

2. REVIEW OF LITERATURE

The review of literature pertaining to the study “**Exploring the recycling potentialities of cotton waste for production of innovative sustainable products**” is given under the following heads:

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2.1. Cotton

Cotton accounts to 40% of the total fiber produced in the world, utilising 8.2 million hectares of land area (www.pbs.org). According to the 2013-14 metrics, there are eighty cotton producing countries in the world, among which China, India, United States of America, Pakistan and Brazil hold the top ranking (www.ststista.com). On viewing the trend in cotton consumption over the last 25 years, the Cotton Advisory Board (CAB) quotes that, 158.3 lakhs of bales produced during 1996-97 have increased upto 242 lakhs bales in 2009-10. Focusing on the export market of cotton, a steady rise is seen from 16.82 lakh bales in the year 1996-97 to 101.43 lakh bales in 2012-13 (www.cotcorp.gov.in). The world cotton production is forecasted to rise up by 4%. According to estimates cotton output from India is expected to be 403 bales will surpass China in near future

(Vora, September 04, 2014). With the introduction of Technology Upgradation Fund scheme (TUFS) by the Government of India in 1999, the domestic market for cotton has also gained its momentum and now farmers have opted for cotton against other crops. (www.fibre2fashion.com/news)

In an ideal soil condition cotton will begin to germinate in five to ten days. The true leaves arise in two to four weeks duration and the plant gets a stand in this stage. In approximately five to seven weeks the small flower buds, covered with leaf like bracts appear and these are called the 'squares' (www.cottonsjourney.com). This part swells and pushes through the bracts into a flower. In three days, the pollination occurs and yellowish white flowers appear. This turns into a reddish flower which soon withers off, exposing the cotton boll inside. The cellulosic rich cotton fibers descend from these seeds (Deterling and El-zik, 2010). These are further collected and stored for further use.

Ginning is the next process, of processing the collected kapas from the field and separating the seed from lint (fiber) (Mthembu, 2013). The collected seeds are used as cattle feed and delinted (removal of the fuzzy lint hairs on seed surface) for the extraction of oil. The cotton fibers are further subjected to spinning, which converts fiber into yarn, that can be used in the production of cotton woven textiles (P. Patil and Arude, 2014). During the process of spinning, cotton fibers are cleaned several number of times, to ensure trash free clean cotton to be converted into a yarn (Hasani and Tabatabaei, 2011).

However, the cultivation of cotton is not eco-friendly and sustainable. For this reason cotton is called the 'dirty crop'. During the process of raising the crop, enormous amount of fertilizers and pesticides are used, to overcome the pest attack and to protect the crop. The farmers have to make huge investment on the crop. (www.ota.com/organic). Globally, cotton is grown on 2.5% of worlds cultivable land area using 24% of world's insecticide and 11% of pesticides (www.organicauthority.com). Reports state that in India, cotton cultivation is done on five percent of the available land area to which 54% of pesticide is used annually. The DNA mutation was studied to be 3.5 times higher in farmers and showcasing that the whole generations to come are also affected (<http://peopleandplanet.org>).

In India, one in ten pesticides used has resulted in three to four symptoms that show pesticide poisoning on the farmers who used it. It is stated that the pesticides commonly stored in the household near their kitchen and the usual practice of using the pesticide as cans to raise and hold water from wells (www.toxicsaction.org) were one of the reasons for acute pesticide poisoning. (www.toxicsaction.org). Aldricrab and Endosulfan, are two of the commonly used pesticides, a drop of which can kill a person and we find reports stating that the ground water is polluted by such chemicals (Chaudhry, 2007). The farmers lack awareness about pesticides, protective clothing and also on the effects of abuse of such hazardous chemicals and hence it is significant to shift to organic cultivation that uses eco-friendly green manures. Finally, when a consumer buys a 100% organic t-shirt, it reduces 150 grams of agricultural chemicals (<http://www.tiffanytreloar.com.au/project-332/>). We understand that, 65% of the pesticides used in the cotton directly or indirectly enter into the food chain of human beings through milk and meat of animals. The latest reports, confirm the presence of toxin associated with cotton farming is found in human breast milk (<http://ejfoundation.org>).

It is estimated that the time taken, to ban a pesticide in the most developed country like USA, is approximately ten years. The Environmental Protection agency has listed, 7/10 chemicals used on cotton as either banned or carcinogenic in nature. (US EPA report, 2001). The nitrogen based synthetic fertilizer's releases nitrous oxide, which is found to be 300 times more powerful than carbon dioxide as greenhouse gas. Contrastingly, the application of organic manure recycles the nitrogen back into the soil, which reduces both nitrogen emission and pollution (Kramer , *et al.*, 2006).

Reported evidences on soils being sterile, have forced the farmers to shift on restoring the lost nutrients through green manures and organic amendments. The restoring action will bring better yield and also balance of nutrients in the soil. This is achieved through Integrated Pest or Nutrient Management (IPM or INM) (Praharaj, 2010). Food and Agricultural Organization (1988) explains the major objectives of Integrated Nutrient Management Systems (INMS) which is to maintain the soil health by balance use of fertilizers, increase the nutrient stock in soil by

combined use of organic and biological nutrients, minimize the loss of nutrients from the soil, that in long term there is a reduction on dependence on inorganic chemical fertilizers (Praharaj , *et al.*, 2007). This is achieved by using both chemicals and green manures. The common fertilizers and supplements used on cotton include chemicals like urea, Di-ammonium phosphate (DAP), ammonium phosphate sulphate (ASP), rock phosphate powder, gypsum, potash, ferrous sulphate and sulphur. Additionally, organic supplements are also used in cotton cultivation, which includes, cow dung and urine, vermicompost, neem cake, castor cake, green manure, azotobacter preparations, phosphate-solubilising bacteria preparations and green algae (Jackson, 2005). The normal dosage of chemical and green manure in integrated nutrient management system is 50-100% of 40-20-20 NPK along with 5-10 tons/ hectare of farm yard manure, along with urea sprays (www.cicr.org.in). The Recommended Dose of Fertilizer (RDF) will be supplied during sowing, squaring and at peak flowering, whereas the green compost or farm yard manure will be applied inside the furrow during the sowing, considering the nature of slow release of nutrients from compost (<http://agritech.tnau.ac.in>).

