HEMP PRODUCTION

Review of Literature with Specified Scope

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Abstract

A review of literature published between 1854 and 2018 on the processing of hemp for textile production, with a specific focus on decortication, softening, and spinning, plus additional notes of the advantages and disadvantages of cottonizing and chemical processing. The resurgence of hemp technologies creates a level playing field; opportunities for both large, vertically-integrated corporations and small horizontal or cooperative business to claim ownership over new methodology in hemp processing. The baseline process presented is relatively straightforward up until softening, when a choice must be made between chemical or mechanical softening. Our environmental ethics say mechanical unless we can find a low-impact chemical method.

Introduction and Background

There is an incredibly rich history of the mechanical processing of hemp leading up to the turn of the 18th century. A wealth of information was published or patented between the 1850s and the early 1930s, with the jewel of the collection being Modern Hemp, Flax, and Jute Spinning and Twisting, published in 1907 in London by Herbert Carter. The book is a valuable resource to the modern hemp farmer, complete with detailed descriptions of the entire production of hemp, from proper planting methods to final spinning, and machine specifics for each step of the process. This paper aims to give an overview of Carter's work, with notes from additional literature from that period along with current publications. Those interested in further specifics, especially on machine detail, are encouraged to refer to Modern Flax, Hemp, and Jute Spinning and Twisting.

Between 1930 and 1994, there were very few patents registered that specifically addressed hemp processing. We discuss the events that contributed to this lack of interest in and accessibility of hemp fibers in the following section. In the mid-1990s, hemp production again became of interest and value with most research and patenting being done in China, where the focus on improving spinning methods. American research regained footing in the mid-2000s, leading up to a federally-condoned, state-run pilot program in 2014 that allowed 19 states to plant hemp as an agricultural experiment. In 2018, the Farm Bill reclassified hemp as an agricultural commodity, rather than the controlled substance that it had been mislabeled as for decades.

Brief History of Fiber Processing

Hemp hasn't always had the controversial reputation that it holds today. It was such an important agricultural crop in England during the sixteenth century that King Henry VIII passed an act in Parliament that fined farmers who didn't grow the crop (Blair et al., 1991). In the United States, George Washington grew it on his farm for use in cloth, net, ropes, and sails (Mount Vernon Archives). Most American hemp was harvested and processed by African-American slaves; it was often retted and hackled right in the field it had grown in and then carded, spun, and sometimes even woven into rough cloth or twisted into rope on the same plantation (Thomas Edison House Archives). In the early 1900s, Kentucky produced three-quarters of American hemp (Carter, 1907). The dust created by the extremely physical process caused respiratory disease in those exposed to it. In the Jim Crowe South, hemp processing was the hardest job on the plantation, often used as punishment.

In the late 1800s, a phenomenon known as "mill hills" developed in the U.S. and abroad. To power their machines, mills were often situated near a river or on a hill to capture wind power. Mill owners constructed villages to house their workers. At the turn of the century, 95 percent of families working in the textile industry in the southern United States lived in factory-run housing (Leloudis, 1986).

A mill hill or village might be made up of a superintendent's residence, a group of small single-family homes, a church, a schoolhouse, and a company store. These facilities attracted laborers but also provided owners a way of exercising control over their workers. In 1910, investigators from the

United States Bureau of Labor noted that "all the affairs of the village and the conditions of living of all the people" seemed to be "regulated by the mill company. Practically speaking, the company own[ed] everything and control[led] everything, and to a large extent control[led] everybody in the mill village" (Leloudis, 1986). As textile production became more vertically integrated, many of these mills closed and neighborhoods built around them declined.

At the start of the 20th century, Italy produced the most and the finest hemp globally: about 50,000 tons a year, valued around 38 British pounds per ton. Russia—or the Soviet Union—was a close runner-up, producing as many as 40,000 tons of hemp, sold at only 22 British pounds per ton. Most hemp markets have three grades of quality, often based on color and delicacy, but the Russian market had a full sixteen grades based on small variations in hue and quality (Carter, 1907).

