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RESEARCH PAPER

Structure-Properties of Disposable Diapers and Scope of Natural Fibre

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ABSTRACT

Disposable baby and adult diapers represent an important product in the journey of modern society, providing an ease of convenience, performance and affordability. A child of one year age, on an average 3–7 diapers are required to be changed in a day. Such products are discarded after its one-time use in comparison to reusable cloth-diapers. Diapers are broadly designed and manufactured for two age groups, viz., (i) baby diapers for age of 2 to 11 years and (ii) adult diapers for age of 25 to 60 years. Diapers are made of three main layers, where the top-sheet is designed to isolate the baby's soft skin from the wet inner core. Absorbent layer is made of wood/ cellulose pulp sheet, embedded with super-absorbent-polymer (SAP) or as a separate layer to absorb and hold the liquid. The back sheet is made of water impermeable synthetic polymer layer/ film to avoid any leakage of absorbed liquid. Length and width of a baby diaper varies in the range of 35 - 52 cm and 26 - 31 cm for the size of new born baby to X large size. Maximum volume of liquid absorption by the different diapers are as follows 60, 105, 150, 180 and 210 ml for the categories of new born baby, small, medium, large and X large, respectively. It is also overtly that more attention is required to the product after its usage to mitigate with post usage unguarded dumping, burying and burning of soiled disposable diapers. Use of antibacterial fibres, metallic wires embedded in smart diapers, application of natural fibre/ pulp and development of biodegradable super-absorbent-polymer have also been summarized to address some of the current challenges in this area. Natural fibres like cotton, bamboo and jute could find its application in the disposable diaper making, in addition to synthetic polymeric and fibrous materials.

HIGHLIGHTS

- Development and properties of baby and adult disposable diapers.
- Structure, properties and specification different diapers.
- Recent developments, smart diaper, antimicrobial finish and scope of natural fibre.
- Waste disposal and development of biodegradable diapers.

Keywords: Diaper, Baby and adult diapers, Smart diaper, Structure, Natural fibre

Nowadays, disposable-baby-diaper (DBD) represents an important product in the parenting journey of the modern society, providing an ease of convenience, performance and affordability. Considering a child of age one, on an average 3–7 diapers are required to be changed in a day. In common hygiene practice, disposable-baby-diaper

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(DBD) is discarded after its single use, whereas the cloth-based diapers are mostly reusable, otherwise needs to be soaked, washed and dried. This allows the DBD as a preferred choice and is becoming indispensable, especially in the present society. Disposable diapers have become an important desirable product, offering convenience and hygiene practices for parents and infants' caregivers. Diaper is also important for the adults with incontinence. It provides a high level of liquid absorbency with comfort and ease of use, resulting a desirable choice over the cloth diapers in many households. Development of disposable diapers has been driven with the need of efficient waste management, as it could help in preventing leakage and maintain dryness for extended time periods. The DBD available in the market are made of three main layers in addition to SAP, where the top-sheet comes in contact to the skin, and is designed to isolate the baby's soft skin from the wet inner core. An additional acquisition layer is also some time placed above the absorbent core to quickly pull of the liquid and prevent water pooled on the top layer. The most vital i.e., absorbent layer is consisted of wood/ cellulose pulp in sheet-form, embedded with super-absorbent-polymer (SAP) or as a separate layer to absorb as well as hold the liquid/ urine many times of its own weight. The back sheet is made of water impermeable layer/ film, usually made of polyethylene or polypropylene synthetic polymer to avoid any liquid leakage and absorption in this layer. Diapers are broadly design and manufactured for two age groups, namely (i) Baby diapers for age of 2 to 11 years and (ii) Adult diapers for age of 25 to 60 years. Market size of disposable diaper was US$ 1.6 Billion in the year 2023 and it is expected to touch US$ 3.0 Billion by year 2032, with a CAGR of 7%. On the basis of weight of infant and/ or toddler, the baby diapers are categorised as: New born: 2-5 kg; Small: 3-8 kg; Medium: 6-11 kg: Large 9-11 kg; X Large: 13+ kg. Indeed, weight of a diaper also varies with the age of the baby and as per the agreement between the buyer and the seller (IS 17509: 2021). It is no surprise that the consumption of disposable diapers (DDs) grows exponentially since, in the first years of a baby. Every child uses about 3-7 diapers in a day (Czarnecka *et al.* 2022; Khoo *et al.* 2019), and the number of newborns in the EU alone exceeds 5 million per year (Czarnecka *et al.* 2022). The major drawback of DD is pertaining to their single-use application. After their actual usage for few hours, they are discarded and mixed up with the household waste or with waste stream (Karimi, Yu, and Brouwers, 2020). Used diapers are also progressively increasing the municipal waste stream and now have been estimated to be one of the major solid-waste generations, contributing 12% to garbage dumped in landfills (Cordella *et al.* 2015; Czarnecka *et al.* 2022). The world is witnessing a serious challenge due to gradual increase in number of plastic wastes generated from the different fields of applications, where notable part of contribution is coming from the disposable sanitary napkin and diapers. In the modern society parents tend to choose DDs over the cloth ones, due to its lower price and provides requisite performance. In addition, the DDs are also cost effective than that of cloth diapers, offering a better suited to modern parenting life-style. In the recent development of biodegradable diaper, where it is prepared using a superabsorbent polymer (SAP), chlorine-free wood pulp/ tissue, latex-free, and partially biodegradable polymer. Such products fetch higher price in the nice market compared to commonly used disposable-baby-diapers (DBD) and cloth diaper.

