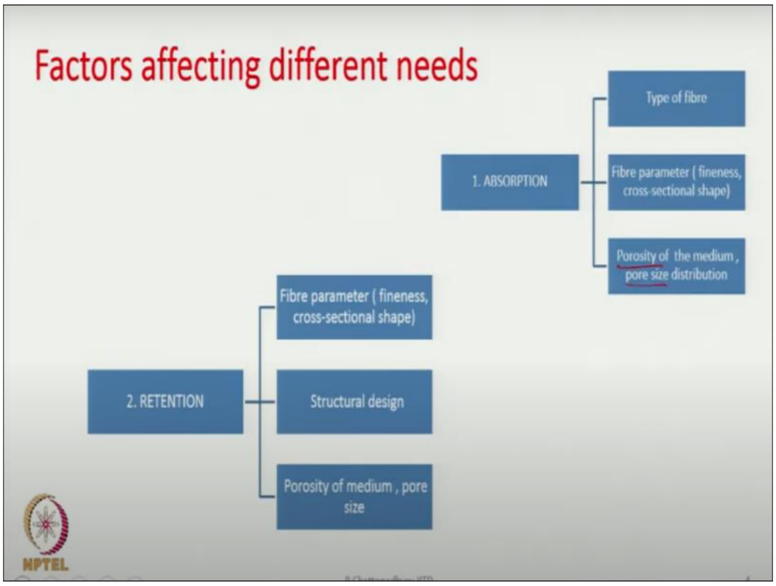

Next are the factors affecting different needs. One of the factors is absorption. This absorption depends upon several factors. Various parameters can be changed to enhance the absorption. Absorption primarily depends on the type of fibre used. Other fibre parameters, such as fineness and cross-sectional shape, also significantly impact absorption capacity.

Additionally, the structure created from these fibres is equally important. That is the porosity of the medium, whether it is a nonwoven structure, woven structure, or any other form. Ultimately, the fibres are to be given a specific shape to make a stable structure. Structural parameters, such as porosity and pore size, are crucial because they are the pores within which the liquid is retained.

Another thing is the capillary phenomena through which the liquid moves within the porous structure formed by the fibres. To enable effective liquid movement, a porous structure must be created. The liquid will move through the pores, and it will spread out over the entire part of the structure. Therefore, factors like fibre type, fineness, cross-sectional shape, and structural design all influence absorption.

Next comes retention, which also depends on these fibre parameters, including fineness, cross-sectional shape, and the overall design of the product structure. Additionally, it also depends upon the porosity and pore size of the medium. Each of these factors impacts the product's ability to retain liquid effectively.

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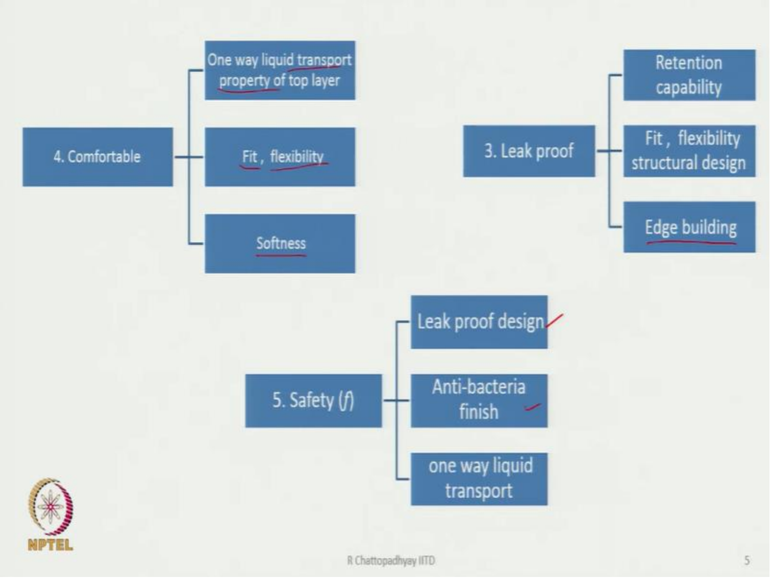

Next comes the leakproof design. For leakproof performance, the important aspect is the retention capability of the entire fibrous structure. It also depends on the fit and flexibility of the structure. Leaking typically occurs when external pressure is applied to the product. The external pressure, if it is acting on a small area, is very high, leading to the possibility of failure of the structure.

Therefore, the flexibility of the entire structure is important in distributing pressure evenly and ensuring a proper fit. Even in cases of accidental leakage, the liquid should not escape. The fit between the incontinence product and the skin is critical to ensure the liquid remains within the structure and should not drip. The other aspect is edge building and the process of building edge structure. Comfort is another key consideration.

The importance of a comfortable product has already been discussed. To ensure comfort, certain factors must be considered. First, the one-way liquid transport property of the top layer is important. In a layered structure for incontinence products, this top layer should prevent liquid from moving out of the absorbing medium, even under pressure.

There are some means to prevent the movement of the liquid outwards, even under some external pressure. That means that the design has to be created such that there is a one-way liquid flow, and the reverse flow has to be minimized. Hence, in one direction, the liquid flow is faster, and whenever the liquid is in contact, it absorbs very fast.

When external pressure is applied to the product, it is essential that the liquid does not move out of the structure. This can be achieved by incorporating one-way liquid transfer properties into the design. Additionally, fit and flexibility are important factors. A proper fit product ensures that pressure is distributed evenly, preventing excessive pressure buildup in certain areas of the skin.

The overall softness of the product is equally important. If the product is not soft and feels hard, it can cause friction between this product and the skin, which is very soft. Continuous friction that happens between the skin and the outer shell of the product can lead to irritation, redness, or even rashes in the skin.

Therefore, the product must be very soft, especially in the areas that come into direct contact with the skin. This is to ensure that the friction between the skin and the inner shell of the product is minimal. The external part of the product, which is visible and will not remain in contact with the skin, does not play a role, but the inner part, which is in contact with the skin, must provide low friction.

From a safety perspective, several key factors are considered. Safety is the function of a leakproof design, one-way liquid transport, and the antibacterial finish that is given to the product. Without such a finish, it can lead to rash generation and bacterial attacks. An antibacterial finish helps in avoiding these things.

Additionally, the one-way liquid transport design ensures that reverse flow is minimized, even under pressure, reducing the chance of liquid moving out. Some factors have to be considered during the design process, and products can be designed to satisfy the objectives or requirements.