In 1937, Congress passed the Marihuana Tax Act, which regulated the importation, cultivation, possession, and distribution of marijuana. Agricultural hemp was caught up in this legislation, making commercial production less economically viable. Without the finances that the industry had previously provided, scientific research on hemp diminished and nearly disappeared (cbp.gov).

The Marihuana Tax Act was briefly lifted during WWII to encourage farmers growing hemp to be used for ropes and sails for the U.S. Navy, but production decreased rapidly after the war (Higdon, 2018). From the 1950s through the 1980s, the Soviet Union was the most significant global hemp producer (Carter, 1907). In 1970, Congress passed the Controlled Substances Act, which put marijuana on par with narcotics and effectively made it illegal to grow hemp in the United States. Despite the legislation, "ditch weed" grew wild in the fencerows of American farmland (Higdon, 2018).

When the U.S.S.R. collapsed in the 1990s, global hemp production declined dramatically. The 20th century left hemp processing technology virtually frozen in time, unable to advance along with other textile processes. Today, hemp is finally re-emerging as a fiber with a variety of uses that go beyond rough burlap and rope. For farmers, producing hemp requires far less water and pesticides than cotton production, and provides a variety of consumer benefits: greater moisture permeability and wicking effect than cotton, resistance to wrinkling and ultraviolet rays, anti-static, non-clinging, and antimicrobial (Wu et al. 2009). Additionally, hemp has the highest heat ratio of all commonly-used fibers, making it a superior insulator (Mahapatra, 2018).

Decortication Technologies & Processes

Hemp is an annual plant, sown in the spring and harvested in the fall. It is coarser and taller than linen, with stalks as tall as fifteen feet high. The more densely sown, the longer and straighter the stems grow, with fewer branches. The pollen-bearing flowers, or staminate, and the seed-producing flowers, or pistillate, are on separate plants, leading to the common parlance referring to male or female plants. Hemp is harvested when staminate plants are flowering. The stalks are cut or pulled up in handfuls, keeping the root ends even. The stalks are separated according to length to improve ease of processing.

Decorticating, or separating the fibers from the rest of the plant, involves rippling, retting, grassing, and scutching. Rippling is the removal of the seed capsules from the stems by drawing them in handfuls through a very coarse hackle.

Retting

Hemp is a bast fiber, meaning the fiber-producing part of the plant is made up of strands that run the length of the plant, surrounding the woody core of the stem and covered by a thin, gummy varnish that creates the very delicate "bark" of the plant. Pectin adheres the fibers to the air-filled, woody core. Retting dissolves both the exterior varnish and the pectin by fermentation created from repeated wetting and drying. In humid areas, hemp maybe be dew-retted: the stalks spread thinly and evenly over a close-cut field. Prolonged exposure to sunlight and nightly dew dissolves the pectin. Dew retting requires ten to fourteen days, depending on temperature and humidity (Carter, 1907).

Water retting is a practice that imitates dew retting, using the Legrand process. The water used must be clean; muddy water turns the fibers dull and grey, and iron in the water creates a "foxy brown" (Carter, 1907, p. 4). The Legrand process involves dipping bundles of hemp stalks into a series of water tanks referred to as scouring, retting, and rinsing tanks. Retting bacillus dissolves the pectin and produces a mucus-like substance that must be washed away, or scoured so that lactic acid doesn't develop and prevent the retting fermentation. The stalks are bundled upright and packed into a crate that is repeatedly raised and lowered in the scouring tank to wash away slime produced as the pectin of the plant dissolves.

The crate is then introduced to the second tank of fresher water for additional retting. It is raised and lowered several times (drying somewhat between dips) before being washed and rinsed in the final tank. Fresh water flows through a filter into the rinsing tank, then is siphoned from the rinsing tank to the retting tank, and from the retting tank to the scouring tank, so that water is always flowing through the system. This style of water retting benefits co-operative retting, in which several hemp farmers set up retting tanks together and process their harvests successively (Carter, 1907).