2.2. Cotton waste industry

There are 4000 ginning and spinning industries distributed around the country (<http://dcd.dacnet.nic.in/TMC.htm>). A huge amount of solid cellulosic wastes from spinning industry, in the form of blow room waste, card room waste, comber waste, draw frame waste, roving waste, leaf butts, locules, crushed seeds, small portion of twigs, sweepings, dropping lap waste, ring rover, pre-comber drawing, card sliver, preparatory sweep, lap former, spinning sweeps, comber sliver, post comber drawing are eliminated during cleaning of cotton in the spinning process (Chinnaswamy, 1999). The wastes are usually evacuated to maintain efficient functioning of the mill (Sreenivasamoorthy, 1983).

This is taken to the willow mills for the recovery of good quality cotton fibers for the purpose of utilizing it for other end uses. Low count coarse fabrics of 5s-6s count, that are used in the making of towels, scrubbing cloths, dish rags, cheap cotton blankets and flannelettes (Thornley, 2006). The final cotton trash is used as a bulking agent in composting, as fuel and in ethanol production. Apart from this, it is used in edible items as high fiber dietary products, raw material in tooth

paste, salad dressings and in making viscosity enhancers used in ice cream making (Department of Health and Agein, 2008). This waste is also sold to make rags, stuffing and bedding materials, currency and paper making and as a base in mushroom cultivation (www.kkcottonwasteco.com). After utilization of cotton fibers for such end uses, there is a final trash from cotton spinning process, uneconomical to process and unutilized, this is due to lack of awareness on this waste disposal and reuse.



Picture of an industrialist in front of the huge pile of willow waste in his mill at Hillsboro Gin

Source: The Decatur daily news, "Cotton-pickin' waste no more?", April 18, 2006

Retrieved from: <http://legacy.decaturdaily.com/decaturdaily/news/060418/trash.shtml>

2.2.1. Willow waste

Indian cotton has high amount of trash, which was a setback in cotton export market. Government initiatives like Technology Mission on Cotton (TMC) insist on cleaner cotton that is in par with international standards. This in turn produced higher amount of unspinnable cotton dust and trash (www.cotcorp.gov.in). The current

problem with the willow waste has to be considered for further examination since in future there will be more such wastes.



Picture of waste cotton stored in mills used for the purpose of mushroom cultivation

Source: Specification, Classification, Category of Cotton Waste

Retrieved from: <http://www.cottonwaste.net/spec/cw/>

In literature, willow waste or willow dust is defined as a bulky solid cellulosic textile mill waste evolving from spinning industries (D'Souza and Balasubramanya, 1999). According to the data's, every year, 30 to 33, 000 tons of unutilised willow waste is disposed in the landfills (Bhide, 1974). Another survey, done few years after states that this quantity has risen to approximately 90,000 to 1, 80, 000 tons, which is either thrown away in landfills or incinerated (International Cleaner Production, n.d.).

Reports of the selected waste explains the waste to be a storehouse of negative bacteria and toxic inorganic elements above the permissible limit (Sangeetha , *et al.*, 2013). The lipopolysachharides present in the cell wall of cotton dust affect the lung and prolong exposure leading to tuberculosis (Kane, 2001). Currently, there are three methods of handling willow waste. One is to dispose of willow waste by burning off in landfills. Second is digestion of the waste in aerobic conditions (presence of oxygen) into a compost with manurial values and third is anaerobic fermentation (absence of oxygen) resulting in biogas and slurry (Sreenivasan, 2007).

In a study, willow waste was subjected to composting using sodium hydroxide at 0.1% and a microbial consortium at the Central Institute of Research on Cotton Technology, Mumbai. Five hundred kilograms of willow waste was composted in a period of thirty days. The prepared compost was found to be better than farm yard manure and was recommended to be suitable for any crop variety. When applied on the plants, it was found to improve the soil structure, water holding capacity, micronutrient content and overall plant growth was good (Sreenivasan, 2000).



(a). Willow waste stored in the mills

(b). Men spraying the microbial consortium to compost willow waste.

Source: VISION 2025, CIRCOT perspective plan:

Retrieved from <http://www.circot.res.in/pub/v2025.pdf>

An intensive research was done by a group of scientists, headed by Balasubramanya and Khandeparker, from the Central Institute for Research on Cotton Technology (CIRCOT), Mumbai, started with identification and bio-conversion of willow waste into bio-gas and slurry (Balasubramanya, 1986). In a period of sixty days, the pilot plant using batch fermentation technique yielded 670 m³ per ton of biogas from willow waste. It had 60% of methane and 300 kilograms of slurry. The nitrogen, phosphorous and potassium content of the slurry was reported to be 2 – 2.5% (N), 1 – 1.2% (P) and 1.8 to 2.2 % (K) (Balasubramanya, 1988). The carbondioxide and residual nitrogen was converted into methane gas and

carbon rich slurry. The average methane from the study were 39%, 35% and 33% respectively, compared to 42%, which was obtained using 100% cow dung (Anuraja and Turuswamy, 2001).

