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Baby Diapers Past and Present: A Critical Review

Pietro Febo and Alessandro Gagliardini

Abstract: Disposable baby diapers are a popular consumer product, the use of which contributes nearly 77 million tons of solid waste to landfills, with a degradation period of at least 500 years! Moreover, their use continues to increase worldwide. More than 200,000 trees are lost each year to their manufacture in the US market alone, with a consumption of 3.4 billion gallons of fuel oil, which contributes to the production of greenhouse gas emissions, furthering the environmental strain due to the Earth's climate changes. It is therefore necessary to change the way these products are consumed and to find more eco-compatible solutions, by using biodegradable polymeric plastics and/or re-usable cloth diapers. This chapter reports the historical evolution of baby diapers, its global market, the connected environmental problems, and the efforts that are being made in order to create bioactive and biodegradable baby diapers.

1. Introduction

The continuous increase of the world's population and the high level of human development has created a negative ecological footprint (i.d. 1.2 kilograms per person per day), with an annual cost in natural capital degradation estimated at US\$4.7 trillion/year [1,2]. Thus, the current global waste levels are approximately 1.3 billion tons/year and are expected to increase to around 2.2 billion/year by 2025, i.e., from 1.2 to 1.42 kg per person per day in the next 15 years.

Managing waste properly is, therefore, essential not only for building sustainable and livable cities and developing countries, but also for reducing greenhouse emissions and natural environmental disasters, the latter of which have seen their frequency increase year by year. For this purpose, it is interesting to underline that the majority of waste is produced by food production, distribution and consumption, estimated to be around 0.5/1 billion tons/year and by disposable baby diapers that reached a worldwide figure of 3.5 million tons/year. Thus, it is necessary to create a sustainable chain of food and to produce baby diapers made of biodegradable and natural polymers in order to achieve zero waste, driving industrial changes towards a new techno-economic system, the so-called bio-economy.

Technological advances, in fact, are set out to replace finite resources and conventional industrial processes with procedures and components that are biologically derived. These innovative bio-based processes, expected to be more

sustainable because of their use of renewable resources and their decreased levels of CO₂ emissions, should ensure economic growth as well as contributing to the achievement of environmental and climate goals.

In conclusion, promoting a more inclusive and sustainable industrialization by using natural biopolymer obtained from waste materials, will foster innovation and provide access to more affordable economic growth through the development of new markets and employment potential. New ways of producing biodegradable and reusable baby diapers could be part of these innovative processes.

2. The Diaper's Story

From time immemorial, there has been a need to protect babies due to their physiological needs; infants were supposed to be wrapped in swaddling bands in many societies and since antiquity. The swaddling bands were made of strips of linen or wool that were wrapped tightly around each limb and then crosswise around the body (Figure 1).



Figure 1. Different types of baby diapers used in different periods [3].

After their use, the diapers were seldom washed. They were usually just hung by the fireplace or outside to dry and then used again.

Between the end of the 19th and the beginning of the 20th century, infants in Europe and North America started wearing what could be considered the prototype of the modern diaper. A square or rectangle of linen, cotton flannel, or stockinet was folded into a rectangular shape and held in place with safety pins. Such new diapers were originally made with white cotton or linen fabric (or similar), which are absorbent natural materials (Figure 2).



Figure 2. Linen fabric and similar natural materials [3].

It seems that the first mass-produced cloth diapers were introduced by Maria Allen in 1887 in the United States [4–7].

At the beginning of the 20th century, many mothers had concerns related to the negative effects caused by diapers such as rashes or redness of the skin (Figure 3).



Diaper rash

Figure 3. Diaper rash (diaper dermatitis) [8,9].

Diapers were also associated with the presence of bacteria, viruses and fungi. Concerned mothers understood the need to eradicate, or at least be able to control them. The mothers began using boiled water in order to reduce the common rash problem. The identified process consisted in putting used diapers in a big pot of

boiled water; however, this required great amounts of energy and time. Skin rash was a serious problem in those days.

It is presently still not yet clear who can be credited as the real inventor of the disposable diaper. Current knowledge establishes that the first disposable diaper concept was most probably made by using unbleached craped cellulose tissue just after the second world war in Europe and specifically in Pauliström, Sweden.

A few years later in the United States, a Westport housewife named Marion Donovan invented the Boater, a waterproof covering for cloth diapers (Figure 4) [10].



Figure 4. The Donovan Boater [11].

Her first model of the disposable diaper was made of shower curtain plastic into which a conventional cloth diaper was inserted. She obtained four granted patents for the designs, including the use of plastic snaps that replaced the traditional and dangerous safety pins.

Following this new innovative design, the first disposable diaper made with non-woven fabric was created in 1949 in the USA. In the same year, a British mother developed a two-piece disposable diaper. Following this, disposable diapers with a rectangular one piece diaper were invented, followed by the launch of the roll diaper (Figure 5).



Figure 5. The Roll Diaper [12]. For a timeline of major diaper development, see reference [13].

Following these years, the disposable diaper was still considered a luxury item and used only for special occasions such as vacation trips and the like.