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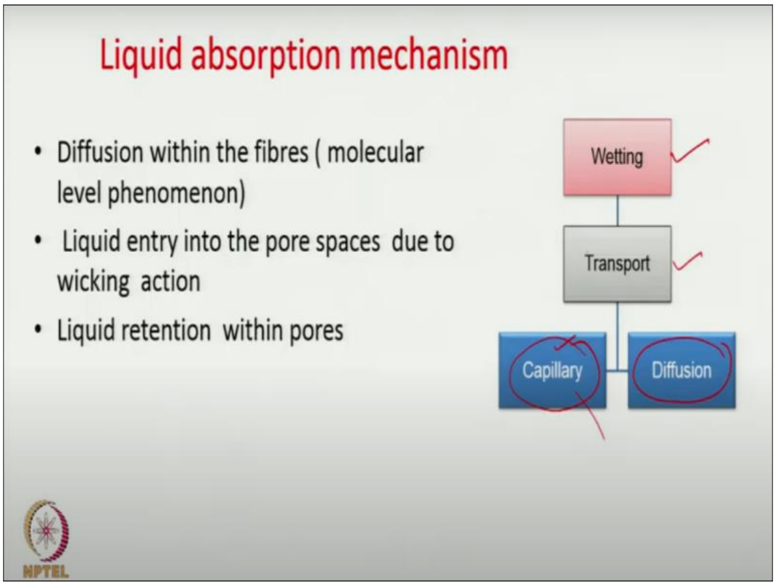

The primary function of the product is liquid absorption. It is important to consider the key aspects which were discussed previously. The liquid absorption mechanism involves several key factors: wetting, liquid transport through capillary action, and diffusion processes. These are the fundamental elements regarding liquid absorption.

The transportation of liquid within the structure primarily occurs through capillary phenomena, which rely on the presence of capillaries within the fibrous structure. For this mechanism, there must be a network of capillaries that allows liquid to flow through. The other thing is diffusion, which plays a role in liquid absorption at the molecular level. Diffusion occurs when water molecules penetrate the fibres and occupy spaces in the amorphous regions of the fibres.

Generally, the amount of liquid that enters the fibre through diffusion is much less compared to the liquid retained within the pores of a fibrous structure. Diffusion allows some liquid to penetrate the fibre itself, but most of the liquid typically resides in the spaces between fibres. In some fibres, like cotton, this is possible because cotton is hydrophilic, meaning water molecules can easily penetrate the fibre and get absorbed. It can penetrate rayon fibres but not polyester or polypropylene fibres. This makes penetration difficult in these fibres.

However, it is possible in cotton or rayon fibres or pulp, as they are cellulosic fibres with enough space available within the fibre structure, particularly in the amorphous region, where water molecules can easily enter and remain within the fibre. However, when penetration happens, the proportion of liquid that goes into the fibre is less than what flows into the pores of a structure made up of millions of fibres. Therefore, the focus should be on creating pores so that space is available between fibres to hold the liquid. The liquid is also retained within the pores in case of external pressure due to capillary tension.

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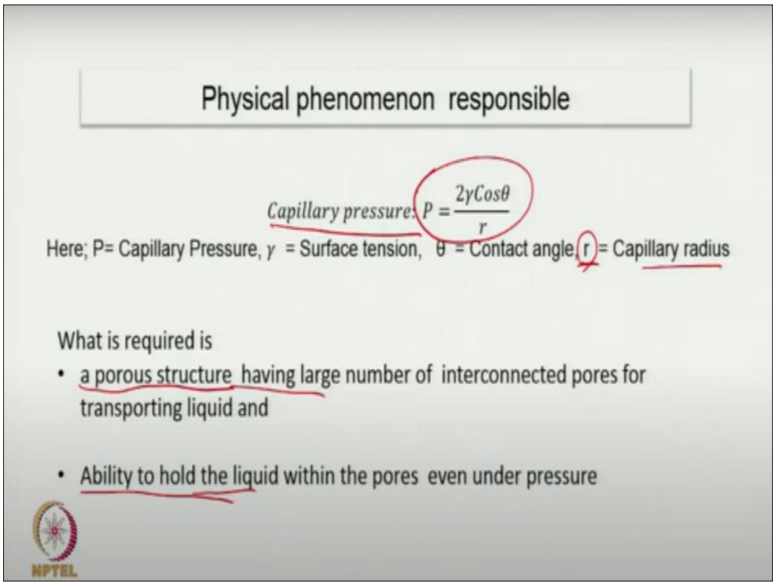

The physical phenomenon responsible for this is well-known, described by the equation for capillary pressure,

$$P = \frac{2\gamma \cos\theta}{r}$$

where 'γ' is the surface tension of the liquid, 'θ' is the contract angle, and 'r' is the capillary radius. Therefore, what is required is the creation of a porous structure that allows liquid to flow due to the capillary pressure generated. The magnitude of this capillary pressure is determined by the parameters,

$$\frac{\gamma \cos \theta}{r}$$

There is no control over 'γ' which is the surface tension of the liquid. For example, if the liquid is urine, its surface tension value is fixed and cannot be altered. The next factor to consider is the contact angle, which depends on the type of fibre chosen. Thus, the contact angle is influenced by the specific raw material selected.

Therefore, based on our needs, the appropriate raw material is selected. Another important factor is the value of 'r', the capillary radius, which depends on how the structure has been created. All types of structures can be created from fibres, including spun yarn, which is a type of fibre structure. Fabrics are basically knitted and woven fabrics that are fundamentally made from fibres. These are essentially different methods of arranging fibres, each given distinct names.

Nonwoven fabrics represent another type of fibrous structure. Whether it's yarn, woven fabric, knitted fabric, towel fabric, or nonwoven fabric, they all fundamentally consist of fibrous structures, and each will contain pores between the fibres. A structure that contains the maximum number of pores created by a given number of fibres has to be chosen. Another important consideration is pore size.

If the pores are too small, the liquid that is retained will be less. If the pores are bigger, they can hold more liquid. Therefore, it is essential to understand how to create a porous structure that can effectively hold a significant amount of liquid. Thus, two important factors of a porous structure are the ability to retain liquid within the pores and the capacity to hold that liquid even under pressure.

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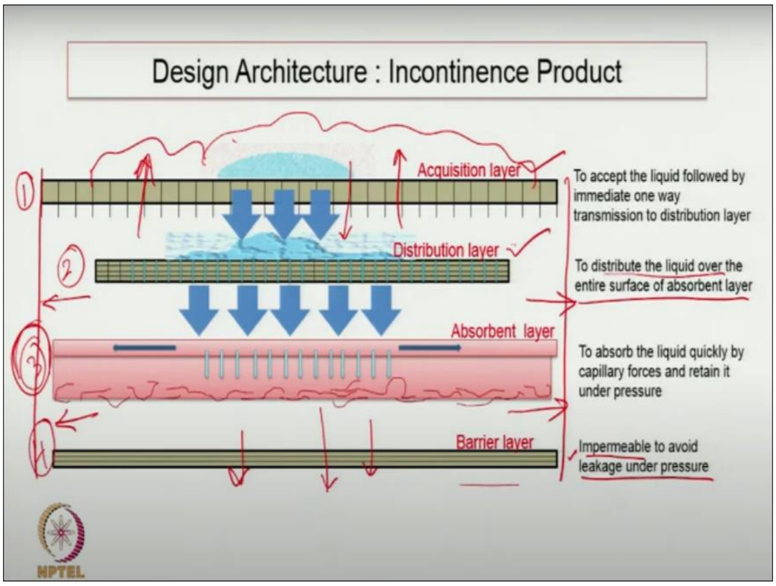

Next comes the design architecture of incontinence products. As illustrated in the schematic diagram, there are four layers of incontinence products labelled as layers 1, 2, 3 and 4. This means that incontinence products typically consist of a four-layer assembly. Each layer serves a specific function in the overall design.