The study extended to having an industrial linkage with two textile mills. Century textiles and industries Ltd, Mumbai and M/s Hanjee fibres, Surat, installed plants that can produce hundred tons of compost per month selling at INR 2400 per ton from raw material that cost INR 100/kg (Khandeparker, 1984). Later extraction of biogas from the willow waste was studied. Two hundred kilograms of willow waste in three hundred litres of water subjected to alkaline aerobic digestion evolved with 40 m³ of biogas for 30 d RT (Dubey and Chandra, 2000). The problems faced in the practical application are high expectations for government subsidy to the production plant running and the maintenance, usually seen as an additional burden to the engineers (Sreenivasan, 2007).

Willow waste was used as a base for producing edible mushroom production (Balasubramanya, 1988). Lime stone powder, without much of economical value was mixed with willow waste to produce a low cost and light weight composite and was found to be comparable with concrete block. A performance study showed that the material had high energy absorption capacity, less weight and was smooth compared to concrete and was suggested for use in wall, wooden board substitute and as sound barrier panels (Algin and Turgut, 2008).

2.3. Sustainable products

2.3.1. Composting and vermicomposting

A report says that every year 700,000,000 tons of organic waste is eliminated, which is either incinerated or thrown away in the landfill, (Bhide and Monroy, 2011). Organic waste and decompose in landfills release carbon dioxide and methane, which contribute to the climatic change in the form of greenhouse gases. Landfill gas is made up of 54% of methane and 40% of carbon dioxide. Methane is 24 times more damaging than any other greenhouse gas (<http://www.grida.no/>). Incomplete composting results in a Compost-Like-Output (CLO), which is dangerous to health with heavy metals. Municipal solid wastes are usually dangerous for the same reason (Page, *et al.*, 2014).

Most of the organic wastes are compostable. Approximately 300 million tons of crop residues are eliminated, among which only 2.5 million tons is used for animal feed and compost on agricultural fields (<http://www.fao.org>). Now, almost 175 industries are involved in production of compost at commercial scale using locally available organic wastes. The produced organic manure, compost, farm yard manure, soil conditioner is used for farming, horticulture, aromatic and medicinal plants, propagation and in nursery (Suryawanshi , *et al.*, 2013). Compost has a wide market, which includes vegetable crops, agriculture, horticulture, landscape, rehabilitation, mulching, growing medium, nursery, market gardening, soil mixing companies, organic fertilizer manufacturers, exports and in soil sanitation (Dominic , *et al.*, 2002).

Organic manure comprises of farm yard manure, compost and green manure among which cattle manure holds the maximum share. In India, the area under green manure supplementation is around seven million per hectare (Westerman and Bicudo, 2005). The pulp and husk from coffee manufacturing process were made into compost using cow dung and effective microorganisms as decomposing sources in a period of seventy days. The results showed that the cow dung had better nutritive value compared to effective microorganisms (Kassa , *et al.*, 2011).

Vermicomposting involves bio-conversion of organic wastes into a nutritively superior product with various enzymes and hormones, which can benefit the soil, plant and ecosystem, using earthworms (Patil , *et al.*, 2012). It is an eco-friendly waste management technique and superior to composting, due to the rate of decomposing and quality of the resultant vermicast (Lim , *et al.*, 2014). The quality of vermicast is due to the enzymes present in the gut of earthworms, through which the waste is bio-stabilized (Nedunchezhiyan , *et al.*, 2011). Unlike conventional composts, vermicompost retain the nutrients for a much longer duration, supplying both micro and macro nutrients required by the plant and also increase the available nitrogen in the soil (Ludibeth , *et al.*, 2012).

Vermicompost has 2 - 3% of nitrogen, 1.85 - 2.25% of phosphorous and 1.55 - 2.25 % of phosphorous along with plant hormones like auxin and gibberellins with other enzymes that stimulate plant growth and destroy pathogens (Kamineni and Sidagam, 2014). It plays a significant role in altering the physio-chemical and

biological properties of the soil (Gómez , *et al.*, 2013). As a natural source of plant nutrients and microbial energy, it helps in cationic exchange and act as a chelating agent. It plays a significant role in altering the soil texture and composition (Chattopadhyay, 2012).

There are about 3600 different types of earthworms, among which the non-burrowing African species *Eisenia foetida* and *Eudrilus eugeniae* are commonly used in India (Sangwan , *et al.*, 2010). Among these, *E. Foetida* is more popular in India, due to adaptability characteristics and speed in conversion of waste into vermicompost (44-50 days) say Sharma , *et al.*, (2013).

Bulking agents are added to stabilize the mixture and to begin the vermicomposting process, Commonly used bulking agents are cow dung and garden waste (Rupani, *et al.*, 2013). To begin the process of vermicomposting, the organic wastes collected are shredded and kept ready for use. For the purpose of aeration and to hold the earthworms from escaping into the soil, husk or polythene was used as the bottom layer. Above this, 15 - 20 centimeters of organic waste was layered and rock phosphate powder was sprinkled to improve the quality of resultant vermicompost. This is allowed to compost for twenty days (Nagavallema , *et al.*, 2006). As the heat subsides later, around 500 to 700 selected earthworms will be released into the cracks seen on the surface. The brim of the rings and edges were sealed with sack and wire mesh to hold moisture and to prevent the vermicomposting bins from pests and birds. The moisture content is a very important parameter and it is maintained by sprinkling water frequently. After a period of sixty days the vermicompost is ready for use (Hussaini, 2013).

Globally various organic wastes dumped without end uses are vermicomposted using precise earthworms. In Punjab (India), the spinach wastes which are found in large quantities in the city's super market was collected, composted and vermicomposted (Sharma , *et al.*, 2013). The abundantly available coconut wastes in the form of husk and flakes in Malaysia were converted into an organic fertilizer using earthworms. The results showed that smaller the particle size and the faster is the rate of vermicomposting (Tahir and Hamid, 2012). Experiments on application of vermicomposted water hyacinth and supplementation on selected plant variety has shown good results compared to the control sample. The observed plants had better height with more number of leaves with a favorable root and shoot ratio, larger

inflorescence and higher biomass (Batham , *et al.*, 2014). The vermicompost is a very good supplement for any plant variety. One hectare requires two to three tons applied along with seeds during sowing or as row application when seedlings are 12 - 15 centimeters in height, followed by normal irrigation. Small scale units can produce 5-70 tons of vermicompost per annum and large units can make upto 100 tons (Gupta , *et al.*, 2014).