The first truly disposable diapers were made using a very simple rectangular design. The absorbent core structure was made of several layers of tissue paper, and using a plastic film with no tape on the outside, which came with the product.

In 1957, Mölnlycke entered the market with a product made of paper pulp encapsulated in tissue and surrounded by a knitted net. The sanitary napkin, on the other hand, experienced a rapid growth in the European and North American markets. It was not until the end of this decade when Vic Mills, who worked for the Procter and Gamble company, invented "Pampers", as he was looking for better products to use for his baby grandson. The diaper was, however, not launched on the market until 1961 [14].

From the 1960s onwards, the disposable diaper evolved quickly as the industry was able to gauge mothers' needs. Tissue was replaced with pulp a decade after the first disposable sanitary napkins arrived on the market. In 1966, Pampers launched

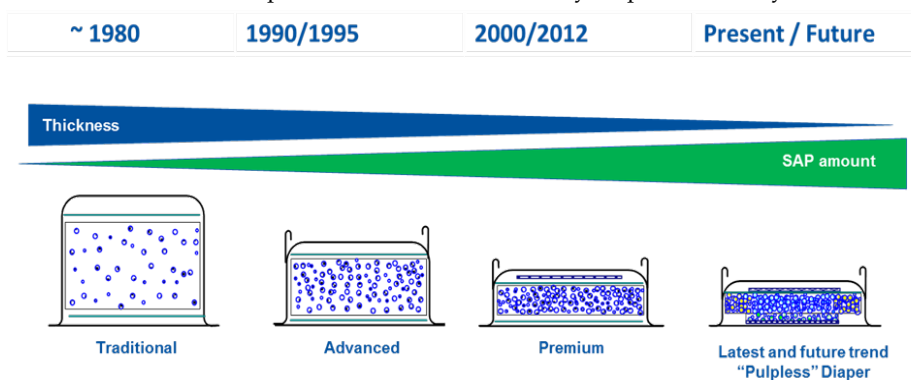
a new C-fold design and by 1969 they initiated a third sizing option. A typical commercial diaper machine ran at speeds of 150 diapers per minute.

The 1970s proved to be the literal baby boom for the disposable diaper industry in developed countries and even in some other, less developed areas of the world. Competition between Procter and Gamble and Kimberly Clark to gain control of the world diaper market resulted in quick diaper design improvements and lower prices for the consumer. In 1976, Kimberly Clark introduced its shaped Huggies diapers. Lateral elastomeric was used at the end of the decade by most producers in an attempt to improve the fit.

Then, in 1982, Unicharm introduced its concept of SAP (super-absorbent) [15] in Japan, following its use in sanitary napkins.

As of 1985 and to this day, there are huge and continuous developments in the diaper's structure and composition. Today's market allows for several companies producing different shapes and product designs. As reported in Table 1, the ratio of cellulose to pulp/SAP has significantly changed over the years in combination with the reduced thickness of the product.

Table 1. Development in the structure of baby diapers over the years.



3. Technical Requirements and Performance

In today's global market, there are several types and structures of disposable diaper products designed to satisfy the needs of all babies in all countries (Figure 6).



Traditional mix
Pulp/SAP
(different ratio)



Fluffless
(higher SAP in
different and controlled
channels)



Extra Absorb
channels to
distribute wetness
evenly

Figure 6. Different types of baby diapers used currently and globally.

There are numerous different factors related to, among others, country, culture, religion and baby age that can affect the type of diaper. However, there are some needs that are universal:

- a meaningful ratio between product cost and quality; and
- no side-effects such as skin dryness or rashes.

These differences incite the different diaper manufacturers to constantly research and improve on their current designs in order to reflect customer needs.

In addition to the dryness performance of diapers, all companies are paying attention to developing and delivering a new generation of diaper products, paying particular attention to including minor details such as the softness, gentleness, sustainability and naturalness.



Figure 7. Safety and security of baby diapers according to publicity claims.

As reported in Figure 7, the safety and security of baby diapers are actually based on eliminating the use of some components considered to cause allergies and sensitivity problems. However, the real issue at hand is the necessity to make these products 100% bio-degradable, and to ensure that they do not use fossil materials for the sake of later generations. Thus, future baby diapers should be obtained from agricultural waste and the industrial by-products necessary to produce the natural bio-polymers that are indispensable to making disposable diaper components.

In this way, we could eliminate the many environmental problems linked to diapers and produce skin-friendly and environmentally-friendly products, thus safeguarding the ecosystem and biodiversity of our planet.

4. Environmental Problems Linked to Diapers

An infant requires up to 7000 diaper changes before leaving diapers behind. This typically requires 300–600 cloth diapers from birth to potty training, adding roughly 14 kg of cotton to landfills. In addition, the use of cloth diapers also entails other costs, such as greater water and energy use: about 76,000 liters of water are needed to launder diapers for one infant. The 450 billion disposable diapers used each year contribute to nearly 77 million tons of solid waste to landfills, and a disposable diaper takes at least 500 years to degrade [16], (Figure 8).