Water retting can be an environmentally taxing process, due to the high quantity of fresh water required and the potential for wastewater pollution. Enzymes have the potential to offer a more environmentally acceptable retting process by simulating the natural microbial retting process in a controlled way that uses less water. The cost of the necessary enzymatic solutions seems to be accessible, making enzymatic retting an advantageous method (Mareck et al., 2008).

Grassing and Scutching

After draining, the hemp is spread thinly and evenly over a close-cut field or on wire racks exposed to sun and air to dry or be grassed. Once dry, the woody core becomes brittle, and the stems are rolled between heavily-fluted rollers, breaking the core into dust in a process called scutching. Historically, dry stalks were beaten by hand with a wooden paddle. Scutching by hand was one of the hardest jobs on a plantation, often given as punishment to slaves.

In 1912, Frank O'Neill, Jr. of Paris, Kentucky, invented a new hemp brake, the machine for breaking or separating fiber from the woody core of hemp. This new and improved hemp brake broke the woody portion into small pieces, separated it from the fibers, gathered the broken pieces and the wood dust and discharged them from the machine separate from the fibers (O'Neill, 1912). This decorticator, a relatively cheap piece of machinery, replaced what was easily identifiable as the worst job on the farm and limited the handler's exposure to lung-damaging dust.

Softening Technologies & Processes

Once decorticated, raw hemp fibers are baled and stored in a cool, dry place out of direct sunlight before being softened. The majority of softening is referred to as hackling because the harvested stems run through a series of "hackles:" instruments with steel pins used to comb out fibers. Piecing out is the splitting of strands of hemp fibers into handfuls suitable for hackling while keeping the root ends square and even. Creating small pieces of fibers raises labor cost but produces excellent thread under otherwise ordinary conditions. Larger pieces mean cheaper but imperfect hackling. The handfuls are first fed into the straight-fluted rollers of a hemp-softening machine, which move in both directions. The forward motion is greater than the backward motion, allowing the stems to pass through the machine after being thoroughly softened. Any short, coarse, or broken fibers that dislodge during processing are referred to as tow. Tow can be collected, re-hackled and prepared for coarser spinning or technical uses such as insulation material.

Hackling

Hackling uses three tools: a hackle, a ten, and a switch, each made up of steel pins set in a plank. A hackle is a beach plank 1¾" thick, 16" wide and 5" long, set with eleven rows of five 7" pins. A steel touch pin about 2" long is set in a block and bolted to the plank, to the left of the hackle. A ten is finer than a hackle and is made up of 17 rows of 26 4½" pins, each row being about 7" long. A switch is the finest of the three with 22 rows of 90 2" pins set in a beach plank about the same size as that of a ten.

Wrap one piece around your right hand and spread the end with your fingers and thumb evenly across the hackle. Pull the piece through the hackle twice to open the root end. Twist the piece around the fingers of your right hand and then loosely around the touch pin of the hackle. With a sharp tug, break or pull off any loose or irregular fibers that remain and deposit them in the hackle. Turn the piece and treat the top end similarly.

Repeat this process on the ten. Spread the roughened pieces as flat as possible over the ten, root end first. Grasp the piece tightly in the middle and pull it repeatedly through the ten, then rotate and repeat so that both sides of the root are hackled. Switch your grip and repeat with the top end. Run both sides of both ends through the switch in the same manner. To finish, hold the piece between the fingers of your left hand and wrap some of the fibers from the root end around the piece. Lay down the wrapped pieces to build a firm bunch, with an end weight of about twenty pounds (Carter, 1907).

Carter states that hand hackling, using the three tools mentioned above, creates greater yields, especially in small mills. He then goes on to explain in detail the specifics of hackling machines that could be useful to larger-scale operations. In a simple hackling machine, pieces are screwed into holders, two steel plates (approximately 4" by 10" each) bolted together by a coarse screw and secured at the back by a lock nut. The addition of a pair of washers holding a ring of steel bearings can create greater power and less friction. The top washer is held in place by a cover that is riveted to the plate. The washers allow for perfectly-tightened holders, which increase the efficiency of the hackling process. The plates are lined with corrugated rubber and thick flannel or felt, which holds the fibers firmly and prevents individual fibers from being pulled out (Carter, 1907).