The first layer is known as the acquisition layer. Its primary function is to receive the liquid, followed by immediate one-way transmission to the next layer, which is called the distribution layer. The purpose of the acquisition layer is that it must be designed to quickly accept the incoming liquid and transfer it to the distribution layer. The purpose of the distribution layer is to spread the liquid evenly across the surface of the third layer, known as the absorbent layer. This third layer is the most important because it is where the liquid is ultimately retained.

The absorbent layer plays the most significant role in the performance of the product. Beneath the absorbent layer lies the fourth layer, called the barrier layer. The barrier layer is an impermeable layer designed to prevent leakage of liquid under pressure. When the entire assembly is subjected to pressure, there is a risk that liquid could escape through this layer or move downward. To stop this downward movement, the barrier layer serves as an impermeable sheet, ensuring that there is no opportunity for the liquid to escape.

The barrier layer must be designed to be thin to minimize the overall weight of the product. It also should be impermeable. Additionally, it should possess sufficient strength to withstand pressure. This ensures that, during actual use, when liquid is retained within the absorbent layer and pressure is applied, the barrier layer does not burst or tear. The barrier layer must possess sufficient strength to meet specific requirements.

By considering these aspects of the function of the barrier layer, the material that must be chosen should be completely impermeable, thin, and strong enough to withstand the pressure that may occur during actual use. For example, a patient using the product might turn or sit on the bed, creating additional pressure on the barrier layer. The same scenario can occur with a child who may jump or fall, generating additional external pressure on the product. It is important that the entire structure does not burst under such external pressure, especially when liquid is contained within it, as this would create a messy situation.

Therefore, the design must ensure that it prevents liquid from escaping not only from the bottom but also from the sides. Liquid can also escape from the sides of the top layer. When pressure is applied, the liquid naturally seeks a way to flow out. It will flow out along that particular part. To prevent this, we must ensure that the sides are properly sealed. This means implementing seals on both sides of the structure to effectively contain the liquid and prevent any escape. As previously mentioned regarding the acquisition layer, the top two layers must be designed to allow the liquid to move downward while resisting upward movement. This functions similarly to a one-way valve: the valve opens to permit flow in one direction and closes to prevent backflow. Such a thing has to be created by using textile material.

A one-way valve has traditionally been designed by mechanical engineers. But in this case, the same concept has been adapted for our needs. The key point is to ensure that while we cannot completely stop the liquid from flowing outward from the top layer, we can minimize this flow. If we need to completely stop the liquid flow, then impermeable materials must be used, which further stops the downward movement of the liquid as well.

Ultimately, the liquid will first accumulate in the acquisition layer during an insult, and then it will flow downward, as indicated by the arrows in the diagram. This process is crucial to understand, and it is important to consider how to design to meet the requirements.

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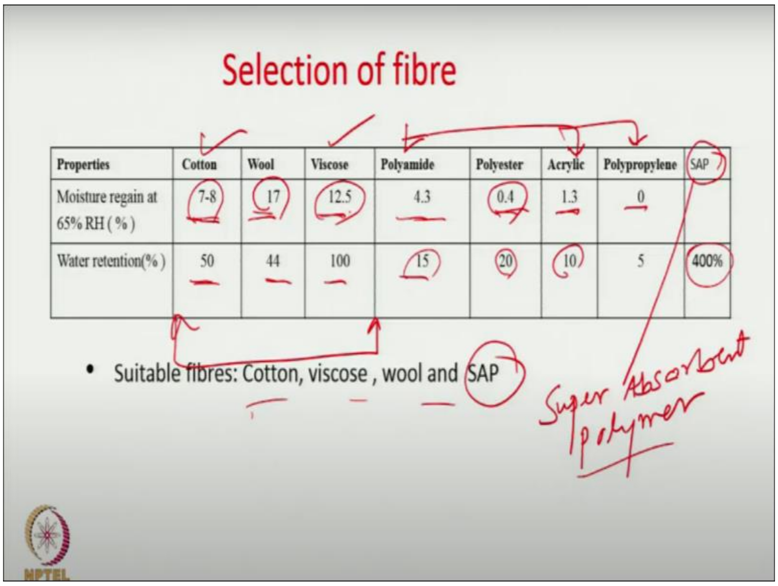

The development of the absorbent core begins with the selection of fibres. Since the core must be effective at absorbing liquid, it is essential to choose fibres which have good water absorption, moisture content, and moisture regain properties are good. The table provided contains relevant data, and textbooks must be referred to identify which fibres have good moisture regain properties.

In textiles, there are numerous fibres to consider. Here few fibres have taken cotton, wool, viscose, rayon, polyamide, polyester, acrylic, polypropylene, and SAP. SAP stands for super absorbent polymer. Fibre is also basically a polymer. Excluding SAP, the potential fibres are cotton, wool and viscose rayon. The remaining three fibres, polyamide, polyester, and polypropylene are less effective in terms of moisture absorption. When considering moisture absorption, it is essential to choose fibres like this.

However, it is important to remember that most of the liquid will be held within the pores of the structure. Even when using a porous structure made from polyester, the diffusion process allows only a small amount of liquid to enter the fibre compared to the larger volume retained in the pores. In that case, it does not matter if polyester or acrylic has been chosen, as they can still create pores that allow for significant liquid storage.

While considering this point of view is advantageous, there are additional factors to consider. Specifically, fibres such as cotton, wool, viscose, and rayon exhibit very low contact angles. This means that wetting occurs very quickly; liquids can easily penetrate and saturate these fibres, allowing for rapid wetting. Whereas fibres like polyester and acrylic do not exhibit this. Additionally, the retention part of the liquid also must be considered. When comparing the retention capabilities, the values for polyester, acrylic, and polypropylene fibres are relatively low. Whereas these fibres, water retention is much better even under pressure because retention is equally important in this case.

Hence, two key factors must be considered: first, whether they can absorb water themselves and absorb water quickly, and second, the overall structural capability of the material to retain water. This data was gathered through a literature survey. So, such literature survey research is important when one wants to design. Therefore, the potential fibres which can be used are cotton, wool, and viscose rayon.

Among these fibres, wool is very expensive. Furthermore, while fine wool is very costly, coarse wool may cause discomfort by pinching sensation in the skin. The main issue with wool is that it can easily absorb moisture in its vapour state. However, the surface of the wool is hydrophobic, causing liquid water to slide off easily. These factors, along with its high cost, make wool a less favourable choice.

The second reason is that cheaper wool is coarser, which can irritate or penetrate the skin, making it unsuitable for use. So, cotton or viscose rayon is a suitable option. Additionally, wood pulp, another cellulosic material, can also be considered. Ultimately, we lean towards cellulosic materials because cellulose can quickly absorb water. Water absorption in cellulosic materials occurs through diffusion, and any existing pores further enhance this process.

Along with these fibres, Super Absorbent Polymers (SAP) will also come, as they can absorb up to 400% of their weight in water and retain it. SAP is commonly used in products like incontinence pads, where the quantity of SAP is around 30-35% of the material. The remaining material will typically consist of cellulosic fibres. While SAP offers significant advantages in terms of absorption, it also comes with certain disadvantages.

