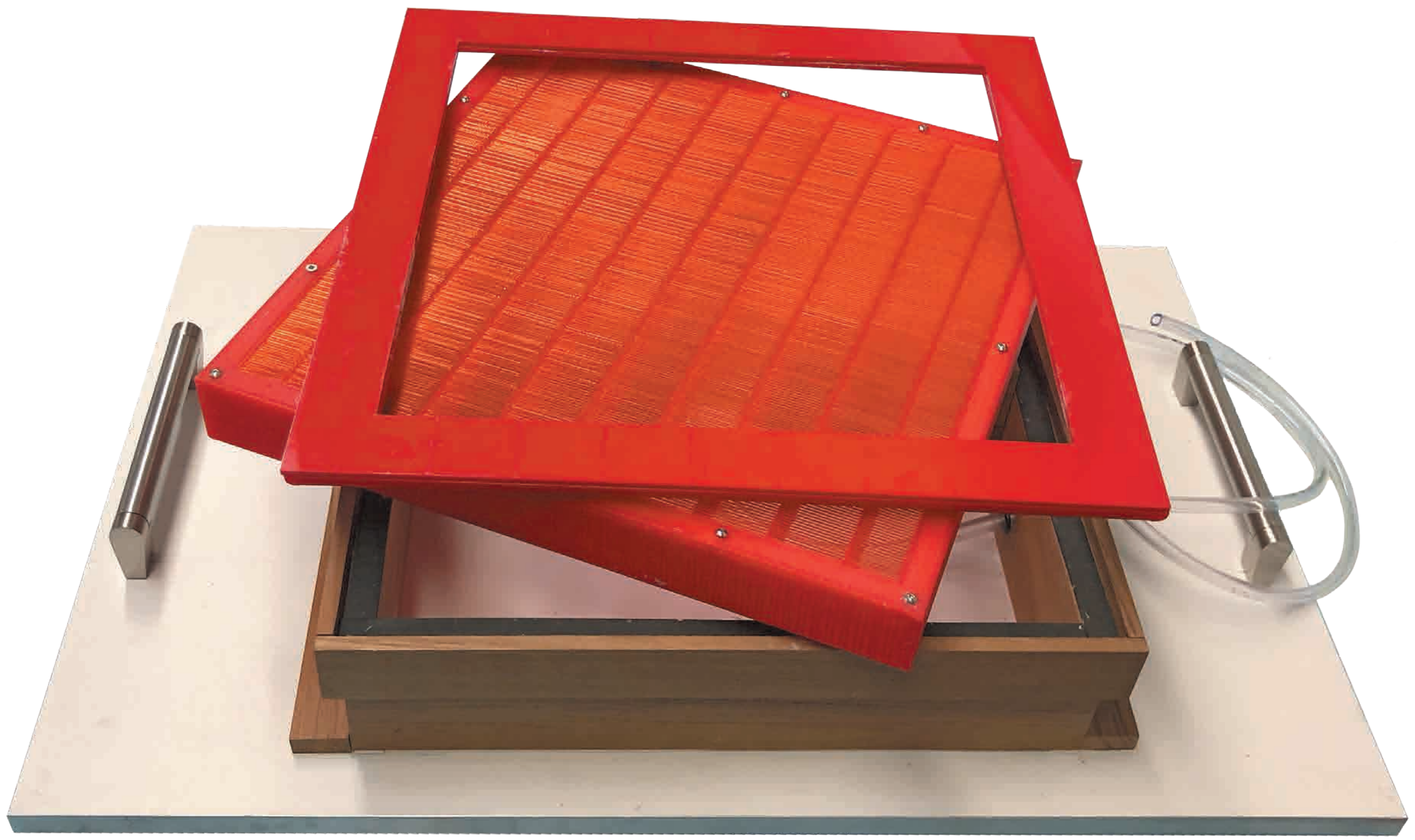
DETERMINATE HAND PAPERMAKING

Techniques for predetermining & making paper of known specifications and qualities

Donald Farnsworth



Leaf casting apparatus with removable mould and deckle (see p. 73)

Cover image: *thin-profile book leaf caster and book stand/support (see p. 113)*
Back cover image: *determinate leaf casting apparatus (see p. 73)*

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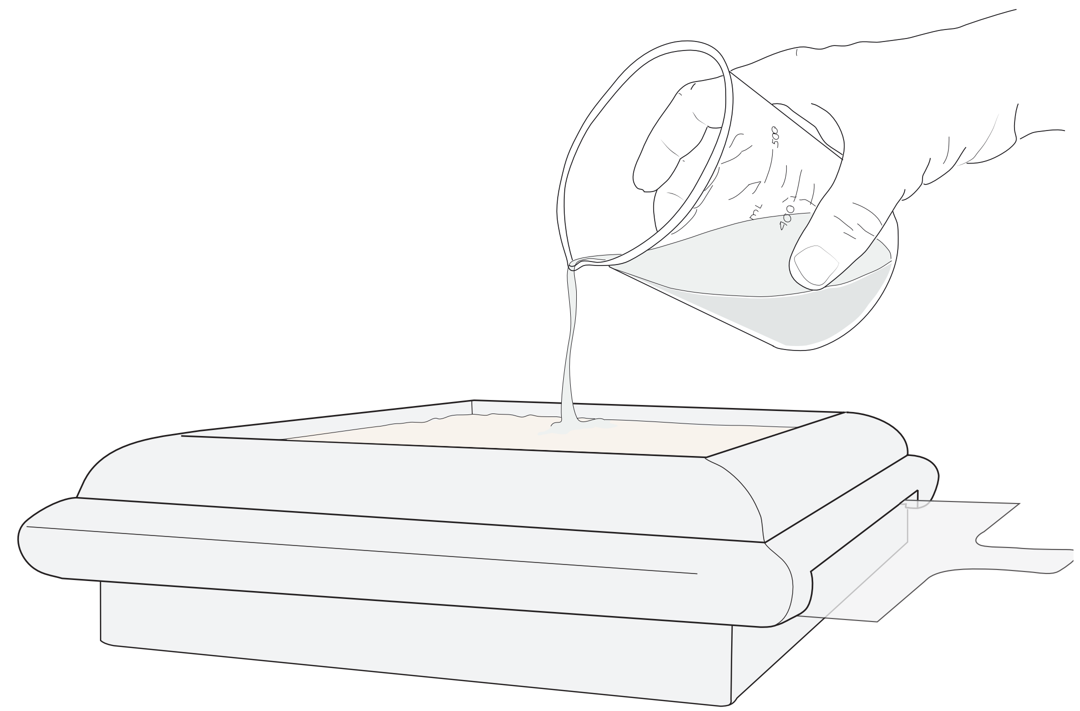