Structure of baby and adult diapers

Diaper is generally consisted of multiple layers (tentatively 3-7) and number of layers may vary from brand to brand, and agreement between the buyer and seller. Each layer is designed to extend a specific purpose, such as absorption, comfort and barrier, as described below in details.

Top layer: Top layer directly touches the baby's skin, and is typically made of soft non-woven of lower areal density. Thus, it becomes soft and flexible, and provides maximum comfort to a baby or adult. It should be hypoallergenic. Main function of this layer is to soak away the liquid/ moisture from the skin to inside the product, offering a dry feel to its user. It is also required to be porous so that liquid could easily penetrate from the skin surface to the underneath distribution/ acquisition/ absorbent layers. Fig. 1 shows the schematic diagram of a baby/ adult diaper, typically consist of five layers, where the thickness of the absorbent core layer generally remains higher compared to any other layer.

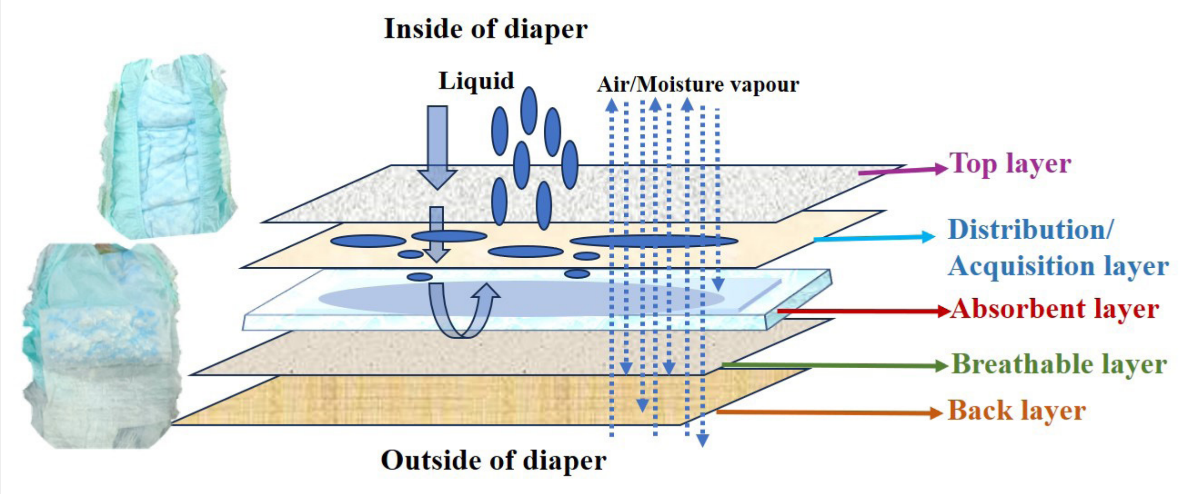

Fig. 1: Schematic diagram and structure of a diaper

Distribution/ Acquisition layer: This layer aids the liquid to evenly spread across the absorbent pulp and/or pulp-SAP layer to assure maximize absorption. Some diaper has an additional acquisition layer, placed above the absorbent core to quickly pull the liquid and prevent liquid return-back to the top layer. It also facilitates the faster absorption of liquid. The main objective of this layer is to evenly distribute the fluid in the absorbent core, while preventing it from accumulating in one zone. Non-woven or perforated plastic films, tissue paper or other specially designed materials are suitable in this layer (Samanta *et al.* 2023).