Spinning Processes and Technologies

Preparation for Spinning

Carding involves combing fibers and drawing them into long strips known as sliver (rhymes with "diver"). Carding effectively combs fibers of long or short staple length, whether they are already running parallel or have yet to be untangled. (Staple length refers to the length of an individual fiber; hemp and flax are long staple length fibers, whereas wool and cotton are short staple length fibers). In the late 1800s, the spinning of hemp required fibers to be drawn out by hand from the mass; this labor-intensive practice still produced a rough yarn, useful for cordage, sails, or burlap.

Shortening the length of the fibers, or cottonizing, can increase the ease of spinning. The sliver is held under tension between sets of draft rollers, which operate at successively increasing speed to break individual fibers into staple lengths and then form them into roving. According to Carter,

"The roving frame is one of the most important and interesting machines in the spinning mill. It is important because badly-made roving can never make good yarn. It is interesting on account of its winding and differential gears, which is the most ingenious and beautiful piece of mechanism."

The roving frame gives the sliver a slight twist, about 180° per inch, and winds it onto a bobbin. The differential gear that Carter so admires allows the bobbin to wind slower at the start and faster as the process continues because the length of roving needed to circumnavigate the bobbin grows as it fills (Carter, 1907).

In a "Gypsy" machine, presented by Daniel Treadwell in 1883, roving feeds into a machine through a hatchel, or wide-toothed comb, set on a belt and into a set of rollers. This hatchel allows each fiber to move forward without tugging any other fiber along with it. The rollers are weighted so that when there is not enough fiber between them, the hatchel moves forward and introduces more fibers to the rollers. When the yarn becomes the required size, the hatchel recedes.

In this method, challenges can arise when the sliver breaks; the leading piece is pulled on by the rollers, but the remaining piece is still within the rollers and no longer being pulled forward, resulting in a rough or snarled surface. In 1947, Klein Norman Edward and Milliken Research Corporation patented a process for converting fibers into long, uniform yarns, free of soft or nubby areas. The Milliken process traps the free ends of the broken fibers by feeding a sliver between a pair of tight rollers and a pair of belts that move at a higher surface speed than the rollers. This process draws out and breaks the short or ragged filaments that have broken off between the rollers and belts. (Edward, K. 1946).

Wet Spinning vs. Dry Spinning

After being softened, combed, and twisted into roving, the hemp is spun into yarn by wet or dry spinning processes. Dry spinning reduces labor and material cost and produces coarser, stronger yarn. In general, wet spinning produces the most delicate yarns, during which the fibers pass through a bath of hot water before being spun. This method softens any remaining pectin and eases the drawing out and separation of fibers, in turn producing a finer yarn (Mahapatra, 2018).

In 1985, a German group perfected the production of hempen yarns with a fineness of below 200 tex. Tex, commonly used in Canada and Europe, is a unit for measuring the linear mass density of yarn, equal to the weight in grams of one kilometer of yarn. (A denier is a more common unit used in the U.K. and U.S., equal to the mass in grams of 9,000 meters of the fiber. Seemingly arbitrary, the denier is based on the weight of silk: one strand of silk weighs approximately one denier; a 9,000-meter strand of silk weighs about one gram.) The process involves shortening the fibers to a length of 120mm to 300mm before softening, before mixing with cotton or wool, blending the fibers uniformly together, letting the fiber pulp rest, and then carding, refining, and spinning (Boris et al., 1985).

In 1996, a Chinese group filed a patent for a process in which scutched hemp is degummed and cottonized to produce fibers around 700 mm in length before being very finely carded. This process reduces the nubbiness of the final yarn and removes any short or ragged fibers before spinning (Wang et al., 1996). Afterward, the roving can be boiled in caustic soda for refinement, then bleached with hydrogen peroxide (Mahapatra, 2018). The finished roving has high spinnability and can be used to create high-quality, finely-spun hemp yarn (Wang et al., 1996).