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with Nick Stone

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Donald Farnsworth

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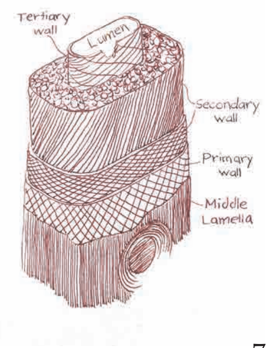

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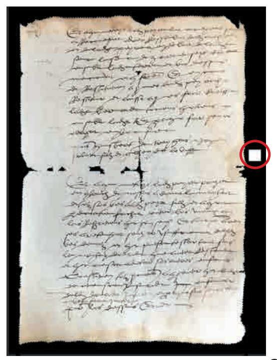

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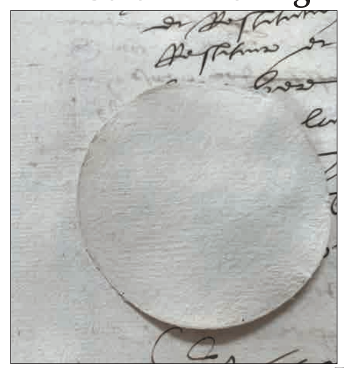

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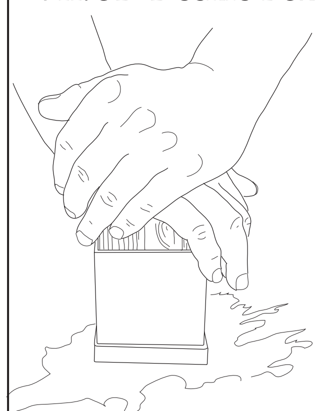

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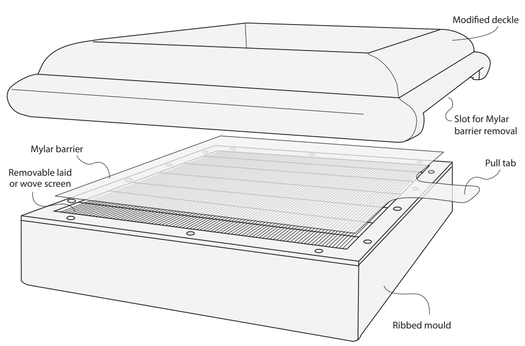

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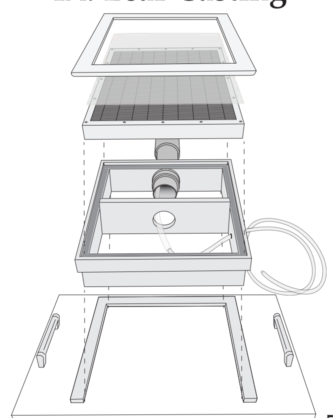

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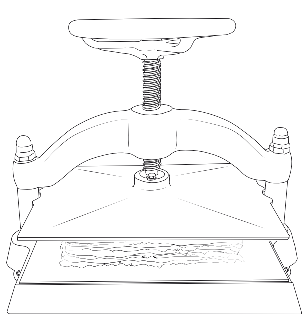

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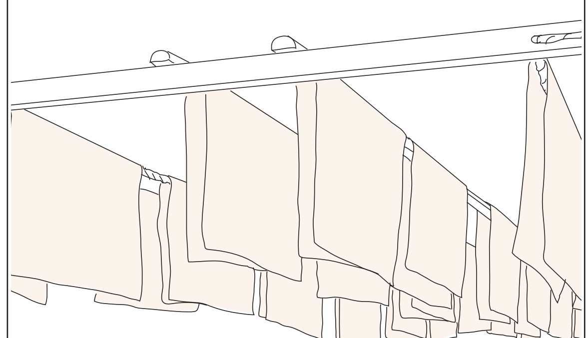

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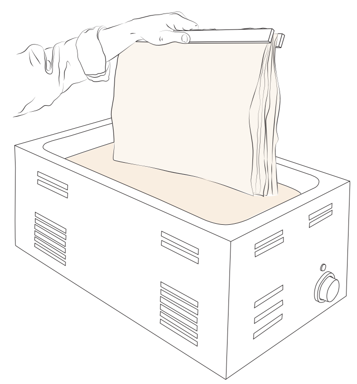

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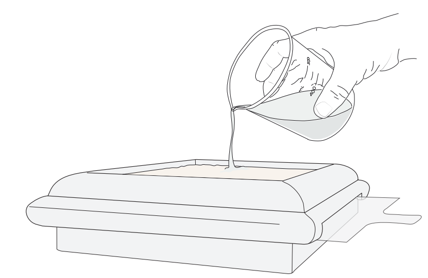
Introduction

Determinate paper refers to the production of a sheet of handmade paper that reliably manifests a given set of characteristics, including weight (grammage), density, texture, color, content, or other criteria.

In the Western handmade papermaking tradition, one forms a sheet using a traditional mould and deckle. Dipping/pulling the mould through a vat of furnish with a scooping motion; some furnish spills off while the remaining stock drains on the porous brass screen surface of the paper mould, caught within the deckle, forming a saturated mat of fiber. Each wet fibrous sheet is transferred or "couched" onto a felt, and the process repeats. The vat concentration changes due to the sheet by sheet reduction of pulp and draining "white water" dripping back into the vat. (More pulp must be added to compensate for fiber removed – but how much?) This change in concentration results in papers of various weights. This volume will center on regulating traditional papermaking, including a "deckle box" approach. With a redesigned deckle box, we pour a measured amount of furnish into a confined space of a tall deckle; all of the furnish will become the sheet, allowing us to accurately predict the finished paper's grammage. It also describes how to choose fiber content and controls to influence surface, dimensional stability, and water absorption.