Absorbent core: It is the most important component of a diaper, generally made of super-absorbent-polymers (SAPs) and cellulose wood pulp/ fibre pulp/ fibrous sheet, which collectively absorb and hold the liquid, placed in between the acquisition layer and the backing impermeable sheet of a diaper. Wood pulp is the most common material used as an absorbent core, derives from the plant biomass after different chemical interventions (Samanta *et al.* 2023). Air laid structure, mostly formed from the cellulosic fluffy fibrous pulp, is commonly used as an absorbent material. The fluffy pulp is hammer milled into individualized fibres and subsequently air conveyed to a moving belt-like structure to form a sheet. Majority of super absorbent polymers (SAP) consist of sodium polyacrylate and available in granular or other forms. In SAP, millions of polymers are chained together in the form of a chained fence structure, which are linked together to form a three-dimensional network of polymers. In dry state, the polymers remain in coiled shape, but in the presence of liquid (water), the polymer chain molecules uncoil, thus the polymeric network expanded, exhibiting a large quantum of liquid absorption capacity. The SAPs can absorb liquid several times of its own weight. Absorption capacity of SAP is generally higher as compared to the absorption capacity of pulp material, helping the diaper to be thin, highly absorbent and dry-feel. Absorbent core is required to have good absorption as well as liquid holding capacity, ensuring adequate comfort to its user. It is also expected aiding the speed up the liquid absorption. Main important features of SAP are high liquid absorbency, leakage protection, thin product structure and desirable-lasting performance. Additionally, it should be free from any lumps, oil spots, dirt or foreign material.

Back sheet: It is a water impermeable layer, mainly placed bottom side of a diaper, usually made of polymers like polyethylene or polypropylene to prevent any liquid leakage. Some back sheets also have a soft and cloth-like feel to enhance additional comfort.

Properties, standard and liquid absorption of diaper

In order to certify the diaper products from the Bureau of Indian Standards (BIS), it is necessary that the disposable diapers designed and developed specially for the newborns and toddlers should comply with the below specification, as covered under the IS 17509: 2021-Disposable Baby Diaper Specification. Disposable baby diapers and tailored specifically for the newborns and toddlers, consist of various materials, featuring an absorbent core capable of efficient retaining requisite liquid volume, often crafted from superabsorbent polymers as one of the components. Absorbent core present in the middle layer(s) of the product is consists of cellulose pulp, tissue, wood pulp, other absorbent and super absorbent materials or combination of these materials. As per the standard, such diapers play a crucial role in maintaining baby cleanliness, fostering practicality, and enhancing the overall well-being of infants and their caregivers. It is considered as important items as far as baby's comfort and cleanliness are concerned. Diapers are available in a diverse range of sizes to accommodate the growing stages of the baby, as mentioned in Table 1.

Table 1: Diaper details as per the Indian Standard (IS) 17509: 2021–Disposable baby diaper specification (www.bis.gov.in)

Product name	**Disposable baby diaper**
Applicable Indian Standard	IS 17509: 2021
Applicable certification scheme	Product certification scheme, (ISI Mark Scheme) Scheme 1 - Schedule 2
Compliance requirement	Mandatory
Scope as per standard	Standard covers the requirements of disposable (non-reusable) baby diaper for external use.