The investment is one time and the infrastructure raised is simple and easy to build and operate, the technique is economical and produces sustainable eco-friendly products (Pandit , *et al.*, 2012). It can be done on large scale and small scale depending on the amount of wastes and available space for composting. Small scale production is limited to 5-10 tons and large scale extends upto 50 - 100 tons annually (ICAR, 2008). One ton of organic waste in approximately 1500 sq.mts with six workers is sufficient to convert 70 tons of earthworm casting annually (Mishra , *et al.*, 2014).

Vermicomposting has a three-tier advantage by benefitting the farmer, environment and industrialists. It helps in increasing the soil nutrient and thereby boosting the quality and quantity of the plant products obtained. In future, the dependence on chemical fertilizers can be reduced and the technique can help in bringing additional earning to the farmers and a means of uplifting rural economy (Joshi , *et al.*, 2013).

2.3.2. Handmade paper

The invention of paper made books possible and in one written by Studley (2014), explains the use of cotton rags, celery stalk, iris, gladiola, straw, wheat, cattail, hemp, bamboo, potatoes, reeds, beans, horse chestnut, marsh mellow, thistles and bluegrass as a raw material in paper making. With account to the history, it transcends from oracle bones, stone, clay and bricks, metal, wood, vegetation, bark of trees, parchment (animal skin as sheet) and then to vellum (calfskin, goatskin, lambskin), papyrus (aquatic plant), rags, bark, straw, wood, hemp, and other vegetative matter and finally refined to the modern-day paper. Bark was used in many cultures and writing paper was used as an aid or substitute for memory. Animal skin was made like a parchment and used for writing. Papyrus was used as paper in olden times, which was made by slitting and laying row of reeds

and placing the next layer perpendicular to the previous one. This was very widely used in Egypt. However, the inefficiency to use papyrus as books paved way to find alternative lightweight foldable papers. Ts'ai Lun, a Chinese court official is believed to have made the first paper using old rags, hemp, tree bark and fishnet during 105 AD. He reported this invention to Emperor Ho-ti and received the official patent for paper making.

The art of paper making however dates back to 200 years BCE. Samarkand, now called as India, produced paper by recycling waste textiles like gunny bag, fishnet, ropes, apart from utilizing the fibers from flax, jute, and other vegetable fibers. Since 2000 years, the craft is done in India and it has a great cultural significance attached to it. The tradition is passed from families of paper makers through bloodline and depending upon the creativity of the paper maker hundreds of variations could be possible (Hubbe and Bowden, 2009).

During the British period, Indian handmade paper making industry had a setback, due to the compulsion on importing mill made papers from other countries. The handmade paper was an idea of chemical scientist KB Joshi, who introduced paper made from wastes and suggested to M.K. Gandhiji (Hubbe and Bowden, 2009). The industry was a brainchild of Gandhiji, part of Swadeshi Movement, and was seen as a glory of India's cottage industry. He took efforts in revitalizing the industry and helped in gaining momentum, by encouraging and purchasing the handmade papers for his Ashram. It is believed that the master copy and draft of the Indian Constitution was believed to be made from papers, utilizing textile wastes. After independence the Khadi Village Industries Commission (KVIC), was on the list of crafts to be encouraged and promoted (S. A. and S. Banerjee, 2009).

Now, the Handmade Paper Institute of India, (Pune), is reported to manufacture 500 different types of paper which is exported to 75 different countries around the globe, including Germany, Sweden, Japan and Thailand. Cotton and currency waste are used as raw materials here to make the process fully eco-friendly. Eighty percentage of the products manufactured here are exported to various countries. The Kumarappa National Handmade Paper Institute (Rajasthan), is an economist body under the Khadi Village Industries Commission, Ministry of Micro, Small scale and Medium Enterprise. The major focus is exploration of

alternative raw materials for handmade paper making. Currently paper mulberry, sun hemp, anka, daphne are major raw materials apart from sisal, mentha, barkanda, bhimal, jute, baggasse and banana are involved in the production of handmade paper at this institute. They have recently taken the paper sheets into a mulching material or germination paper suitable for agriculture (KNHPI Handmade paper Unit_Profile, n.d.).

Handmade papers help to conserve resources and generate less pollution. Handmade paper is cheaper than virgin paper, reduce demand for wood, thereby no deforestation. Contrasting to the mill made paper, handmade papers has a unique texture and color, high tensile strength, burst and tearing strength and folding endurance and usually don't brittle in ageing process. Handmade paper uses less energy (Hari Muraledharan, 2010).

Agro-residues, annual crops, wild plants are the three different categories of renewable sources used in handmade paper making. China, India, USA, Mexico and Indonesia are leading producers of handmade papers. The statistical report unleashes the fact that, the demand for handmade papers is about 7.2 million tons, but the current production is 6.7 million tons only (Ghosh et al., 2009).

In the year 1953, there were 35 to 40 units, which have increased to more than 3000 units around the world. As per estimates 500 handmade paper making units are found throughout India, producing 50,000 tons of handmade paper and boards. The production has reached INR 250,000,000 and providing an employment for 50,000 people, mostly from the rural areas (Dwivedi, *et al.*, 2004). Traditionally used raw materials are highly priced, making it uneconomical. Due to this, there has been a significant drop in the export of Indian handmade papers. Now, exploring of new sources to make handmade paper is the major focus of institutes working on handmade paper (Kumar and Singh, 2013).