A known quantity of furnish trapped in the deckle resulting in a specific (knowable) GSM weight paper

Producing large-format sheets of paper by hand poses numerous difficulties – particularly the cost and scale of large moulds, vats, hydraulic press, and felts – Whereas producing high-quality sheets of small dimensions is relatively simple. With small format hand papermaking, the determination of complex criteria such as content, weight, watermark, and texture of the finished sheet can be simplified as described herein. All of the techniques discussed may be selectively applied, modified, or recombined to suit the individual or project at hand.

Raw material: Western

In Renaissance Europe, vast quantities of paper were made by hand from linen and hemp rags. The rags were sorted and composted in a process called retting. Next, they were placed in a stone trough with water and pounded to a pulp by large water-powered hammers; a trickle of water coming in and draining out of the pounding mortars cleaned the rags during maceration.

This pulp manufacturing model would be a fine place for us to start; sadly, building a large stamper mill in this day and age is neither efficient nor feasible. We can skip much of that hard work by turning to paper pulp suppliers who sell various fibers that have been partially processed and are ready for blending or beating and sheet forming. Paper suppliers sell many varieties. Some need only be soaked and blended (like cotton linter); others (like abaca) require cooking in a caustic, and still others need to be both alkali-cooked and pounded (i.e., kozo, gampi and mitsumata).

Fortunately, today, the list of possible fiber choices is long and diverse; after all, every plant has cellulose fiber that can be made into paper one way or another. Cellulose fiber (found in all plants) is the most abundant chemical compound on earth and has a natural affinity for self-adhesion – perfect for papermaking. Here, in these pages, we will steer away from the hardwood and softwood fiber sources so commonly used in commercial papers to focus on archival (low lignin content) fiber choices for paper. Besides the linen, as mentioned above and hemp, one can produce a wide variety of paper from flax roving, abaca half-stuff, cotton rag, jute, sisal, bamboo, esparto grass, and cotton linter. Each has its unique appeal, characteristics, and processing needs.

Whereas linen is more likely to make crisp, rattly writing paper with little processing, fibers sourced from seed hair (like cotton rag and linter, for example) can produce blotter paper when beaten briefly. Further processing of a seed hair fiber is required to make printmaking papers and additional beating (and introducing longer fibers) for writing papers. Cotton staple fibers (rag half-stuff - see p. 20) can be robust and strong when a Holland-type beating engine is used to defiber, hydrate, and fibrillate the rags. To make such a paper more dimensionally stable, retted and lightly beaten linen can be added; this is more or less the formula used to make the art papers popularized by J Whatman, England's papermakers for the Arts and Crafts Movement. These days cotton linter, the fuzz found closest to the seed, is commonly used to produce art papers and is also used as a filler fiber to provide bulk when combined with stronger, longer fibers.

A note on flax

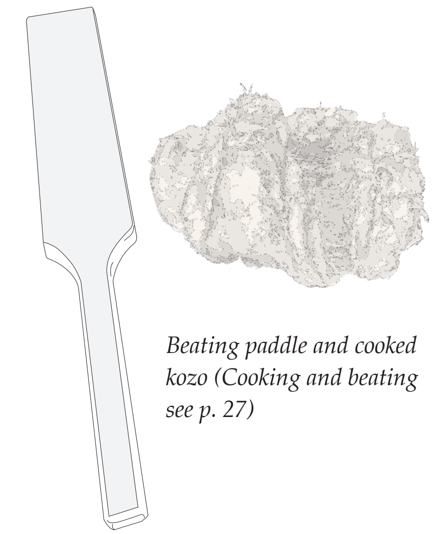
Like all living things, flax contains a set of genes that make the plant able to adapt to its surroundings. Interestingly, researchers from the University of Warwick have found that historically these genes were able to thwart artificial selection by human beings, which led to its emergent suitability as a papermaking fiber. Flax became domesticated 10,000 years ago; because it was primarily used for oil, humans artificially selected for the larger, oil-laden seeds. Two thousand years later, as the plant moved through Europe, natural selection led flax's genes to alter its flowering time and architecture, making it taller and better able to survive – but also reducing the seed size, thus making the plant more suitable for use as fiber.

Source: *https://phys.org/news/2019-01-impact-flax-evolution-limited-thought.html*

1. The "cook"– i.e., rags and other fibrous material boiled in an alkali – serves to remove lignin, a class of complex organic polymers that fill the spaces in the cell wall between cellulose, hemicellulose, and pectin in plants. Flax has less than 5% lignin whereas hardwood is comprised of approximately 29%, with lignin and softwood at 22%.

Raw material: Japanese

Kozo, mitsumata and gampi are the three main fiber species whose inner bark (bast) fibers are used in Japanese papermaking (*washi*). If you elect to use these amazing plants, the inner bark (with the outer bark already stripped) is available from papermaking suppliers. Preparing these fibers for papermaking requires soaking for a day or two and cooking for half a day in a mild alkali-like soda ash to remove lignin; rinsing; and pounding with a mallet. In this papermaking paradigm, harsher alkali and longer cooking produces softer paper while shorter, gentler cooking yields harder paper, as a longer cook and harsher alkali both diminish the fibers' natural binder, hemicellulose.