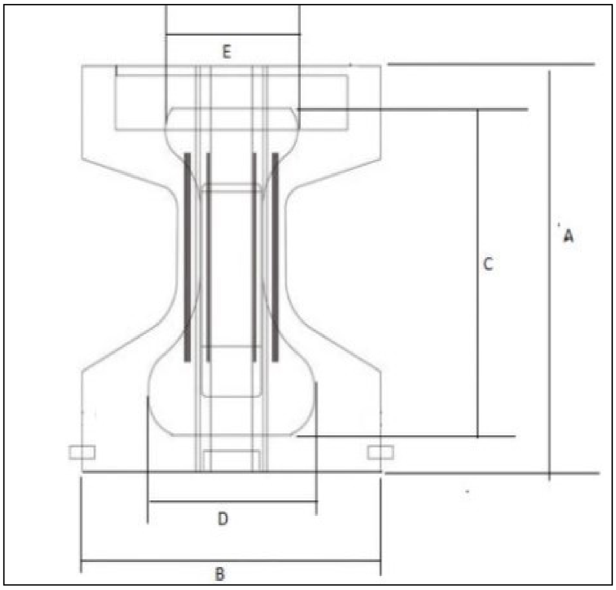

Fig. 2: Schematic diagram of baby diaper (IS 17509: 2021)

Fig. 2 shows the schematic diagram of a baby diaper with growing age of the baby and the exact dimension of the different components/ portions of a diaper. From the Table 2 it can be seen that length of a baby diaper varies from 35 cm to 52 cm for the size of new born baby to X large size. Width of the diaper may vary from 26 cm to 31 cm for the new born baby to X large baby size. The important layer i.e., length of the absorbent core increase from 28.5, 30, 34, 37, and 37 cm with the growing age of child, categorized as new born baby, small, medium, large and X large. On the other hand, absorbent core width in the front as well as back sides remained same for all categories of baby diapers, that is 11 cm. It is also important to note that the maximum volume of liquid absorption by the different diapers increases from 60, 105, 150, 180 and 210 ml with the increase of age of baby, under the categories of new born baby, small, medium, large and X large, respectively. The core crotch value is 85±05 for all categories of diaper. The other requirement of a diaper, as covered in the above standard is mention below:

- ***Performance:*** Diaper's pH value, absorption rate, rewet under load and minimum absorption capacity.
- ***Types and sizes:*** It is classified based on the infant or toddler weight, and the fastening and securing mechanism need to be satisfied.
- ***Hygiene:*** Against bacterial and fungal bioburden, e.g., with *staphylococcus aureus*, a common skin pathogen. Total viable count i.e., number of bacteria and fungi shall not be present more than 1000 cfu/g, whereas *Staphylococcus aureus* should be absent.
- ***Biocompatibility:*** Evaluations of cytotoxicity, skin irritation and skin sensitization are necessary. It is also required to ensure that raw materials used in manufacturing of final product are safe to the user, based on known toxicological characteristics. Biocompatibility of the material is required to be determined by measuring cytotoxicity, irritation and skin sensitization, as per the IS/ISO 10993 (Part 5) and IS/ISO 10993 (Part 10) test, respectively.
- ***Manufacturing:*** Diaper should be manufactured in a hygienic environment.

Table 2: Diaper dimension for the different ages of baby, as per IS 17509: 2021

Size	Diaper length (A) in mm	Diaper width (B) in mm	Diaper crotch (mm)	Absorbent core length (C) in mm	Absorbent core width Front (E) and Back (D) in mm	Core crotch	Maximum absorption capacity (no. of Gushes)	Maximum absorption capacity (requirement)
New born	350±10	260±05	195±10	285±10	110±10	85±05	3	3 × 20 ml
Small	390±10	260±05	195±10	300±10	110±10	85±05	3	3 × 35 ml
Medium	440±10	310±05	195±10	340±10	110±10	85±05	3	3 × 50 ml
Large	480±10	310±05	215±10	370±10	110±10	85±05	3	3 × 60 ml
X Large	520±20	310±05	215±10	370±10	110±10	85±05	3	3 × 70 ml

** Rate of absorption/gush(s), Max. 60 for all sizes; ** Rewet under load (g), Max. 5 for all sizes..*

Table 3: Different parameters of baby and adult diapers

Parameters	Baby diaper	Adult diaper
Product length (cm)	11.5 - 14.5	27
Product width (cm)	16.3 - 17	18.7
Weight of each diaper (g)	22.5 - 30.2	68.2
Maximum thickness (mm)	4.1 - 5.8	7.9
Areal density in the absorption part (g/m^2)	600 - 840	970
Unit price	Much lower than adult diaper	Much higher than baby diaper
Picture of sample		