A very interesting study was reported (Takahashi, *et al.*, 2014) in converting hemp paper into a garment after surface modification using crumbling. Handmade papers can be made using one source and without any blends, for example the Japanese handmade paper is made from 100% bamboo fibers (Devi, *et al.*, 2007). Banana stem is made up of low lignin and high alpha cellulose, with an average fiber length and diameter. The whole part of banana pseudo-stem is found to have good

mechanical properties (Kongtud, 2011). Date palm leaf (DPL) has high cellulose than rice straw or baggasse and hence good quality paper with appreciable properties was possible from this. A study without addition of any natural or synthetic resin is experimented in making handmade paper.

The interview by Mamta Sharma, The Economic Times, 2014, discusses about the new opportunity for paper bags with the growing demand from mall and ban of plastic carry bags. The government of Haryana (India) implemented this ban on plastic carry bags under Section 3 of the Environmental Protection Act, with penalty of upto INR 25,000. This has shifted the focus of industrialists to invest and hold a market by shifting to production of eco-friendly carry bags. The bags will be tested for reusability, impact strength and weight holding capacity. (Muthu, *et al.*, 2013).

Nineteen branches of the Reserve Bank of India, every year stock up 10,000 tons of currency waste. This was briquetted but still the waste management is an un-resolved issue. Hence a study to convert the currency waste pulping using bio-enzymes was done. The data's conveyed that this paper is better than handmade paper made from mixed office wastes. There was increase in strength when hosiery wastes were added. The bags made from these papers are found to be an sensible replacement for plastic bags that are recalcitrant in nature, [Sunitha, *et al.*, (2009) and Khandelwal, *et al.*, (2011)]. Therefore, natural renewable and biodegradable papers and packaging materials which are cheap and obtained from non woody sources are highly recommended (Hossain, *et al.*, 2009).

TARA is a mini paper recycling unit in Birla Institute of Technological Studies, Pilani (India), sponsored by the University Grants Commission (New Delhi). Here a small group of rural women joined together and produced high-quality paper from recycling, paper wastes found and collected inside the University (Prakash, 2012). As a societal development project Nambisan (2010), used the weeds and agro-wastes in the production of handmade paper. Under the notion, "Kudumbashree", the investigator tried grouping women from self-help group and created awareness, by popularizing the technique of handmade paper among them.

Facts say that approximately 27 trees are cut down to make one ton of paper. Since 1992-0212, the increasing literacy rate and modernization has resulted in

increased consumption of paper from 1.5 to 7.5 metric tonnes (Saakshy, *et al.*, 2013). It is noteworthy to find a solution before the quantity gets unmanageable to recycle.

2.3.3. Wipes

‘Wipes are paper, tissue or non woven which when subjected to light rubbing or on friction help to remove dirt, dust or liquid from the surface, Rengasamy (2014). It is a sign of convenience and a product made popular as a result of increase in the living standards of people around the globe. The traditional pieces of cloth as handkerchiefs were replaced by tissue papers and now into a more functional product called wipes (www.india.org). In other words, wipes are materials to rub with, which are desired to be soft cleaning and expected to absorb and hold the medium into it (Szewczyk and Wisniewski, 2007). Now, this has become an important utility in everyday living which servers a just born baby to the huge industries. Even though there is a huge market prospect, frequent fall in prices, brand power domination, difficulty faced in maintaining the quality are problems faced by the wipes industry (The Analysis of Wet Wipe Industry, 2012).

The total demand of wipes in Asia/ Pacific region was forecasted to be 1.8 billion in 2011 with Japan and China as largest market holders. The market expanded form the baby care to personal, house hold, higher end applications in industries now (www.prlog.org). The demand for wipes in USA was \$1.9 billion in 2008 and was expected to rise 3.9% every year until 2013. The product share in the wipes industry hold the baby care wipes with 28%, followed by general all purpose industrial wipe with 17% market share, disinfectant wipes with 12%, medicated wipes with 7% and other wiping cloth at 26% market share (Edser, 2009).

The extremely quick, convenient kitchen wipes are materials used in houses to clean glass, wood, metal surfaces from dust, dirt and stains. In the existing green trends, one time use and throw away products are made from biodegradable materials so that they do not harm the environment when thrown after use (www.thehygienecompany.com). The leading non-woven manufacturers are shifting to manufacturing of flushable or degradable or compostable bio-based materials. An example is the famous American based company in California, ‘Clorox’, has added

cleaning wipes into Green works range of product list, that uses, natural household cleaning products (<https://www.clorox.com/>).

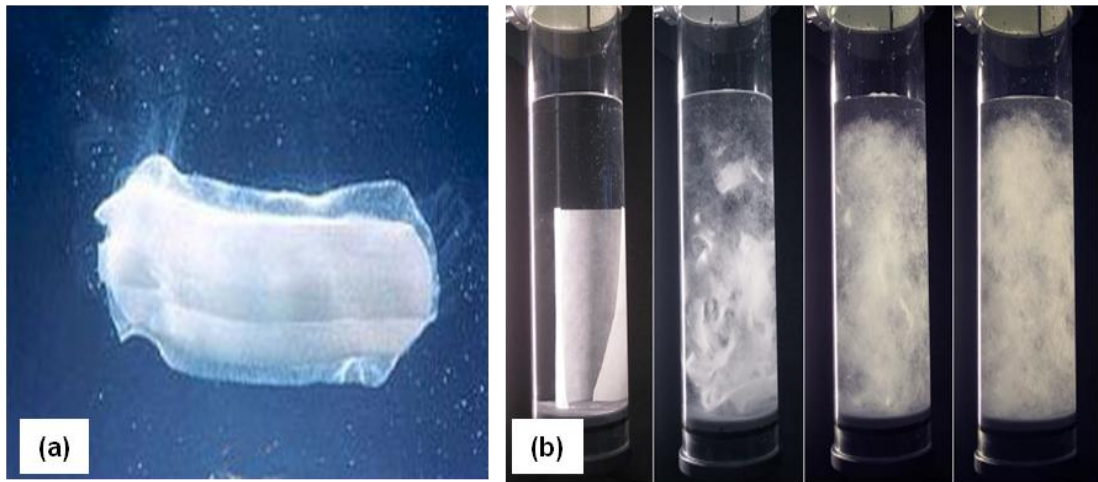


A picture of Big Wipes™ symbolising its action on paint and stains, also being skin friendly

Source: How Can Big Wipes Help?