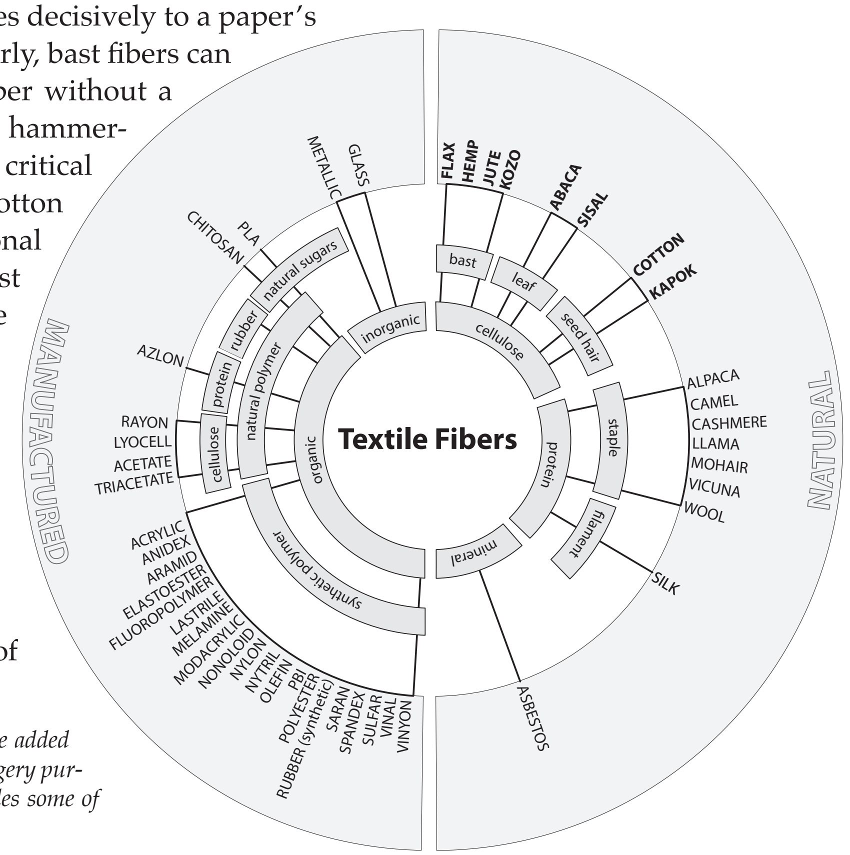


Beating paddle and cooked kozo (Cooking and beating see p. 27)

Hemicellulose (polysaccharides of simpler structure than cellulose), a natural binder not found in abundance in seed hair fibers like cotton, is very important both in Japanese papers, and in the linen and hemp papers of the Western tradition. Obtained from jute, kenaf, flax and hemp plants, bast fibers[3] are very durable, due to length, wall thickness, degree of polymerization, crystallinity, wet compactability, hemicellulose content, cohesiveness, elongation and tenacity. The presence of hemicellulose contributes decisively to a paper's strength and tenacity. Treated properly, bast fibers can produce a crisp, rattly sheet of paper without a prolonged process of beating and hammering. Cotton lacks hemicellulose's critical bonding capacity, distinguishing cotton papers from the typically dimensional stable and crisp papers made of bast fibers such as linen and flax or the mulberry fibers used in Japanese papermaking.

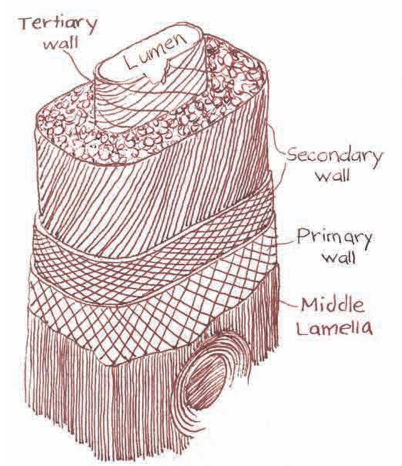
3. Bast fiber is the fibrous material from the phloem (living tissue of a plant) — the inner bark "skin" fibers that surround the stem. Bast fibers are soft with nodes for flexibility. Cotton contains little hemicellulose and no nodes.

Plant fibers are comprised largely of



Textile Fibers chart: although various fibers can be added to paper for decoration, fire-retarding, and anti-forgery purposes, the upper right quadrant (bold text) includes some of the fibers used in hand papermaking.

Cellulose & lignin



Cellulose

cellulose (polysaccharide consisting of chains of glucose monomers) and **lignin**, (a natural polymer that lends rigidity to the plant's cell walls). The presence of lignin in processed fibers will yield a sheet that is not archival. Many commercially available fibers like abaca (whether bleached or unbleached) contain residual lignin and should be cooked with soda ash in a stainless steel pressure cooker to dissolve and reduce the lignin content. Bleaching can disguise the presence of lignin; even pure white fiber can release the dark brown liquor of lignin in a cook. Artists, conservators, and others concerned with longevity and archival quality are advised to remain vigilant of lignin hiding in their linen rags and bast fibers, concealed by bleaches and optical brighteners.

Additives

Japanese and Western paper:

Calcium carbonate (raises the pH, and acts as a buffering agent to improve longevity); magnesium carbonate (an anti-oxidant and buffering agent); titanium dioxide (a whitening pigment); clay (for a smoother and more opaque paper); retention aid (cationic starch that helps additives and fines stick to the cellulose fiber and increases freeness) and methyl cellulose (a mild paste) – as well as colorants and inclusions – can be added to both Eastern and Western paper.

Internal sizing: Alkyl ketene dimers like Aquapel and Hercon 40 are added to the furnish to yield a water-resistant finished paper. These modern-day products are not reversible; I prefer sizing with animal skin glue after the paper is made (see p. 145).

Unique to Japanese papermaking:


Tororo-aoi

Tororo-aoi is used to make neri, a starchy substance crucial to the manufacture of washi. This slimy, viscous additive is blended with the pulp to make a more even sheet (aka formation aid). Tororo-aoi (neri) is derived from the *Abelmoschus manihot* root, a flowering plant in the mallow family Malvaceae; aids in the sheet formation – the uniform distribution of long bast fibers. Although a starch, neri does not size the paper. Tororo-aoi is always used in Japanese papermaking, but can also be added sparingly to Western bast fibers like flax, hemp and abaca. Formation aid is available in powder form from handmade papermaking suppliers.

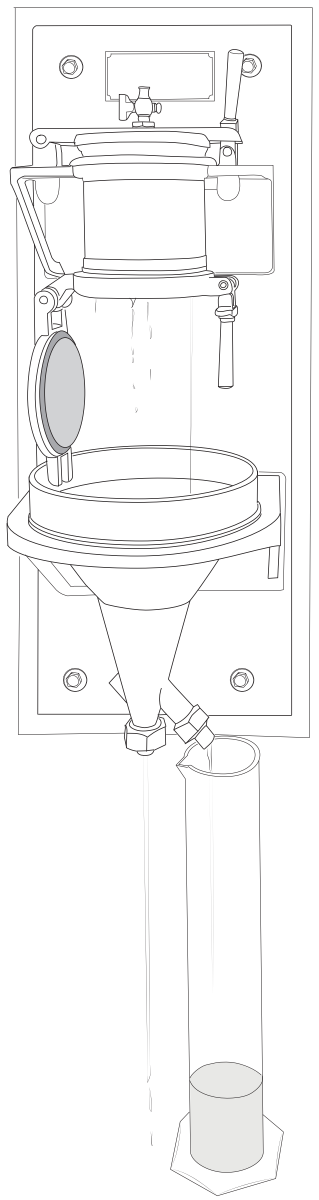
Hemicellulose & fibrillation

Overview: ***Fibrillation*** *and* ***hydration*** *are the results of pulp processing in a beating engine; pulp's* ***freeness*** *indicates the effectiveness of this processing, measured by how freely the pulp surrenders its water.* ***Hemicellulose*** *in the raw material imparts similar characteristics without processing.*

The hemicellulose content of a given fiber type plays a critical role in determining the behavior of a pulp or sheet made from that fiber. Hemicellulose is embedded in the cell walls of plants and consists of polysaccharides like cellulose, but arranged in shorter, branched chains. The hydroxyl groups in hemicellulose contribute to the strength and continuity of the paper's fiber network, creating a stronger, crisper sheet without additional beating. Tear and tensile indices are directly proportional to the cellulose/hemicellulose ratio.