- ***Packaging and marking:*** Diaper is required to be packed and marked in accordance to the Indian Standard. The products may be distributed in rigid or flexible packages, made of suitable materials, ensuring proper sealing possibility in order to avoid any moisture absorption, soiling and contamination during the storage as well as transportation. Packages to be used shall be free of any torn or damaged areas.
- ***Additional requirement:*** In addition to above requirements, there shall be a suitable process e.g., mechanical or adhesive to ensure a good fit of diaper at the waist and around the legs. Manufacturing materials shall be safe for its user and shall not provide a physical hazard. Adhesive used to keep the diaper components together should not be harmful to the baby skin and also should not migrate to the absorbent core or top sheet.

Table 3 shows the dimension and other parameters of baby and adult diapers, available in the market, along with picture of different layers. It can be seen that for a particular size of baby diaper (weight of baby), length of the part of the absorbent zone is 11.5 - 14.5 cm and the width is 16.3 – 17 cm. These values are 27 cm and 18.7 cm, respectively in case of adult diaper. This might be due to design of product required for higher liquid absorption compared to baby diaper. It may also be noted that weight of an adult diaper is much higher, as compared baby diapers, possibly due to higher areal density of the absorbent core layer. The maximum thickness of a diaper in the absorption zone was measured and found to follow a similar trend like products' weight. Higher length, width, thickness and areal density of adult diaper cumulatively offer higher volume of liquid absorption capacity. It signifies that more amounts of raw materials are required to manufacture an adult diaper, leading to higher price as compared to a baby diaper.

Tentative areal density of the different layers of baby and adult diapers was measured. The number of layers generally varies from the manufacturer to manufacturer, and also depending upon mutual agreement between the buyer and the seller. Different baby diapers generally consist of 5-7 layers with the variation in the areal density of different layers, tentatively ranges in between the 15- 90 g/m^2, excluding pulp-SAP layer sheet. In case of some diapers, it was difficult to separate only the pulp-SAP layer from the other layers for measurement of areal density of pulp-sheet or other individual sheet. In such cases, areal density of 2-4 layers was measured together and varies in the range of 500 - 860 g/m^2 for the different types of diapers. The liquid absorption capacity by a diaper was measured as follows: dry weight (W_1) of the diaper is taken and then placed in water bath with enough saline solution or clean water. Thereafter, salted water (0.9%) or clean water is added in the container of 250 ml for about every 10 minutes until the diaper begins to leak. After 30 min, the wet article was removed and hung up over a crossbar until no liquid drops off, and then the hanging hydrated diaper was removed and weighed (W_2) (Bachra *et al.* 2020). Absorptive capacity (wt%) of the diaper is calculated by the following expression: Absorptive capacity (%) = $[(W_2)\ (g) / W_1\ (g)] \times 100$, where, W1 and W2 are the dry and wet weight of the diapers.

Recent developments and smart diaper

A comparative study on absorption properties of baby diaper and super absorbent polymer is reported (Bachra *et al.* 2020). Diapers were collected from the U.S., Europe, Africa and the Middle East, and performed the analysis like Fourier-transform-infrared-spectroscopy (FTIR), Free-swell-capacity (FSC), Centrifuge-retention-capacity (CRC), Absorption-under-load (AUL), Absorption-rate (AR) and Particle-size-distribution (PSD). The highest FSC value was observed for the diaper of Europe sample and lowest in case of Asian diapers. As far as centrifuge retention capacity is concerned, the highest value was noted in case of Asian diaper. The same diaper also exhibits lowest performance in saline liquid towards the FSC, CRC and AUL tests. Many antibacterial components can be synthesized from the various materials, and a good antibacterial efficacy along with wound healing attributes of zinc oxide (ZnO) nanoparticles have been reported in the recent past. Zinc oxide nanoparticles are thus made into films to cohere with cotton fabrics to impart antibacterial property on fabric for its diverse applications. In addition to ZnO nanoparticle, silver ions are also one of the promising inorganic antibacterial materials, as it could resist and kill the formation of microorganisms, viz., Acinetobacter, Escherichia, Pseudomonas and Salmonella. In a smart diaper, it is expected to have some improved functionalities. Top and bottom layers are composed of polypropylene (PP) nonwoven fabrics, enclosing an interlayer made of antibacterial woven fabric, as well as another interlayer for urine-absorption. Absorbent interlayer is further designed with the