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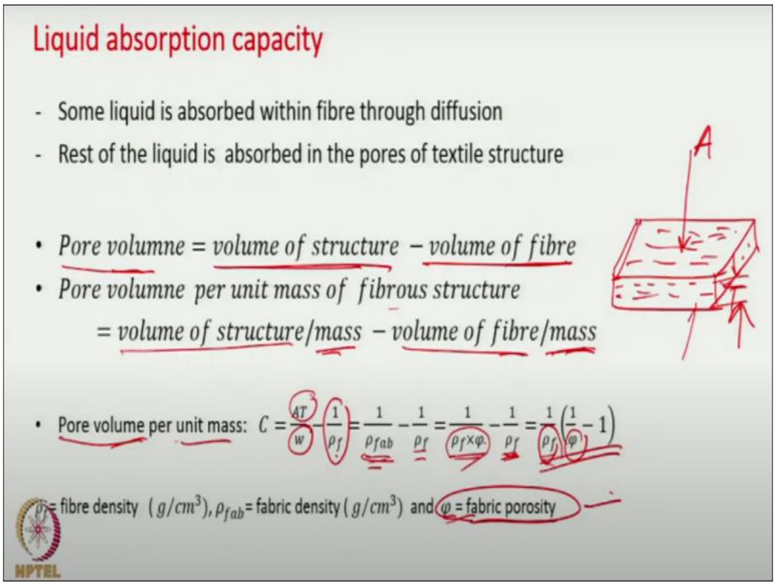

The next step is selecting an appropriate fibrous structure, whether it is yarn, woven fabric, knitted fabric, towel fabric, or nonwoven fabric. When choosing a structure, three key factors must be considered. They are the liquid absorption capacity of the structure, its ability to retain liquid, and its resistance to deformation. These factors are important in determining the most suitable fibrous structure.

Liquid absorption capacity involves two mechanisms: some liquid is absorbed within the fibres through diffusion, while the rest is absorbed within the pores of the textile structure. In yarns, pores exist between the fibres, and when yarns are converted into fabric, additional spaces between the yarns can also hold liquid. In non-woven materials, there are numerous pores between the fibres. The pore volume is defined as,

$$Pore\ volume = Volume\ of\ structure - Volume\ of\ fibre$$

Generally, it is a nonwoven structure for such kinds of applications. Because nonwovens provide an efficient process for transforming fibres into a medium that absorbs liquid quickly. Unlike woven or knitted fabrics, non-wovens bypass the lengthy processes of converting fibres into yarn and then fabric.

By using nonwoven technology, we can skip all the intermediate stages of converting fibres into yarn and fabric. Instead, we can directly assemble fibres using a nonwoven production line. There are various nonwoven techniques, and some are particularly well-suited for materials like cotton or rayon. From a theoretical point of view, pore volume refers to the difference between the total volume of the structure and the volume occupied by the fibres. The pore volume per unit mass of a fibrous structure is calculated as the volume of the structure divided by its weight. The express formula used is pore volume per unit mass is

$$C = \frac{AT}{w}$$

where 'A' represents the area, 'T' is the thickness, and 'w' is the weight of the structure.

For a rectangular, nonwoven structure, the total volume of the structure is '$A \times T$' and '$\frac{AT}{w}$' gives the total volume of the structure. In this case, considering a rectangular assembly of fibres consisting of many individual fibres, the product '$A \times T$' gives the volume of the structure. Calculating the volume per unit mass essentially gives the reciprocal of mass per volume, which is the inverse of density.

Therefore, the reverse of this calculation provides the density of the fibre. Hence, it is '$\frac{1}{\rho_f}$', therefore, it leads to the equation, '$\frac{AT}{w}$'. Bringing '$A \times T$' to the denominator, it becomes '$\frac{w}{AT}$', representing the density of the fabric. Therefore, the relationship between the density of the fabric (ρ_{fab}) and the density of the fibre (ρ_f) can be expressed as '$\rho_f = \rho_f \times \varphi$'. Therefore, the porosity of the structure is denoted as 'φ'.

Thus, this formula determines the pore volume per unit mass of the fibre. The amount of pore volume available per unit mass is important; the more pore volume created, the greater the space available for liquid retention. Therefore, two key parameters influence pore volume: the density of the fibres and the fabric porosity. Fibre density is determined by the specific fibre that has been selected.

Once the fibre is chosen, its density is fixed. However, we have control over the fabric porosity. Porosity is influenced by the manufacturing process. For example, when manufacturing a nonwoven structure, process parameters are adjusted to achieve the desired porosity level. Establishing the relationship between porosity and process parameters is important for producing materials that achieve a specific porosity value.

The other thing is that the overall structure must possess sufficient strength; it should not be a flimsy assembly of fibres. It should have minimum strength to ensure that the material can be handled. If the assembly of fibres are loose, then it will be challenging to transport the fibres from one location to another or to convert them into a finished product. Therefore, the material must have a certain level of strength, which can be achieved through various techniques. One of the techniques is needling, and other techniques are also available.

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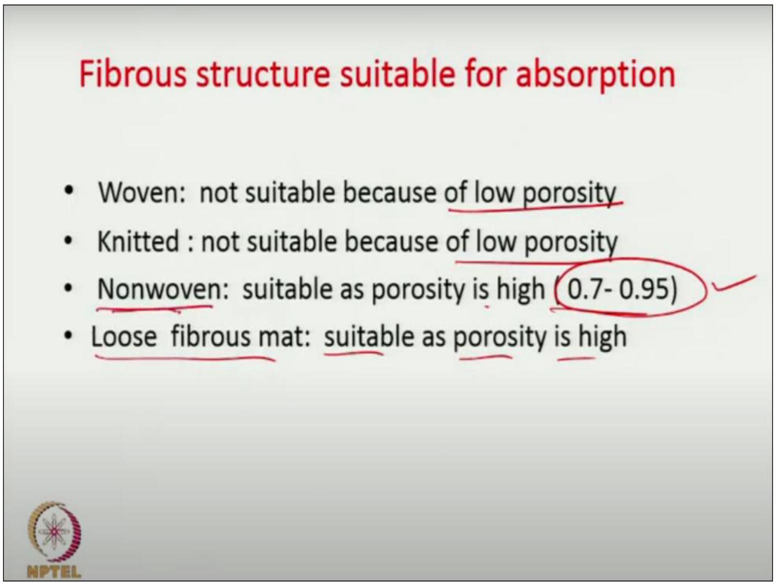

When considering fibrous structures suitable for absorption, woven fabrics are unsuitable due to their low porosity. Similarly, knitted fabrics also exhibit low porosity, making them unsuitable for this purpose. In contrast, nonwoven fabrics are highly suitable because they typically have a porosity ranging from 0.7 to 0.95. This range can be confirmed through literature, which indicates the porosity value of commercially available nonwoven materials.

A porosity of 0.95 indicates a very porous structure, while 0.7 represents a relatively tight structure. Loose fibrous mats, such as those made from wood pulp, can also be suitable due to their high porosity. The wood pulp used in commercial products consists of a powder-like assembly that is very loose in nature, providing minimal inherent strength. So, the manufacturing technique has been now designed in such a way that such kind of wood pulp can be used. Therefore, both non-woven fabrics and loose assemblies like wood pulp can be used.