Fibrillation is the internal and external fraying of a raw material's cellulose fibers during processing. Increased fibrillation results in more bonding potential between the fibers, making a stronger, harder, and eventually a more translucent paper: highly fibrillated pulp makes a sheet with fewer interstices, allowing light to pass through the translucent cellulose fibers. As water is removed during sheet formation, pressing, and drying, the pulp's fibers "zipper" together due to hydrogen bonding between hydroxyl groups (oxygen and hydrogen atoms) in the cellulose and hemicellulose. The electrostatic interaction of polar water molecules with hydroxyl groups of contiguous fibers is the key to understanding why paper is paper and not just tangled fibers (i.e., felt).[1]

1 *For a detailed explanation of this process, see "Contribution of Hydrogen Bonds to Paper Strength Properties" by Przybysz et al:*
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0155809
Also: ***http://www.upce.cz/fcht/uchtml/odcp/zamestnaci/connectivity.htm***



Canadian Standard Freeness tester

Processing as measured by Freeness:

Processing (AKA refining) cellulose fibers gradually changes the characteristics of paper made from those fibers. The constant pounding and beating of rags or half stuff produces four major changes to the cellulose fibers, which in turn modify the characteristics of the sheet:

Hydration: the swelling of the tubular cellulose fiber; effects the dimensional stability of the sheet

Fibrillation: the fraying of the small fibers (called fibrils) that twist around the girth of the cellulose fiber; effects the strength of the sheet

Cutting: shortening of the fibers; effects the "look-through" and strength of the sheet

Production of fines: microparticles of cellulose that fall off the main fibers; effects the texture and ease of formation

Prolonged beating generally produces more hydration of all of the above. All of which makes for slow draining pulp and also causes shrinking during drying. More hydration produces a less dimensionally stable paper. More fibrillation increased the bonding potential between fibers and fines clog the screen and also influencing freeness.

Freeness is measured as the speed at which a pulp drains, which tells us its degree of hydration and refinement due to beating or processing. Using a Canadian Standard Freeness tester (CSF) we can measure freeness to determine the effectiveness of the refining process, i.e., the swelling of the pulp fibers as a result of beating. A freer pulp drains faster on the mould; more refinement causes more swelling, yielding a slower draining pulp.

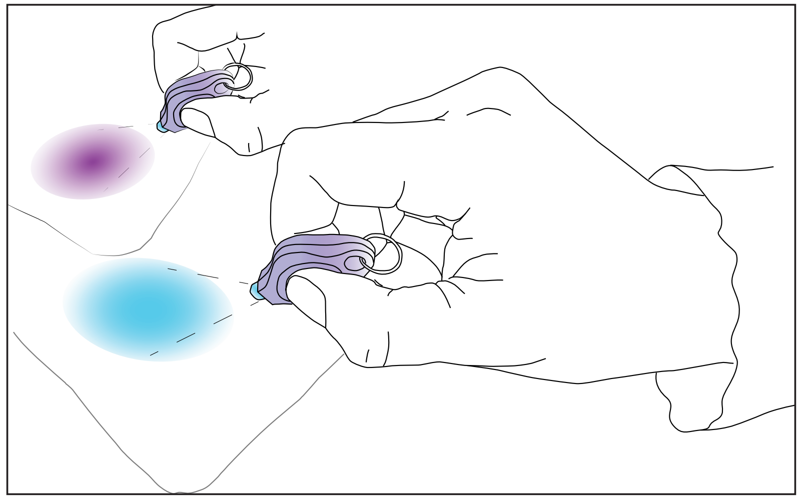
Fillers and cellulosic microparticles ("detritus," "fines," or "crill,") can skew CSF results. Straining furnish prior to papermaking can remove some fines (making a freer – less "wet" pulp). **Alternatively, adding a cationic starch (AKA retention aid) causes the fines to adhere to the cellulose fibers of the furnish and can greatly increases freeness.**

Beware: Optical Brighteners

Test your raw material for the presence of optical brighteners using a UV light source.

Optical brightening agents (OBA), found in laundry detergent and used in the manufacture of cloth and paper, are chemical compounds that absorb light in the ultraviolet and violet region of the electromagnetic spectrum (invisible to the human eye), and re-emit light in the blue region (visible to the human eye) by fluorescence, making fibers appear brighter and whiter.

First, while I was pleased to find numerous suppliers of linen rags via eBay, I was dismayed to discover that they all contained 20th-century optical brighteners — permanently attached to the fibers and impossible to remove. Shine a UV light on the papers I made with these rags and they appear bright blue, demonstrating the fluorescent behavior of the brighteners' harmful chemical compounds. Eventually, I was able to locate environmentally conscious companies on the West Coast that make products using natural linen and hemp without optical brighteners. The scraps left over from cutting out their patterns have been a key ingredient, allowing me to approximate the use of Old World raw material.



Shine a UV light on a sample, if it reflects purple, optical brighteners ***are not*** *present; if it reflects blue, optical brighteners* ***are*** *present.*

Retting overview

Rags in the retting shed at Le Moulin du Verger, Angouleme, France

Retting (composting) is the practice of degrading linen and hemp rags, employing microbes and fermentation to jump-start processing the raw materials used in papermaking. In ideally retted rags, lignin is removed, while hemicellulose and cellulose are maintained and softened. Unhappily, over-retted rags (where the cellulose and hemicellulose have decomposed) leads to a soft, weak paper. With the advent of the Hollander Beater, pre-processing rags using retting techniques have been displaced by high-temperature chemical cooks, bleaching, and the use of powerful beating engines. When using these modern methods, I would caution the maker to go easy on the raw material and take a more gentle path whenever possible. If you choose to ret, described here, you can avoid harsh chemicals and over-beating to make a more traditional and dimensionally stable paper. I respect all kinds of paper; choosing or creating a fine art paper of any sort is certainly a complicated and tricky personal choice.