Notes on Chemical Processing vs. Mechanical Processing

Most of the methods described above are mechanical processing, wherein fibers are separated, softened, and prepared for spinning by a series of machines or hand tools. Around the world, the process of preparing hemp has been industrialized, introducing chemical methods with the intention of increasing yield and decreasing costs. Chemical retting requires high temperature and pressure conditions, which can damage fiber strength and necessitate expensive, specialized equipment. Microbial and enzymatic degumming by restriction enzyme makes the process difficult and costly to complete; however, the simple, physical retting process described previously in this paper does not produce hemp fiber fine enough for clothing that is entirely comfortable to wear. As such, chemical processing is the standard contemporary method, although it has a more significant negative impact on environmental health.

In 2009, another Chinese group filed a patent for a process for preparing finer hemp fibers with reduced environmental pollution. The process involves chemical retting, after treatment, stamping, oil feeding, softening, humidification, stowing, and mechanical opening. The chemical retting involves adding hydrogen peroxide, alkali metal silicates, urea, and a penetrating agent to water and stirring until uniformly dissolved; adding bunches of hemp; heating, and then washing with clear water. The process is repeated twice more, as with mechanical retting. This method can prepare extremely fine hemp fibers and creates lower environmental pollution than other chemical processes (Wu et al., 2009).

Notes on Cottonizing and Non-Cottonizing

Cottonization is the process of turning long-staple fibers, such as hemp, into the texture and consistency of cotton (a short-staple fiber) so that they may be spun and knit on cotton-specific systems, which are more prevalent and less expensive than bast or long-staple machines. Through a process called elementarization, cottonization removes all pectin and lignin, leaving only single hemp fibers, which are then cut or trimmed to between 25mm and 40mm (lengths manageable by short-staple machinery). However, pectin and lignin give hemp its strength and durability, making the spinning of completely isolated fibers rarely possible. Therefore, cottonizing requires a degree of moderation, as total elementarization diminishes spinnability and insufficient elementarization lowers the quality of the yarn, leaving it too coarse for textile use.

In a 1995 article for the Journal of the International Hemp Association, a German team referred to the practice of "steam exploding," originally introduced in the 1930s and used in other fiber-based industries such as paper-making to separate the elemental fibers and dissolve pectin. In the steam explosion method, steam penetrates the space between fibers of the bast fiber bundle. In this way, pectin binding the fibers to the woody core is elementarized "softly" and made water-soluble, then removed by subsequent washing and rinsing. Trials have shown that fibers that have been steam-exploded are suitable for processing on cotton-spinning machines, primarily when used in the production of durable but soft fabric, such as denim (Nebel, 1995).

Modern cottonizing methods combine enzymatic retting, mentioned previously, with the effect of ultrasound cottonization to obtain high-quality cottonized hemp fibers that produce fine yarn. Ultrasound causes cottonization by weakening the pectin and lignin that bond individual hemp fibers, or elementary fibers, to each other and the woody core. Ultrasound cottonization reduces the environmental impact of the standard process by reducing energy consumption, the quantity of chemicals required, and treatment duration. Even without bleaching, fibers produced through ultrasonic cottonization are soft, lustrous, and of a light beige color. When exposed to ultrasound while in a bleaching solution, fibers can be bleached simultaneously with cottonization (Andrassy et al., 2005).

Conclusion

Despite the lack of funding and the apparent lack of interest in the production of hemp fiber over the last eight decades, the technology available to small- and large-scale operations has improved dramatically in recent years. Researchers around the world are developing more efficient, cost-effective, and sustainable methods for preparing hemp fibers for spinning, knitting, and weaving. Most technology benefits only larger-scale producers, but there appears to be a widening variety of options available to smaller or co-operative farmers and producers, including methods that reduce the environmental cost.

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