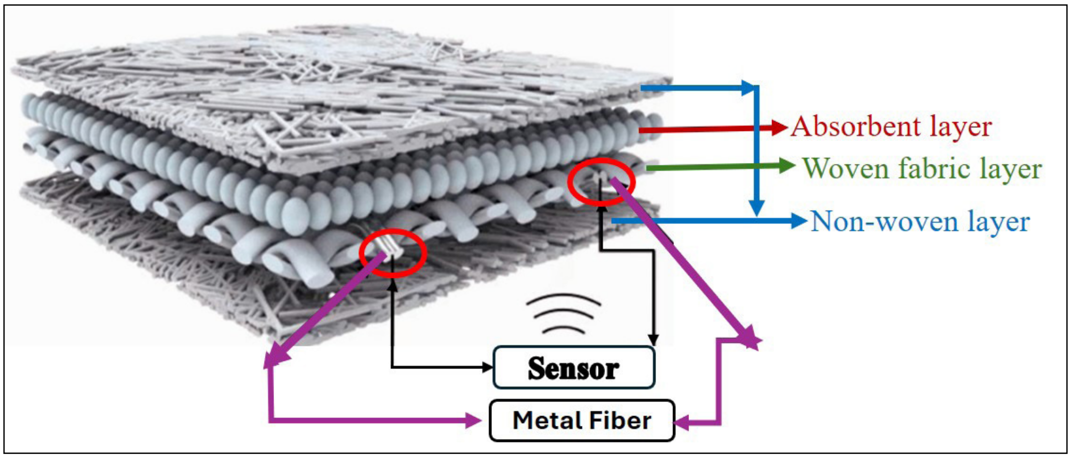

Fig. 3: A typical structure of a smart diaper (Shiu *et al.* 2022)

highly developed microfiber and super-absorbent fibres. Such diapers were developed with the aim to provide additional comfort and better health aspect, while ensuring environmental protection. Top layer is made of PP fabric in place of cotton to keep the user skins dry and cool, while facilitating ease of urine passage to the absorbent interlayer. Once the absorbent interlayer becomes saturated, the antibacterial woven fabrics prevent the skin allergy and the constituent metallic wires generate short circuit resistance, which provide a message for requirement of changing the diaper (Shiu *et al.* 2022).

For certain peoples the wet diapers cause a haul in their daily lives. In case of infants, if the diaper is allowed to remain for a very long time, it may cause serious rashes in their skin. A "smart" diaper is the technical solution for such type of situations, where a diaper is designed with the placement of a chip that connect an alerting device to the person nearby. Here sensor can detect the moistness, smell of the diaper and alerts the receiver by sending the appropriate message/signal. The main aim behind such idea is to support nuclear and busy working small families concerning baby care and elderly. Such type of smart diaper is generally costly than the regular diapers. The main challenge here is that there may be a chance of sensor fall off due to excessive movements during usage. The caretakers have to disinfectant the reusable chip. Some of important attributes/ features/ requirements of such diapers are (i) sensor is located in the diaper in contact to the use, (ii) sensor needs to be programmed to track and sense the dampness and smell in a diaper, (iii) if the chip identifies any such indications, it sends the signal in the form of flags, where a gadget should be intelligent enough to identify the flag signal with respect to the sensor ID so as to identify its users. Smart diapers are rather expensive at the moment and built around a removable Bluetooth sensor, which is required to charge and clean regularly. They are placed in the hydrogel layer, as the hydrogel gets wet it expands and becomes bulky, and from there the sensor could identify the moisture. Lumi by pampers includes two activity sensors that makes the 1st year of the baby easier for the parents (https://www.engadget.com/2019-07-18-pampers-lumi-smart-diapers.html). In addition to detecting the wetness of the product, the sensor also tracts the baby's sleep, where the sensor keeps on sensing the blue wetness strip, placed in the diaper. The Lumi sleep sensor attaches to the outside the diapers with Velcro and automatically tracks sleep through Bluetooth energy.