Making paper from old, worn linen rags was preferred in the past; today, this option appears to be out of the question. I located a source for old linen rags on eBay, where I purchased numerous vintage "pure Irish linen" table cloths. Sadly, I quickly discovered the linen to be unusable, tainted with tenacious, irreversible optical brightening agents. (see p. 13) These undesirable OBAs might have been added by the manufacturer or through washing in Tide and other modern laundry detergents. Therefore, alternatively, we can turn to flax roving or the off-cuts and scraps from eco-conscious producers of specialty hemp and linen products that are not optically brightened. Early European papermakers found that such weavers and garment maker scraps resisted retting and could not be easily processed into fine paper. They relegated these new cuttings to the making of coarse papers or wrapping paper.

Jacques Brejoux checking (tearing) rags retted for two years in his retting shed at Le Moulin du Verger

I agree with early papermakers: I, too, have found fresh linen off-cuts difficult to ret – but not impossible. Whereas, according to some accounts, old rags would ret in less than a month; in my experience, it takes one to two years in a compost bin to break down adequately for papermaking.

Luckily we have Internet access to studies and experts who, for their various reasons, also desire the removal of lignin from plant fiber. After testing worm compost (with some success), I now believe that White Rot Fungus provides what the ancients were looking for to process newly manufactured linen scraps.

Retting: Worm farm

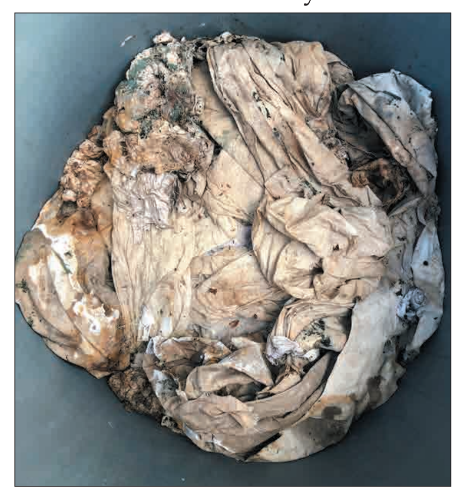
Worms possess the enzymes required to break down the lignin (and cellulose) found in new linen cuttings. Worm farm bins supplied with healthy table scraps, minerals, and interspersed with fresh linen cuttings break down linen in 8 to 12 weeks. Once strong and impossible to tear, these scraps soften and can be ripped with only a moderate effort. At this point, the soiled and darkened cuttings look and feel like old worn-out rags. Next, the cuttings are washed and cooked with soda ash (in a stainless steel pressure cooker) for lignin removal and deep cleaning. The darkened rags can be bleached in sunlight – immersed in an 8% alkali solution of hydrogen peroxide and a half teaspoon of soda ash. Once retted cooked, washed, bleached, and preferably shredded, these aged rags are ready to beat and blend to make a furnish.
Warning: given enough time, worms will eventually "eat" the cellulose, making for a fragile paper and reducing yield. With too much retting, the rags become holy like a modern-day Shroud of Turin and will ultimately transform into worm turnings.

Linen cuttings in a worm farm

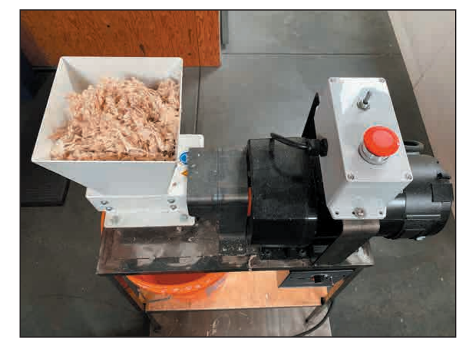
Drying retted, cooked, and bleached linen

Retting: Compost

A moist compost bin of linen textile mill cuttings will develop the microbes necessary to break down rags for papermaking. These indestructible textile scraps can take a year or two to achieve the desired results. In time, the moist rags will begin to putrify. White, green, and black molds and fungi growing on the surface rags will indicate success. Once washed, cooked, and bleached, cut, torn or shredded, beaten, formulated into furnish - at long last, it's time to form sheets.

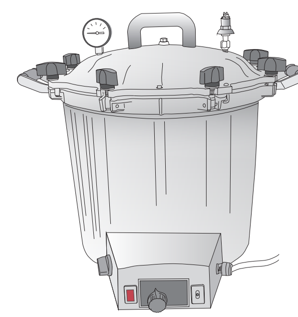


Composted linen fabric



Shredding retted, cooked and bleached linen

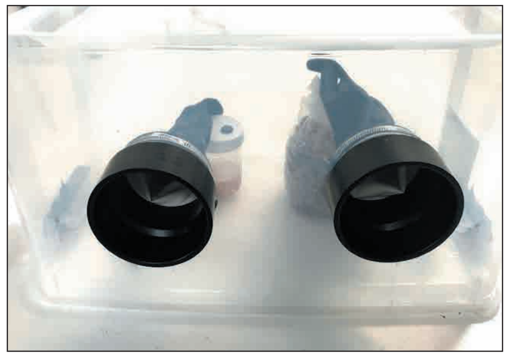
Sterilization with an autoclave: To maintain all staining in the retted rags (for darker paper), forgo bleaching, and submit the musty, microbial laden linen rags to the high temperature and pressure for complete sterilization in an autoclave - 270°F (132°C) for 30 minutes.



Autoclave: This five-gallon autoclave takes one hour to come to pressure/temperature and another half hour to sterilize.