Retrieved from: <http://www.sycamoreisr.com/en-how-can-big-wipes-help-8>

Sycamore (UK) and Dulux companies have jointly commercialized biodegradable heavy duty clean up wipes for industrial purposes. Big wipes™ are the most popular industrial wiping cloth found in the web (www.bigwipes.com). The YouTube video, “Big Wipes Industrial - The Ultimate 'Extreme' Hand Wipe” (<http://www.youtube.com/watch?v=7A9Iz9nw3ZE>), cannot fail to surprise the viewer seeing the demonstration about the Big wipes™. The narrator in the video applies different liquids like paint, varnish, glue, oil on flooring and on human skin and uses Big wipes™ to clean the mess at ease. The product is recommended safe on the skin and dermatologically tested, with antimicrobial finishing, that is compactly packed to be taken anywhere, [Big wipes (2013) and Big wipes (2012)].



Photograph (a) showcasing the disintegration of flushable wipes and (b) steps in disintegration test
Source: Articles on “Flushaway — Biodegradable Feminine Hygiene” and “Flushable wipes awarded quality certificate”

Retrieved from: <http://www.treehugger.com/bathroom-design/flushaway-a-biodegradable-feminine-hygiene.html> and <http://www.innovationintextiles.com/flushable-wipes-awarded-quality-certificate/>



Images of (a) flushable wipes and (b) a screen shot of an video file, showing the rescuer in action of removing the sewage block caused by flushable wipes in Bakersfield city, (California)

Source: “Flushable wipes blamed for sewage clogs” and “Bakersfield sewer systems keep getting clogged because of flushable bathroom wipes”

Retrieved from: <http://nypost.com/2013/09/23/flushable-bathroom-wipes-blamed-for-massive-sewer-clogs/> and <http://www.turnto23.com/news/local-news/bakersfield-sewer-systems-keep-getting-clogged-because-of-flushable-bathroom-wipes-092413>

Gearing up with the latest sustainability issues, the company has now introduced 'Green Big Wipes™', that are degradable and compostable. Thus it is clear that the market is buzzing with researches that focus on wiping cloths that are bio-degradable. The quantity of wastes send to the landfill is one of the largest threats on sustainability. Various pre and post consumer waste are converted into non-wovens. AIRSTEP™ which is made of recycling used fibers as carpet underlay. FOOLSCAP™ suspension files, made form recycling fibers, ALTFAB™ wipes made by utilizing the waste scraps from cotton garment making industry, Flip™ which is made by using denim waste into carry bag and as wrapping bags and Teijin™ made form recycling polyethylene fibers into a fabric again (Caulfield, 2009). Even though this technique in a great way reduces the textile materials from reaching landfill, the technique involves various protocols in preparation of the recycled fabrics. Cleaning, pre-preparation and size reduction is some of the protocols involved apart from the huge costs in installation of the required machineries.

The enormous leap after industrialization has lead to exposure of humans to various heavy metals through air, water and soil, a major reason for the invent of varied types of cancer. These carcinogens are minute and can enter human body through bare skin. Employees working in high-risk lead-related industry tend to transport lead dust to home through their dress, shoes and even vehicles points Yoshinaga (2014). The lead contamination in houses reduces the blood lead level of the child. Government popularized and recommended the use of wiping cloth in the form of electrostatic cloth, sponges, wet disposal sheets or electrostatic dry cloth in the mop heads (Lewis, *et al.*, 2012). Thus wiping can be tailored to a great extent in means of rescue and in maintaining good health among humans.

Disposable wipes, dry or pre-moistened wiping cloths, are replacing the use of old textile items as cleaning materials due to their convenience property and hygiene, (Das, *et al.*, 2005). Unlike the conventional cleaning methods, in the present-day situation, disposable cloth or pad or cloth wetted with a detergent-base have a huge market with increasing per capita income. Procter and Gamble in the year 1999, introduced the wet disposable cloth and currently about 75% of its manufacturing are quick cleaning products (Lewis, *et al.*, 2012).

In the next generation, flushable nonwoven wipes will be frontier in non woven materials (www.smithersapex.com/products/market-reports/flushable-wipes). Since incineration will be out of the possibilities to handle municipal solid waste also, there will be no landfill space to hold the disposal. They will have a very promising way ahead. Spun lace nonwoven made from wood pulp was designed to disintegrate in toilets without clogging the pipes. Rotary shaker table is used to check the responsibility and the flushability of nonwoven samples. It was found that the sample size, liquid volume critical factors, shaking speed and time were directly related to the disintegration ratio (Tang and Jin, 2012).



An image Eco Select™ Pre-Moistened Cleaning Wipes are 100% biodegradable in 21 days.

Source: All Purpose Wipes

Retrieved from: <http://stores.stuffonline.com/page/Stuff/PROD/380629.html>

Currently disposal issues and the anticipated problems in future are echoing around the globe. If we begin analyzing the issue, from a place that has smallest land area, the landfill related problems can be understood. It is important to see this issue in a global perspective to find sustainable solutions. Australia is the smallest continent in the world. Statistical report says, Australian babies use disposable nappies, upto three years of early life. When disposed off they create a huge threat with regard to contamination of ground water, release of harmful green house gases, soil leaching, menace associated with decomposing material and hence many researches are being done to produce flushable or compostable nappies (O'Brien, *et al.*, 2009).