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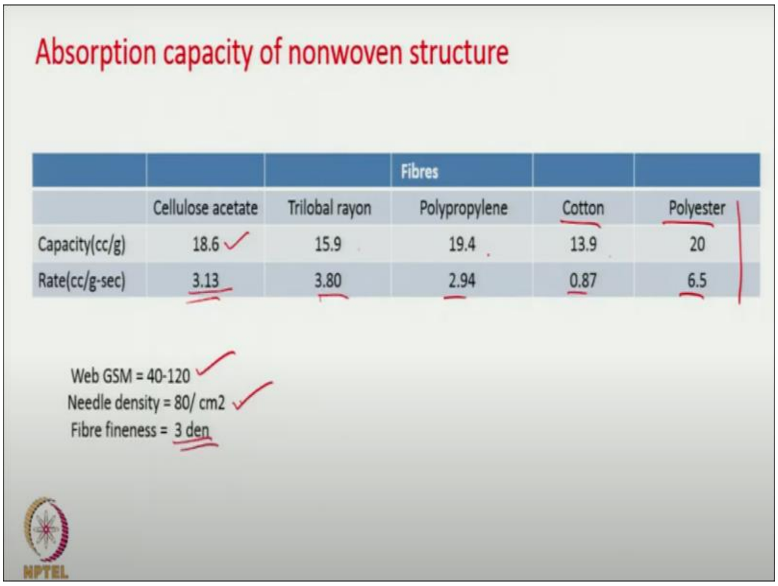

The data for understanding the absorption capacity of a nonwoven structure using cellulose acetate, trilobal rayon, and polypropylene are given. This information is derived from various research articles. The absorption capacity of cellulose acetate is 18.6 cc/g. Additionally, the flow rates in cc/g-sec for trilobal rayon, polypropylene, cotton, and polyester are also provided in the data. As indicated in the literature, the typical values presented here are based on research that used a web areal density (grams per square meter) ranging from 40 to 120, a needle density of 80/cm^2, and a fibre fineness of 3 deniers.

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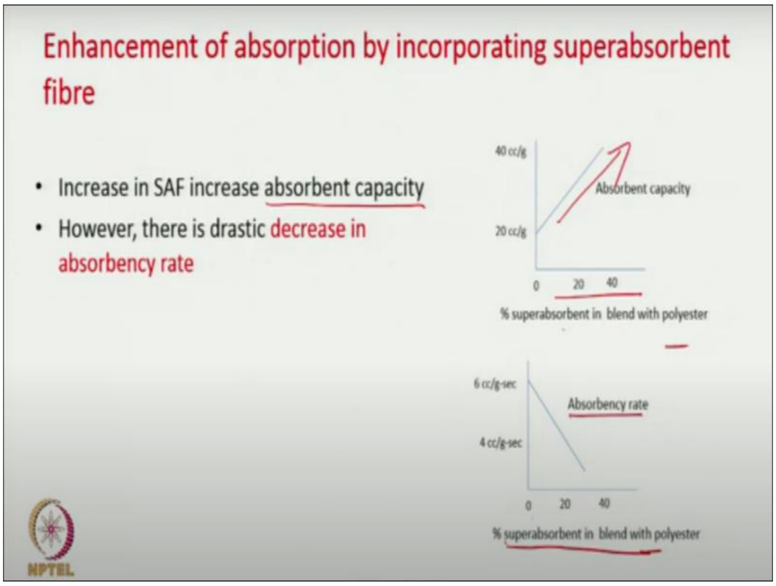

The absorption capacity can be enhanced by incorporating super-absorbent fibres. As discussed earlier, super-absorbent polymers can absorb and retain significant amounts of water.

Consequently, there have been attempts to utilize super-absorbent fibres in commercial products. The two diagrams shown here illustrate the relationship between the percentage of superabsorbent fibres against their absorption capacity, and the percentage of superabsorbent fibres is plotted against the absorption rate.

As the content of super-absorbent fibres in the mixture increases, the absorption capacity rises while the absorption rate decreases. This indicates that while adding more super-absorbent material enhances the overall absorbent capacity, it also slows down the rate at which water penetrates the structure. This slowdown can lead to vapour and liquid accumulation, and it will remain in contact with the skin, which poses a risk. Therefore, it is important to be cautious when using super-absorbent fibres, particularly regarding the quantity of the fibre used.

While increasing the amount of super absorbent fibre can enhance absorption capacity, it simultaneously reduces the absorption rate. Once a super absorbent polymer absorbs water, it undergoes a transformation by itself into a viscous liquid. The polymer completely disintegrates to form a viscous liquid, which blocks numerous pores within the fibrous structure. Therefore, if an excessive amount of super-absorbent fibre is used, the overall absorption capacity may decrease. The blocked pores hinder other fibres from absorbing moisture.

This is a key issue with super absorbent polymers as they transform into a viscous liquid under pressure; their high viscosity prevents easy movement. As the water mixes with this viscous substance, it becomes difficult for the liquid to flow through the material. The super absorbent viscous liquid will not flow like the way the water flows. Therefore, the advantage of super absorbent polymers is the ability to hold the liquid without leakage. However, the percentage of super absorbent fibre must be used judiciously.

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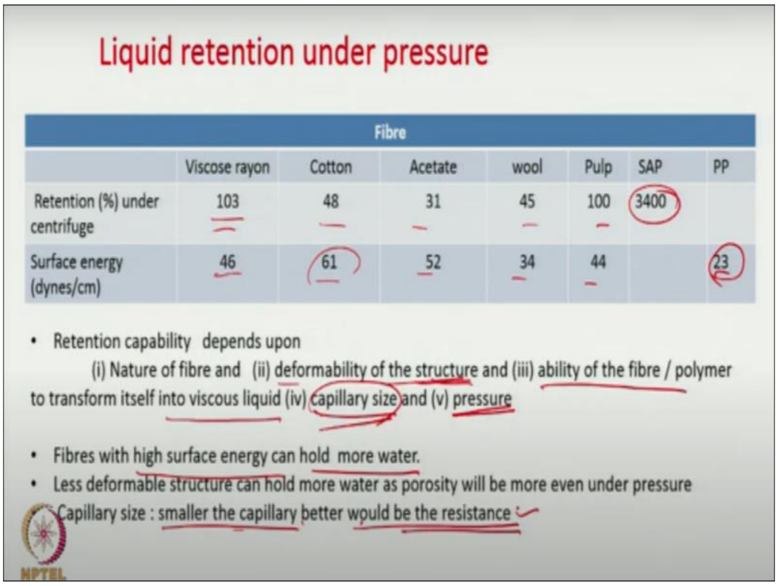

Liquid retention under pressure is an important factor to consider. Some data related to retention under centrifuges are provided in the table, and the values are also stated along with surface energy. Retention capability depends on the nature of the fibres used and the deformability of the structure. For example, if the structure is nonwoven, it depends on how much the structure is deformable under pressure.

Compression by applying a slight amount of pressure or resistance to deformation depends upon the bending rigidity of the fibres. This, in turn, influenced the coarseness of the fibre used. If a coarser fibre is used, the structure becomes more rigid, then deformation is not easy. Therefore, deformation under pressure is less.

Therefore, a significant amount of space will still be available for liquid to be retained. When pressure is applied, the liquid will try to escape from the compressed pores. However, if the pore gets compressed less, then the entire structure is not deformed much due to the rigidity of the structure. Hence, the liquid retention will be higher in this case. Therefore, the structure rigidity plays an important role in liquid retention. The ability of the fibre, or polymer, to transform into a viscous liquid is important.