Development of bio-based superabsorbent polymer from the recycle cellulose was produced by crosslinking the citric acid with carboxymethyl cellulose, derived either from cellulose or recovered cardboard (Lacoste, Lopez-Cuesta, and Bergeret, 2019). Here bio-SAP was produced in the following process: Cardboards → Cellulose through TCF process → converted to CMC by carboxymethylation process → Bio-SAP through crosslinking process. Cellulose yield of 0.88 was obtained under mild oxidizing alkaline conditions from waste cardboards. Fourier-transform-infrared-spectroscopy (FTIR) analyses denotes the presence of some residual lignin component linked with recovered cellulose, providing some thermal stability to the developed product. Bio-based SAPs are important due to their major advantages of biodegradability. In this line carboxymethyl cellulose (CMC), a water soluble and biodegradable cellulose derivative, may be a good precursor for the synthesis of bio-SAP. It is nowadays manufactured by 2-step reactions of cellulose with alkali and monochloroacetic acid (MCA), using organic solvents under heterogeneous conditions. Cellulose is initially treated with sodium hydroxide (NaOH) in the presence of inert solvent that acts as a both swelling agent and diluent, facilitating adequate penetration of NaOH into the cellulose structure. Alkali cellulose is consequently accessible and reactive toward MCA that is added in the 2nd step of reaction. The CMC can be neutralized and dried immediately to give a technical grade or neutralized and washed to obtained a purified one for applications in many industries like cement, paper, coating, adhesives and drug delivery (Lacoste, Lopez-Cuesta, and Bergeret, 2019). Castrillon, *et al.* 2019 studied the application of different polymers as an alternative of traditionally used super-absorbent-polymer (SAP) in the baby and adult diapers, and sanitary pad, which is non-biodegradable in nature and also derived from the petroleum-based products. The biodegradable polymers or such polymer in combination viz., Gellan gum and Jeffamine 130 (O,O′-bis(2-aminopropyl)-polyethylene glycol) with

[1-ethyl-3-(3-dimethylaminopropyl) carbodiimide hydrochloride] (EDC) and N-hydroxysuccinamide (NHS), and other alternative like poly(γ-glutamic) acid (PGA) were evaluated. The polymer one shows water absorption and retention time in the similar tune like commercial grade SAP, made of sodium polyacrylate. The amino acid-based polyglutamic acid-L-lysine crosslinked polymer (PGA) exhibits water absorbance is almost twice than that of traditional SAP. A little crosslinking of PGA might have better capacity of water absorbance along with aiding its degree of biodegradability, and may be used as a substitute of sodium polyacrylate based SAP.

Antimicrobial finish, scope of natural fibre and environment issue

In the direction of reducing environmental pollution arising from the disposal of diapers, the possibility of bamboo and organic cotton, as absorbent material were performed by altering their blend ratios viz., 100/0, 70/30, 50/50 and 0/100 (Shanmugasundaram and Gowda, 2010). Samples were subjected to tests like antibacterial test, liquid strike-through, absorption capacity, acquisition time and rewet time under 2.5 kg load. Out of such various blends, bamboo and organic cotton blended sample with ratio of 70/30 exhibits best result, as far as absorption capacity and antimicrobial efficacy against *E. coli* and *S. aureus* bacteria are concerned. However, the liquid transport from the surface is poor due to its wicking properties. Lin *et al.* 2017 studied the effect of antibacterial yarn in a smart diaper. The 120, 100, and 80 μ diameter metallic fibre, silver plated coper fibre, and coper fibre as a conductive layer were utilized. A 1000 D high-strength polyester (PET) yarn as warp and 30^{S} Ne count antibacterial cotton yarn or 500 D antibacterial nylon yarn were used in the weft direction in the fabric production. In order to enhance the antibacterial efficacy of the cotton or nylon yarn, quaternary ammonium salt was used during dyeing and finishing process. Such electro-conductive yarn aids to the smart engineered structure to detect the moisture level in a diaper to transmit signal to an electronic device. Bamboo fabrics are made of pure bamboo fibre-based yarns, which have excellent wet permeability, moisture-vapor-transmission proprieties, soft hand, better drapery, easy dyeing and splendour colours. It is an emerging fibrous having great prospective of developing sustainable fabric. Bamboo decorating series has the function of antibiosis, bacteriostasis and ultraviolet-proof (Malarvizhi, 2015). Jute-fibre based pulp as an absorbent material was developed by ASAM pulping process, where the fibres were treated sodium hydroxide, sodium sulphite, Anthraquinone, and methanol. Pulps produced in the process followed bleaching leads to achievement of high whiteness index of 88.2. Such pulp after down-sizing by mechanical process could shows water absorbency of approximately 700%. Therefore, such pulp can be used to developing disposable baby or adult diaper in combination with super-absorbent-polymer.