With an increasing alarm on ecological legislation for waste disposal, in future the availability of land to hold wastes will be negligent. Scientists around the world show great interest in engineering textiles that are degraded or compostable. Among many of such products, ENVIRO GARD's flushable pads and liners from Eco-progress International Ltd, Atlanta (USA) is popular. It has been designed as an ultra-thin maxi pad made using super absorbent polymers and waste cotton, which disintegrates when flushed into toilets without clogging the pipes and also tested to be degraded when thrown off in landfills.

Non woven made from recycled wool was tested for it oil absorption property by testing on diesel fuel, crude, base, vegetable and motor oil from water. The fabricated sheets were tested and results suggest the sorption capacity was high and the material has excellent buoyancy after 24h of sorption and also reusable. (Radetic, *et al.*, 2008).

Poultry waste and cotton waste were taken to be converted into handmade sheets and the results were compared with handmade sheets made from standard bleached eucalyptus hardwood fibers. It is believed that keratin has a natural affinity to degrade when mixed with cellulose rich cotton linters. The sheets were prepared by using the (SOP 2016) of Kimberly Clark involving conversion of raw material into slurry and addition of wetting agents and extraction of papers in the desired GSM. The specific volume of the handmade sheets made of keratin/cotton was found to be good compared to the handmade sheets from eucalyptus. There was four fold in case of air permeability and no significant difference in absorbency capacity in the

keratin/cotton papers in comparison to the handmade sheets of eucalyptus. The tensile index, however was high in the handmade sheets from eucalyptus only (Boshi, *et al.*, 2010).

Due to the outstanding absorbency property of cotton fibers, they are greatly used in the production of nonwovens (Edwards, *et al.*, 2013). Raw cotton fibers with a significant amount of wax content are widely used in the production of non-wovens. This non-cellulosic component creates a blockage during the hydro-entanglement technique for production of non-wovens. Traditionally, caustic soda was used to remove the wax content from raw cotton. In order to eliminate chemicals, an alternate and eco-friendly technique was used namely, Atmospheric-pressure Plasma Treatment (APT). In this technique, gases are used and approximately 85% of wax content is removed. This helps in increasing the hydrophilicity, however, intense treatment is proven to weaken the produced cotton non-wovens (Jinka, *et al.*, 2014). Cotton based nonwoven are already in market since the late nineties, (Talukdar, 1994) and is still on top priority list. Hydroentanglement uses water as a dispersion medium and the fiber gets dissolved into it. Plasma being an emerging technology and hence cost effective that will add on the costing of the product. Using willow waste and converting them into wiping sheets will be a more practical solution for industries that suffer with stocking of willow waste. Since further investment in installation of costly machines, will be taken as a recommendation, low investment, eco-friendly and profitable business solutions will do the needful.

It is quite evident that there is a need to manufacture unique low cost wiping materials. With this as an objective, melt blown synthetic thermoplastic microfibers were treated with a wetting agent, pattern bonded to incorporate strength and abrasion resistance, while absorbing water and oil without streaking (Meitner, 1985). This is the existing technique known to industries, but processing of organic wastes into wiping cloths and incorporation of binders and adhesives will aid in creating an eco-friendly wipes. In this scenario, an experiment to convert cotton waste rich in cellulose (absorption) and lignin (strength) into a bio-degradable wiping cloth, will pave way for more researches in this way and refinement of successful product in a commercial scale.

2.3.4. Composites

Composites consist of two or more fibers dispersed on a matrix. The combination of materials creates a new property distinctive from the original raw materials used (Taylor, *et al.*, 2013). Natural fibers have been fabricated for composites since 1908. Now, they have been replaced by traditional thermoplastic polymers in automotive applications with polypropylene being the most commonly used matrix material (Fowler, *et al.*, 2006). These are not eco-friendly and required exploration for renewable and eco-friendly alternatives. Hence various natural fibers like flax, cellulose, jute, hemp, straw, switch grass, kenaf, jute, sisal and bamboo are analyzed for its performance as composites (O'Donnell, *et al.*, 2004). Lignocellulosic wastes along with starch matrix are found to produce a biodegradable matrix, with low cost, low density, renewable and sustainable bio-composites (Fakhrul and Islam, 2013).

Compared to the traditional materials, natural fiber composites are light in weight, low in density, low manufacturing cost, resistant to corrosion, resilient, translucent good mechanical properties and efficient in construction (Ren, *et al.*, 2014). The engineered composites are good alternative in strength and stiffness, and find a significant application in parts that need to designed light weight. They offer freedom in scaling and optimizing the properties of a particular component in a specific application (Edith, 2014). Due to the structural damping properties, these find an appropriate place in automotive industry (Banerjee, *et al.*, 2013).

Many studies based on the combination of natural fiber with synthetic polymers to produce composites of dual property, in terms of semi degradable and ample strength are performed and reported successful. Studies report that hemp/ polypropylene composite replaces 30% glass fiber reinforcement with 65% hemp fiber, 3.07 million tons of CO₂ emission, 1.19 million m³ of crude oil can be saved by substituting 50% fiber glass plastics with natural fiber composites in the automobiles in North America (Muhammad and Mohini, 2003).

Various studies on exploring Fiber Reinforced Polymer Composites (FRPC), which combines natural fiber and synthetic polymers, tested the bio-fibers for different chemical treatments. The first large-scale use of natural fiber based composite for auto mobile exterior was designed by Daimler Chrysler's Composite

Space tyre carrier on a Mercedes Benz A class mini car, banana fiber has replaced polypropylene matrix for reinforcement (Tudu, 2009). Light and tough kenaf fibers were mixed with polypropylene and laminate composites suitable to be used in automobile parts were engineered. These light weight bio-composites were tested and found to improve the fuel consumption due to its light weight property and also reduced the amount of material required (Shibata, *et al.*, 2006).