In the case of superabsorbent polymers (SAP), this transformation occurs, whereas other fibres do not undergo such a change. Instead, they undergo changes in their diameter. For example, viscose rayon, cotton, and pulp have been seen to absorb water, causing individual fibres to increase in diameter due to the diffusion of water within the structure. However, this does not occur with fibres like acetate or polypropylene.

Another important factor to consider is capillary size. This can be controlled by choosing the fibre parameters and structural parameters, whether it is woven or nonwoven. The important fibre parameters are the diameter of the fibre, the cross-sectional shape of the fibre, and the crimp present in the fibre. All these factors will influence the pores and, consequently, the capillary size. The diameter of the fibre, cross-sectional shape, and the presence of crimp all influence the determination of capillary size.

Additionally, the stability of the produced structure is important. In the case of nonwoven materials, the extent of punching, which creates entanglement between the fibres to consolidate the structure, influences the stability and capillary behaviour. All these factors essentially determine the capillary size, which is a function of these parameters.

Next comes the external pressure, which is applied. If the pressure is lower, more liquid will be retained, while higher pressure results in less liquid retention. This is how liquid retention varies. Additionally, fibres with high surface energy can hold more water, as they do not allow the water to move out of the capillaries easily. This will create resistance to the movement of the liquid flow. This gives cotton an advantage.

For instance, while polypropylene nonwoven can absorb some liquid, applying even a small amount of pressure will cause most of the liquid to escape, like the behaviour of a sponge. A sponge can absorb liquid, but by applying a slight pressure, most of the liquid is squeezed out from the sponge. Smaller capillaries provide better resistance to liquid flow, which can be beneficial.

However, smaller capillaries require finer diameter fibres. The problem with the finer fibre is that it is highly flexible, which makes the overall structure flexible. Hence, the deformation of the structure will be very easy if it is made of finer fibres. Additionally, finer fibres are expensive and cost-wise, they are less suitable. If fine fibres are used to improve the retention power of capillaries, it results in finer capillaries. However, the structural deformability gets increases.

Therefore, under the given pressure, the structure deforms easily, reducing pore size in the deformed state. As a result, most of the liquid flows out when using finer fibres. These problems exist, and there is a need to strike a balance. While flexible structures are necessary, we must also ensure they can effectively absorb and retain liquid. The demands on the properties of these structures can sometimes be conflicting, such as flexibility versus liquid retention.

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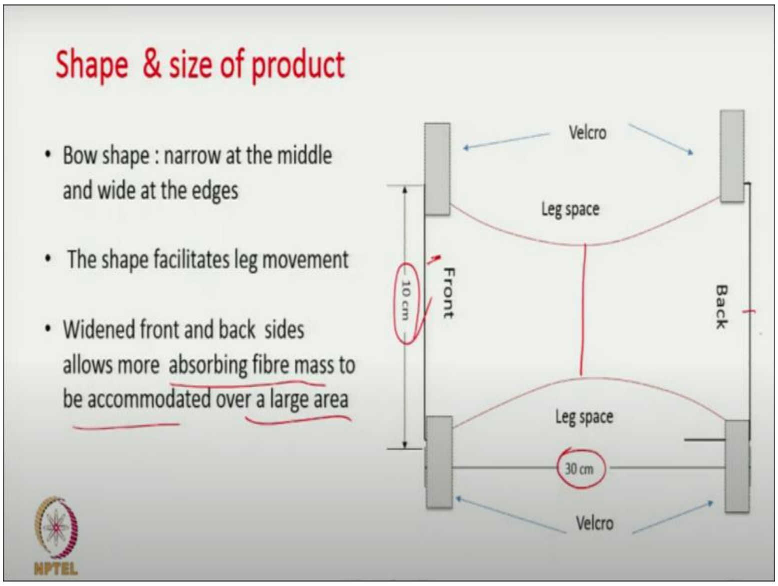

Next comes the shape and size of the products. Typically, incontinence products have a bow shape, narrow in the middle and wider at the edges, as illustrated in the diagram. This design facilitates leg movement, allowing for easy mobility. The wider front and back sides enable the accommodation of more absorbent fibres over a larger surface area, enhancing liquid absorption.

Ultimately, as depicted in the diagram, a wider space available for the absorbing medium allows for a larger surface area. With a wider front and back, more fibres can be accommodated, which increases the overall absorbent capacity of the structure. Hence, the more fibres present, the greater the capacity for liquid retention. Thus, this shape is chosen to enhance absorption efficiency.

The typical dimensions of the structure, as shown here, indicate that the length is 30 cm and the width is 10 cm. These measurements represent a standard size for a baby diaper, specifically designed for children rather than adults.

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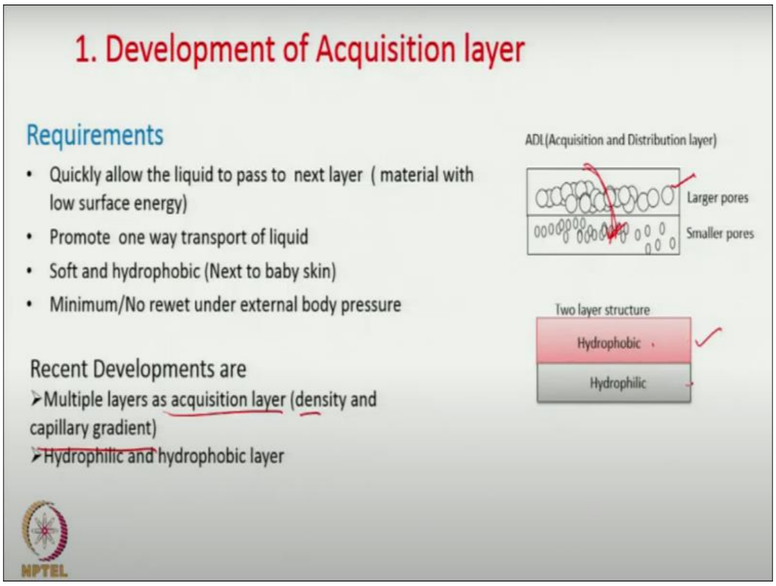

Next comes the structure development of the components. Several requirements must be met to develop different components of the structure, particularly the accumulation layer. The layer must quickly allow liquid to pass to the next layer and promote one-way liquid transport. The layer must be soft and hydrophobic because it is in direct contact with the skin of a child.

The layer should exhibit minimal or no rewetting under external pressure. Recent advancements have focused on incorporating multiple layers, including acquisition layers with varying densities and capillary gradients.

This approach has been done by designing the acquisition layer with a combination of large and small pores, creating a capillary gradient. This facilitates the easy entry of liquid from the top sheet. Additionally, people have developed such kinds of fabrics where one side is hydrophobic while the other is hydrophilic. Alternatively, a thin layer can consist of a hydrophobic layer paired with a hydrophilic layer can also be done.