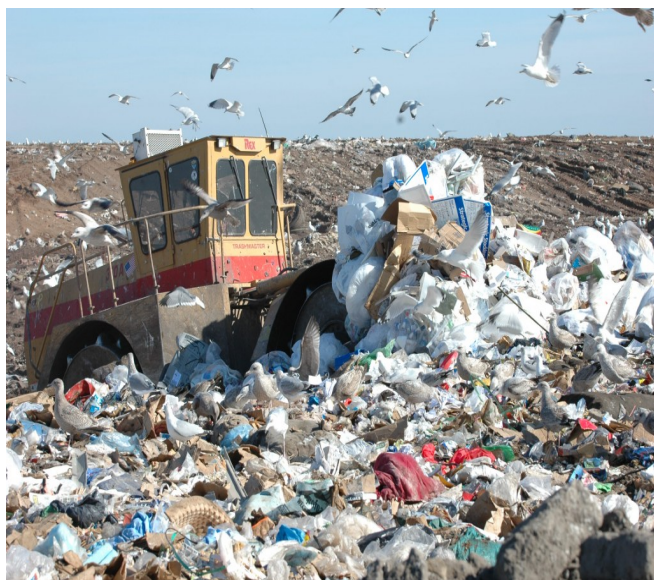


Figure 8. Disposable baby diapers in a landfill [17].

Efforts are being made to reduce these impacts. In 2000, the Mexican company Absormex created a disposable bioactive diaper that degraded 200 percent faster than ordinary disposables. The technology is based on a catalyst additive added to the plastic to enhance biodegradation [18,19]. However even if this diaper has been demonstrated to pass the ASTM D883-99 test, there are still many doubts about the times required for degradation under particular conditions, e.g., in anaerobic conditions.

Another approach currently under investigation is diaper recycling. The idea behind this is to separate a diaper's components (essentially plastic and organic compostable matter) in a process that neutralizes the potential biological hazard, e.g., by sterilizing the used diaper [20–23].

Recently, biodegradable and compostable bio-based resins such as Ecovio [20] and Mater-bi [21] have been commercialized. These resins could be a suitable substitute for the polyolefins and polyesters currently used in diapers.

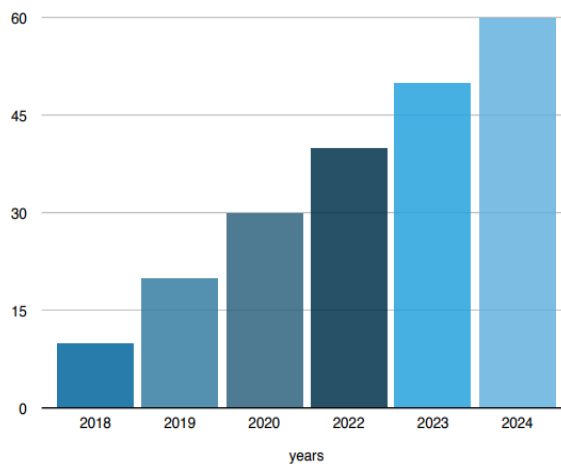
5. What About the Global Baby Diaper Market?

Different market analyses [22,23] have projected that the global market for baby diapers should reach around US\$60 billion by 2024 (Table 2), driven by the growing number of young mothers in the workforce. Further predictions indicate a decline in diaper prices as a result of the mass commoditization of the product, its increasing use to maintain hygiene and prevent rashes on babies' skin, the launch of smaller pack diapers, and a growing preference for diaper pants over open diapers.

Additionally, in developing countries, increasing birth rates, rapid urbanization and continuously improving economic conditions have fueled the growth of the baby diaper industry. Moreover, this market is also benefiting from growing awareness of the convenience offered by diapers in markets like India, South Africa, Mexico, Venezuela and Turkey, due to the ubiquity of parenting websites, baby blogs and social media. Thus, while economies such as the USA, the EU and Japan are characterized by maturing conditions due to declining birth rates, Asia Pacific represents the largest and fastest growing market worldwide. Furthermore, Europe was the largest regional producer market in 2013, followed by Asia Pacific, which is expected to have the fastest growth of 8.3% during the forecast period. Still, disposable diapers have exhibited the largest market share in North America owing to environmental regulations and the adoption of eco-friendly diapers in the American market.

As a result of the abovementioned factors, biodegradable diapers are expected to reach their highest growth rate during the forecast period [24].

Table 2. Baby diaper global market forecasts (2018–2024).
US\$ billion



6. Conclusive Remarks

The demand for baby diapers depends highly on two factors [24]: fertility rates and the penetration of the diaper market across geographic areas. As an example, in Africa the fertility rate is high, but the market penetration rate is low, hence the sale of diapers in the region is also low.

In North America and Europe, the penetration of the diaper market is high, but the fertility rate has steadily decreased. However, the worldwide sensibility leaning toward more environmentally friendly practices is continually growing; therefore, we expect that the future market will see a higher growth of biodegradable and eco-friendly baby diapers.

Thus, it is necessary to increase research studies to recover and produce innovative bio-composites made by natural polymers produced through the use of waste materials and sustainable industrial processes.

This is our dream, together with all the scientists involved in the EU research project PolyBioSkin.

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