Green composites were fabricated using pineapple leaf fiber and soy-based plastic. The effect of alkali treatment on the thermal properties of India grass fiber, reinforced with soy protein and pineapple leaf fiber reinforced with natural rubber and jute fiber were studied and reported. Pineapple leaf fibers were made into hybrid composites (Reis, *et al.*, 2011). Lignocellulosic wastes like pineapple leaf fibers (PALF) are inexpensive, abundant and an excellent choice to synthetic fibers. They are tested to have good mechanical properties (Arib, *et al.*, 2006). Pineapple fibers are made into non woven mats with polypropylene as matrix.

Corn gluten meal was mixed with wood and made into fiber reinforced composites. Such bio-based polymers (produced from natural source) are ideal to produce disposals and which will degrade when disposed to landfill after its life. When used along with synthetics, they help in cutting the cost down in addition to give more mechanical strength to the prepared material (Beg, *et al.*, 2005).

Studies on the thermal behavior and fire resistance property of bio-composites with unsaturated polyester and modified acrylic resins were tested. The reports suggest resistance to temperature was more using natural composites. Flax, with low lignin had the best thermal resistance. Jute fibers showed fast spreading of flame but low smoke emission (Manfredi, *et al.*, 2006).

Plant fiber reinforced thermoplastic composites has found a major hook in the building and automobile industries. Wheat straw, baggasse and corn stover are explored for similar reasons. The research suggests the capacity of fiber composite to perform effectively as a reinforcing material. High degradation temperature of the wheat straw fibers (above 200° C), that makes it thermally stable to be used with thermoplastics like polyolefins (Sain and Panthapulakkal, 2006). The adhesive property of tamarind seed was combined with cellulosic rich sisal fiber and

bio-composites were made. False roofing and room partitioning were few suggested applications using the prepared bio-composite (Veluraja, *et al.*, 1998).

The drawback of such natural fiber composites is high variation of properties during large scale production, which is a drawback in engineering items for industrial applications (Leao, *et al.*, 2010).

2.3.5. Briquette

The cotton plant residues were ploughed into the soil after cultivation in Arizona which on degradation affects the soil structure and results in the invasion of pink boll worms. As a solution to this problem, the cotton plant residues were mixed with pecan shells to make commercially viable briquette. The ash content was low in this compared to the briquettes made from waste paper (Coates, 2000). Biomass can be converted into a densified solid bio-fuel for briquetting and can be used in domestic and industrial purpose in the furnace boiler and kilns (Pandey and Regmi, 2013).

Briquette is a process in which the raw material were compressed under high pressure and molded into a desired shape. Preconditioning and particle reduction are the basic steps in briquetting (Kers, *et al.*, 2010). Briquetting reduces the volume of the raw material by ten times, thus simplifying the storage space and transportation ease. Especially if the selected raw material is flammable, briquetting is an effective solution to reduce the risk of fire hazard. Screw press, hydraulic press and mechanical press are the three techniques to make briquettes (Nielsen, *et al.*, 2009).

The increase in population resulted in huge demand for fuel sources and briquettes made from bio-wastes can be an alternative to kerosene or fuel wood. Such biomasses are both bulky and low in density. They are uneconomical to process, where storage and transportation is also extremely difficult (Adeyemo, 2014). In the present situation the demand for fuel is 213.4×10^3 m tons while a reduction in supply is expected to about 28.4×10^3 m tons by 2030. Fossil fuel, coal, crude and natural gas are inadequate and 80% of energy sources are expected to be depleted by 2030. On discouraging the use of firewood and encouraging the use of new fuel sources, the future can be

safe (Davies and Abolude, 2013). It is estimated that with the increased use of briquettes, there will be reduction in the consumption of fuel wood (Oladeji, 2011).

The commonly briquetted materials are saw dust, cow pea chaffs, corn cobs, groundnut, melon shell, rice husk, paper waste, coco husk, water hyacinth and banana peel. The density of biomass is observed to increase by five times in the process of briquetting (Oroka, 2013). It is found that the lignin content, a natural binder in plants, greatly affects the quality of biomass briquette (Tumuluru, 2014) and studies exploring the possibilities to use various lignocellulosic wastes for briquette have been done worldwide (Akay and Jordan 2011).

Biomasses are hygroscopic but tend to absorb and desorb moisture from the surrounding atmosphere during storage. Limited amount of moisture is important for gasification. Commercially available briquettes have a moisture content of 40-85%, (Singh, 2004). Low moisture materials perform effectively as fuel sources. Wood and paper wastes were added with plastics and municipal solid waste and the strength was found to have increased from 1.5 – 4.5% (Kers, *et al.*, 2010).

Addition of selected binders helps in increasing the rate of burning the physical properties of the prepared biomass briquette. Five percent of starch with the by weight of the raw material is found to be effective (Osarenmwinda and Ihenyen, 2013). The hardness of the briquettes determines the mechanical properties of the finished product. Increasing die pressure and dwell time is found to have increase the quality of briquettes. Die pressure above 600 Kpa for rice straw, 500 Kpa for banana and 700 Kpa for teak leaves gave durable briquettes and corresponding density were 207.48 kg/m³, 179.69 kg/m³ and 227.53 kg/m³ respectively (Saikia and Baruah, 2013).

The combustion rate, ignition time and temperature are important in determining the thermal properties of briquettes. Heat is transcended inside the briquette by thermal conduction, convection of heat by flow of volatile gases and radiation within the pores inside. Increased compression pressure, binder ratio and decreased particle size, reduces the burning rate but gives elongated ignition time of briquettes (Davies and Abolude, 2013). The resultant burnt ash is studied to be an effective fertilizer (Borowski, 2011), thus marking the life cycle of the organic waste clean and safe.