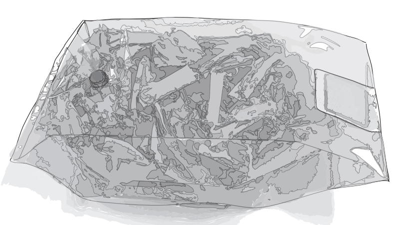
Retted, cooked, bleached and shredded linen

Turkey tail mushrooms grown by Nora Scully



Transfer spawned mycelium to sterile bag of linen rags in a sterile environment like a glove box

Inoculating sterilized 3% solution of malt and dextrose and stirred for 48 hours



Inoculated bag of linen fabric

Retting: with mycelium (white-rot fungi)

Raw Materials: Use linen and hemp fabric, avoiding those that have been optically brightened. Wash, soak, and leave in the sun to dry. Research your mushroom growing project then purchase mushroom growing supplies from a mycology supplier.

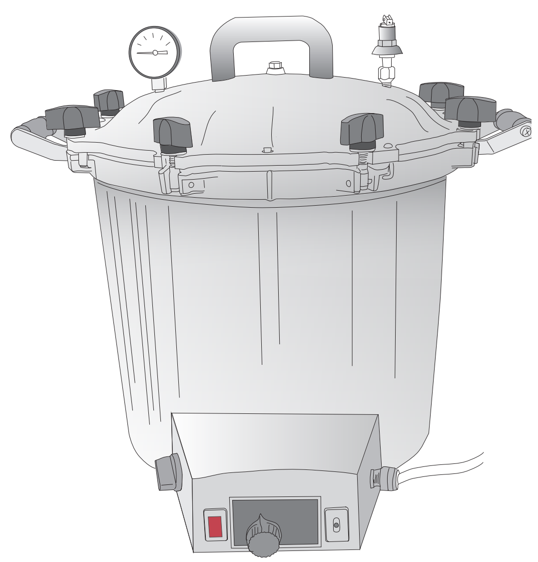
First, a white-rot stock culture is propagated in small containers in growth medium - a Petri dish or jar with air-port lid (in a sterile environment).

Next, to break down linen cuttings with white-rot fungi, soak then stylized your linen rags in a Mushroom growing bag with a self-healing injection port to help guard against contamination during inoculation. The next day, inject the culture through the self-sealing injection port. After approximately three days, when the mycelium has taken hold, tumble or massage the bags to disperse the mycelium. After 2 to 8 weeks, the mycelium will have eaten the lignin in the rags and softened them. Boil the mycelium retted rags in soda ash, and rinse. Your retted rags are now ready for pulping into half-stuff or further processing for sheet formation and paper making.

Research on the industrial potential of white-rot fungi for degrading lignin, while keeping cellulose and hemicellulose intact, can be found here:

Advances in Applied Microbiology, Volume 82
Insights into Lignin Degradation and its Potential Industrial Applications

"White-rot fungi degrade lignin leaving decayed wood whitish in color and fibrous in texture. Some white-rot fungi such as C. subvermispora, Phellinus pini, Phlebia spp., and Pleurotus spp. delignify wood by preferentially attacking lignin more readily than hemicellulose and cellulose, leaving enriched cellulose. "

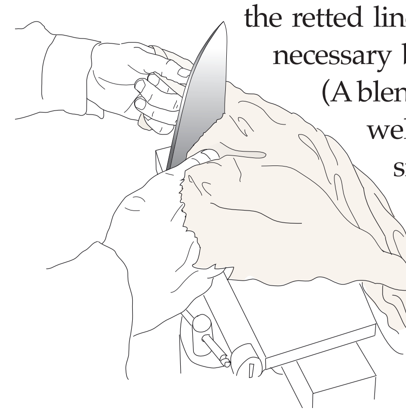


Autoclave: used for sterilizing jars containing a 3% solution of malt and dextrose and inoculation bags filled with torn linen scraps

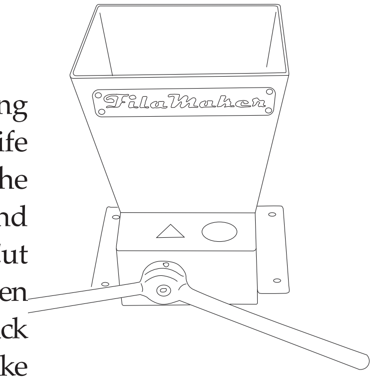
Post Retting:

After retting (in a moist rag pile, a worm farm, or mycelium bag), rags and cuttings will need further processing.

As mentioned above, sunlight bleaching, autoclave steaming and cooking in an alkali are effective processes for sterilizing moldy, musty rags. Tearing or cutting the retted linen rags into smaller pieces is necessary before processing in a beater. (A blender works if the rags are very well retted.) Cutting rags into smaller pieces is traditionally done before retting using a mounded, stationary blade.



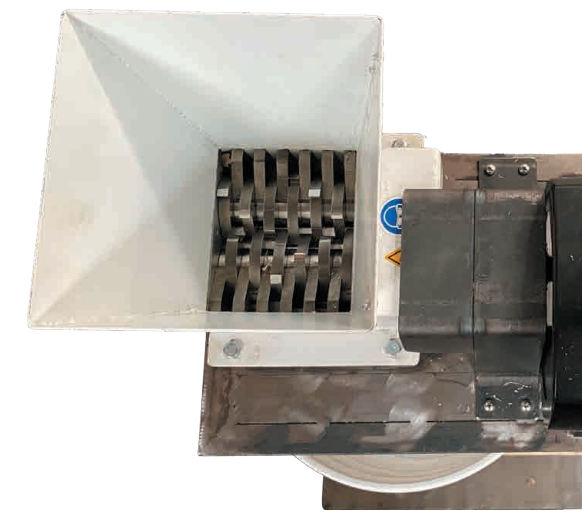
The traditional mounted knife method is effective but dangerous, fatiguing and repetative. Using a mounted draw knife demonstrates that the rags are both cut and torn in the process. Cut at the pull's start, then torn as a rag is pulled back and apart. The rags take less effort to tear/cut after retting and bleaching.



Shredding is preferable to cutting. Some papermakers avoid the lengthy process of retting by cutting (chopping) rags or raw flax roving into ¼ inch lengths. Slicing through the naturally encapsulated cellulose fibers in this way, expose oxidation sites, which, in the long run, will shorten the life of the paper.

A Filamaker shredder is the perfect device for shredding rags before or after retting.