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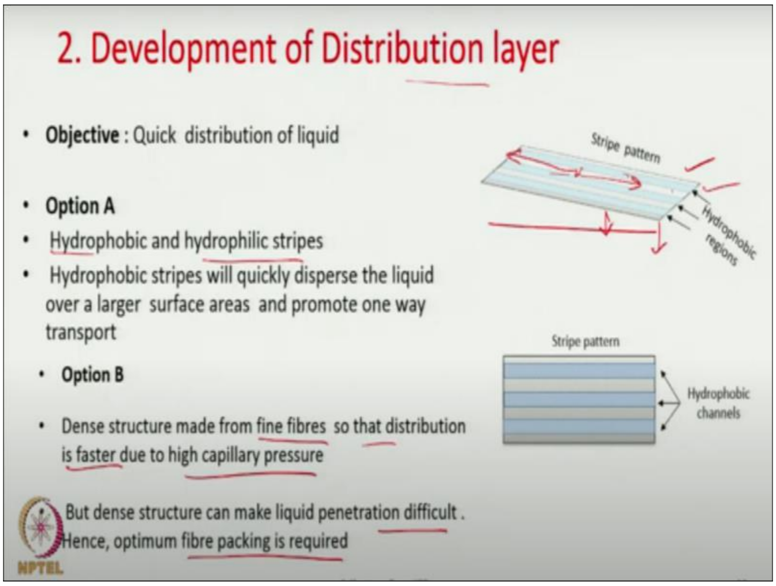

The next option is the development of the distribution layer. It can be done in two ways. The first layer is to accept the liquid as it comes out with a certain force. This layer should facilitate the immediate transfer of liquid to the next layer. It is essential that the liquid is evenly distributed so that the entire absorbing area can participate in absorption simultaneously. Thus, the second layer is designed specifically as a distribution layer.

For the distribution layer, hydrophobic and hydrophilic stripes can be incorporated, as represented in the diagram. Hydrophobic stripes will quickly disperse the liquid as it comes into contact with them. Once the liquid flows over these stripes, it will quickly move to the hydrophilic areas, allowing for efficient spreading in both directions. It enables the fast movement of liquid, and below that, an absorbing medium exists.

The stripe pattern is commonly used in the distribution layer to facilitate effective liquid dispersion. Typically, this approach works well for distribution, but in some cases, instead of using two separate layers (acquisition and distribution), a single (acquisition) layer can be designed to serve both functions. That type of design is also feasible.

The key idea is that the layer should quickly accept the incoming liquid and rapidly transfer it to the absorbing medium, ensuring it is distributed evenly over the entire area of the absorbing medium. With the consideration of these objectives, a design has to be created. Option B is a dense structure made from fine fibre, so distribution is faster due to high capillary pressure.

This approach is viable, but a dense structure can make the liquid penetration difficult, making it essential to optimize fibre packing. Typically, stripe patterns are used, and different patterns are also used, which have alternating hydrophilic and hydrophobic regions. The liquid will immediately flow from the hydrophobic regions toward the hydrophilic regions.

In this design, all the white regions represent hydrophilic areas that function as channels. These channels facilitate the immediate transmission of liquid, allowing it to spread over a larger surface area. Directly beneath this layer is the absorbing core.

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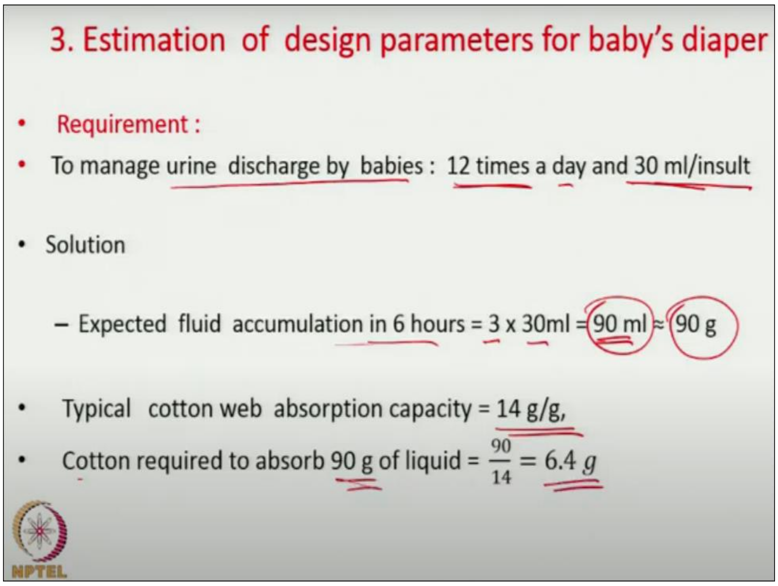

To determine the material required for the absorbing core based on an example. We need to manage the urine discharged by babies, which typically occurs 12 times a day, with an average of 30 ml/insult. The solution is, in a 6-hour period, the total fluid accumulation will be $3 \times 30\ ml = 90\ ml$. Assuming the density of this liquid is 1 g/ml, we need to absorb a total of 90 g of liquid. 90 ml of liquid basically means 90 g.

To absorb 90 ml of liquid, the typical absorption capacity of cotton, which is approximately 14 grams of liquid per gram of cotton, is used. Hence, the cotton required to absorb 90 g of liquid is '$\frac{90}{14}$', which is equal to 6.4 g.

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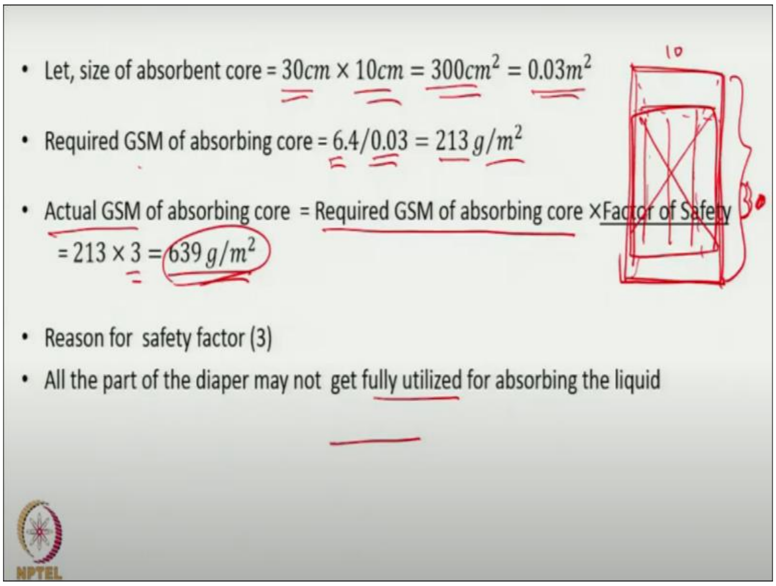

Let the size of the absorbent core is '$30\ cm \times 10\ cm$'. Typically, this is the length and breadth of the diaper. This results in a total area of $0.3\ m^2$. To simplify the calculations, the area is assumed to be a rectangular shape. Let us consider a simple rectangular piece of nonwoven fabric designed to absorb liquid, making it an effective absorbing medium. The required areal density (g/m^2) for this fabric is calculated as '$\frac{6.4}{0.3}$', which is equal to 213 g/m^2. This value represents the areal density of the nonwoven material we intend to use.

Therefore, the actual areal density requirement will be the required areal density multiplied by a factor of safety. There is a need for the factor of safety when developing a product as the actual liquid discharge may vary from person to person. It is also required that that the absorbing medium should not be saturated with the liquid. To account for these uncertainties, a factor of safety is used to take care of these aspects.