Fig. 4: Development of jute fibre-based pulp for application in diaper

Disposable diapers contribute to the comfort, hygiene and convenience to its consumers. In-spite of performance benefits, there are several environmental issues and challenges associated with its eventual disposal, like waste generation & environmental pollution, exposure to chemicals, exposure to pathogens, and aesthetic concerns. The primary issue lies in the large volume of waste generated, as traditional disposable diapers take hundreds of years to decompose in landfills, contributing towards the pollution and waste management. Production of disposable diapers also involves the use of non-renewable resources, such as plastic and synthetic chemicals, which further negatively caused environment. Solid waste generation possibly may be one of the most perplexing impacts of disposable diapers on the environment and are becoming the third largest individual constituent of municipal solid waste, just after newspaper and bottles, accounted for 1.5% and 4% of the total (Ntekpe *et al.* 2020). It is overtly that little attention has been given to the product after its use and therefore leads to unguarded dumping, burying, and burning of soiled disposable

Fig. 5: Unguarded disposal of soiled disposable diapers (Ntekpe *et al.* 2020)

diapers. Most of the disposable diapers discarded in mixture with household garbage waste are also eventually reach to the municipal for landfill. Development strategies in order to reduce the trash output sparked by urbanisation and a rise in living standards has also been reported. In-this method of refuse disposal, refuse is dumped in accordance with a preconceived plan, compacted and covered during and at the end of each day. It is not an open dump, as any poorly managed of such disposal may result in spontaneous ignition accompanied by smokes and smells production. It might also pollute the underground water, if leachates to the ground water layer. Disposable diapers are indiscriminately thrown away or dumped openly at various points (Ntekpe *et al.* 2020). In this direction, the design of biodegradable products helps to recycle through the process like composting, as one of the possible measures. The polymer emphasised in their study is produced from the renewable resources, thus improves its appeal ensuring more intriguing, as far as life-cycle perspective is concerned. Land requirements and agricultural production's emissions balance out the reduced need for landfill space. Considering the product entire life cycle is necessary to make an objective assessment of environmental performance. Environmental effects of new bio-polymer based product over the span of life-cycle is highlighted and compared with the traditional plastic products.

CONCLUSION

Disposable diapers have become a significant product in modern society, offering convenience and hygiene for the parents and caregivers of infants, as well as for adults with incontinence. They provide a high level of absorbency, comfort and ease of use, resulting a preferred choice over cloth diapers in many households. Development of disposable diapers has been driven by the need for efficient waste management, as they help prevent leakage and maintain dryness for extended periods. However, the widespread use of disposable diapers has raised significant environmental concerns. The primary issue lies in the large volume of waste generated, as disposable diapers take hundreds of years to decompose in landfills, contributing to pollution and waste management challenges. The production of disposable diapers also involves the use of non-renewable resources, such as plastic and synthetic chemicals, which further impact the environment. In recent years, there has been growing interest in finding more sustainable alternatives, which include the development of eco-friendly diapers made from biodegradable materials, the use of superabsorbent polymers that are less harmful, and even innovations in reusable diaper options. Additionally, advancements in recycling technologies and better waste management practices could alleviate some of the environmental burden associated with disposable diapers. In recent development on "smart" diaper, where a diaper is embedded with a chip that can be connected to the alerting device, can detect the moistness, smell in the diaper and alerts the receiver by sending the appropriate message. In this line antibacterial fibres, metallic wires embedded in smart diapers and possibility of usage of natural fibre-based pulp have also been summarized to address some of the present challenges in this area. Natural fibres like cotton, bamboo and jute could find its application in disposable diaper making in addition to synthetic polymeric and fibrous materials.

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