This will help address these variations, especially for the total area, which measures '$30\ cm \times 10\ cm$'. Not all the fabric may be involved in absorption. For instance, only a specific portion from this point to that point absorbs the liquid. The remaining material might stay dry, but it is still present. Hence, for designing a practical product, it is essential to consider all these factors. As a result, we apply a factor of safety of 3, which leads to an actual areal density of approximately 640 g/m^2 for the absorbing core.

The reasons for incorporating safety factors have already been stated. Not all areas of the diaper may be fully utilized for liquid absorption, and the frequency of liquid discharge can vary from person to person. To effectively meet the needs of a broad customer segment, the design must accommodate these variations. Hence, the areal density of the absorbent core is estimated to be around 600 g/m^2, which serves as a typical case scenario.

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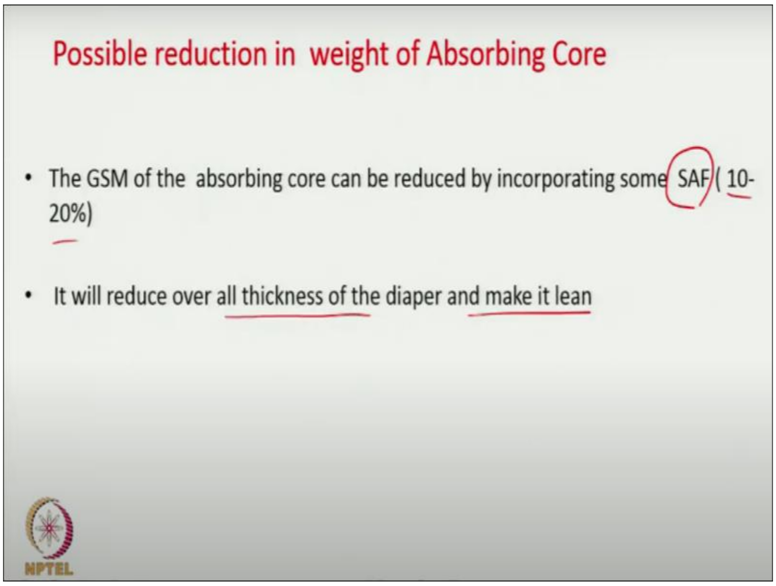

The other thing is the possible reduction in the weight of the absorbing core. Having higher areal density results in increased weight and thickness, it becomes necessary to explore ways to reduce the weight of the core. One effective method for reducing the areal density is by incorporating super-absorbent fibres or super-absorbent polymers (SAP). We can utilize these materials in quantities ranging from 10% to 20%.

Research has shown that excessive use of super-absorbent materials can decrease the absorbency rate, as they tend to transform into a viscous liquid that can block many pores. Therefore, it is important to limit their use to a range of 10% to a maximum of 30%, as is recommended. This approach not only reduces the overall thickness of the diaper but also keeps it lean. The amount of liquid that can be absorbed can be estimated, with the remaining absorption being passed onto other materials, which could be cotton or wood pulp.

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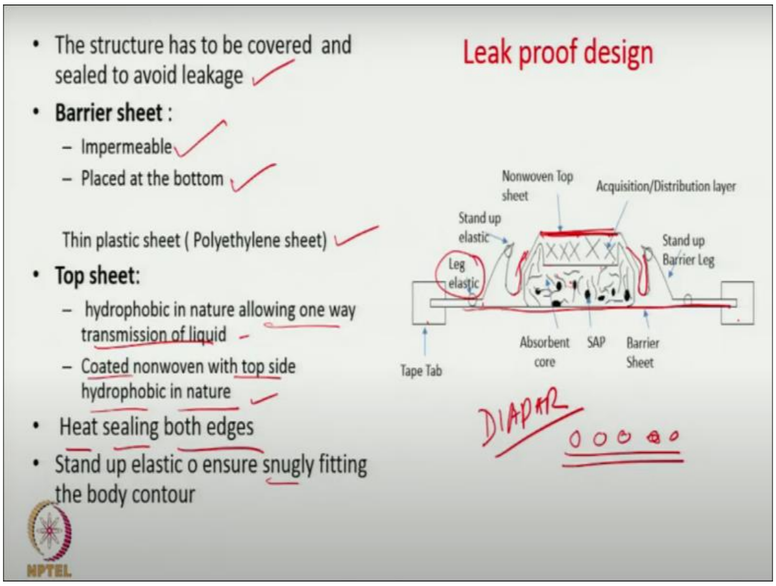

In the leakproof design, here is a typical sketch depicting a simple cross-sectional view of the structure. It is essential that the structure be covered and sealed to prevent leakage. In this illustration, the absorbent core is indicated, along with the barrier sheet. This barrier sheet is impermeable. This barrier sheet ensures that liquid will not be able to pass through it as it is completely impermeable. Inside, the structure contains the absorbent core, acquisition layer, and distribution layer.

On the top side, there is a nonwoven sheet, as shown in the diagram. The impermeable barrier sheet is positioned at the bottom and is typically made from a thin plastic material such as polyethylene. The top sheet is hydrophobic, allowing one-way transmission of the liquid. This must be considered for the top sheet, as the liquid needs to flow only in one direction. When considering two porous layers, one hydrophobic and the other hydrophilic.

It is important to understand how this arrangement will affect liquid movement. When liquid is dropped onto the hydrophobic layer, it will easily pass through and be absorbed by the hydrophilic layer beneath it. This results in a one-way movement from the hydrophobic layer to the hydrophilic layer. To achieve this one-way movement, the hydrophobic layer must be completely hydrophobic while still having pores, allowing the liquid to enter through these openings.

However, just below the hydrophobic layer lies the absorbent core, which will immediately absorb the liquid. This differential in surface energy between the materials in the core and the top sheet facilitates a continuous one-way transport of liquid from the top to the bottom. Additionally, a coated nonwoven material with a hydrophobic top side can also be utilized for this purpose.

There are various design options available for this sheet. This sheet can also have some macro holes to allow for the fast entry of the liquid. However, this also introduces the possibility of reverse flow, which needs to be prevented. This is achieved by incorporating a distribution layer. Hence, different types of designs are possible, and many ideas can emerge in this area.

The key point is that while allowing the liquid to flow from the top to the bottom, any movement from the bottom to the top must be prevented, as well as any leakage from the sides. To achieve this, the sides are fully covered, eliminating the risk of leakage. Additionally, all edges must be sealed, typically using heat sealing methods. This means that the materials used for the top and bottom sheets should be capable of melting at a specific temperature to allow for effective heat sealing.

Therefore, it is essential to select appropriate polymers for both the top sheet and the barrier sheet. Additionally, other fastening devices, such as elastic leg tapes, should be incorporated to ensure a snug fit that conforms to the body contours. The elastic bands allow for adjustment, creating a snug fit for the structure, which is essentially the design of a diaper. This is a nutshell of the design aspect of the incontinence product, and this is the standard practice.

One can think of enhancing the design further to satisfy the needs of people of various ages and sizes. Obviously, one size does not fit all. Hence, depending on the age of a person, different sizes, such as small, medium, large and extra-large, can be designed. This lecture concludes the discussion on this topic. Thank you.