Filamaker shredder - motorized



https://filamaker.eu

Shredded linen rags

III

Half-stuff and freeze-dried pulp

Postponing hydrogen bonding
for storage of processed fiber,
to maintain furnish characteristics,
& to expedite infill and repair projects

Paper pulp stages and nomenclature:

•***Rags***: Linen, hemp and cotton rags are sorted, dusted then washed and retted (composted).

•***Half-stuff***: (aka first-stuff or wet lap) Composted rags, rope or other fibers are beaten to a coarse, imperfect pulp. The equipment for this is called a washing engine or a breaker. Half-stuff is available as sheets, rolls, or bales, all generally dry; the name wet-lap comes from the Fourdrinier process of manufacture. Typically more refinement is necessary to make various grades of papers. Half-stuff is well named as it describes pulp (sometimes called stuff) that is only half-processed.

•***Second-stuff***: Half-stuff further processed using a beating engine.

•***Stuff or Furnish:*** Second-stuff blended with additives ready for sheet formation.

Commercially available fibers: kozo bark and abaca half-stuff

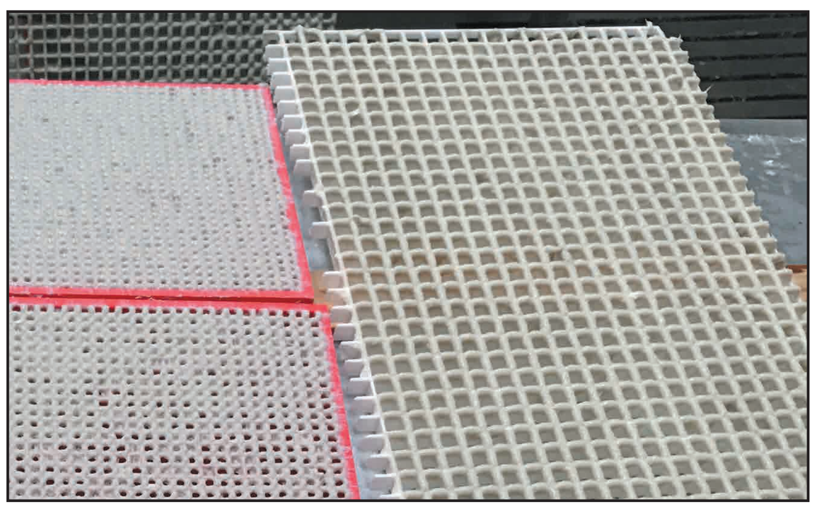
Cheney rag half-stuff (staple fiber) on top of a sheet of Celesa flax half stuff

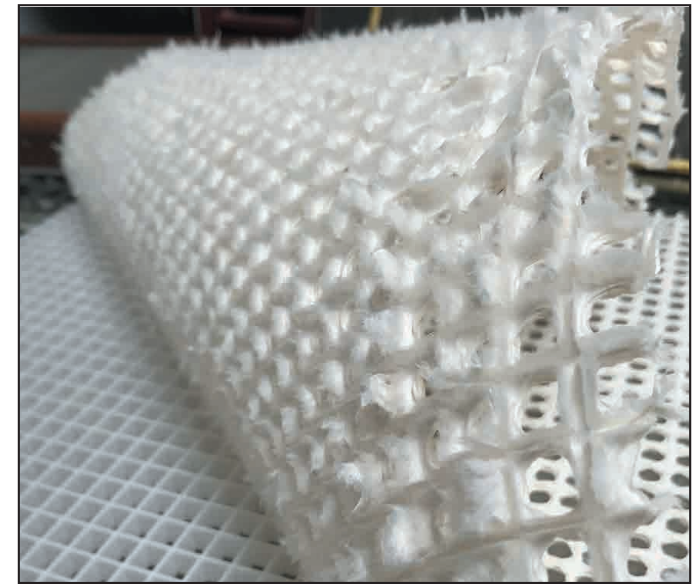
Making half-stuff

Half-stuff refers to partially refined paper pulp, intentionally under-prepared so that it may serve as raw material for studio papermaking. Half-stuff can be further processed and made into paper or stored for later use. In a studio or laboratory setting, how the half-stuff is made has a direct effect on work flow and the paper's viability and repeatability.

Cotton rag, linter, abaca, kozo and flax are commercially available half-stuff worth having in inventory (though cotton linter, kozo and abaca are not suitable for recreating early European paper). Missing from this list are linen and hemp: until a source for linen and hemp half-stuff is found, we are compelled to make our own. In doing so, we also gain more flexibility and control. For 19th century or Arts & Crafts Movement-style paper, a beating engine and paper studio are required. For the recreation of earlier papers, however, such equipment may be an impediment: the beating engine cuts, swells, and abrades the fiber, creating oxidation sites and rendering the paper less dimensionally stable. In contrast, retting and gentle processing yield a better raw material, leaving a larger percent of the fibers wholly encapsulated as Mother Nature made them. That is, of course, unless you make the mistake of chopping and cutting the rags and raw fibers; ripping and retting are preferable and less harmful to the fibers. Once the pulp is made it can be refrigerated for later use.

Refrigeration of wet pulp is not always convenient. Unfortunately, studio-made half stuff pulp dried normally into balls or thick sheets creates weaker paper when re-hydrated (due to the zippered hydrogen bonds being impossible to separate back into pulp). When I want to dry my half-stuff for long term storage, I dry it into a fluffy, feathery matrix grid where less of the normal hydrogen bonding has taken place.





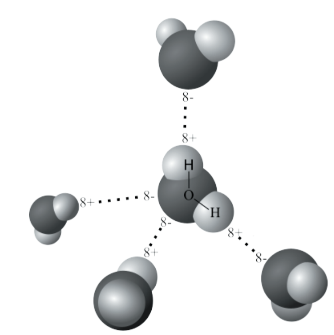
The process came about in the normal unexpected way – by accident. While testing grid paper pulp ideas with the artist Chuck Close, I stumbled upon an excellent process for forming wispy half-stuff sheets. To reproduce my lattice work half stuff, once half stuff pulp is in the vat, dip a light diffusion grid screen (or smaller 3D printed deep grid) and scoop as you would while forming a sheet. Multiple dips for a thicker catch of fibers work best. Next, wet/dry vacuum the back (underside). Let air dry and peel off. The resulting half stuff grid has feathers of wispy fibers and less hydrogen bonding, making it easy to tear for weighing and blending. Because the fibers are fluffy and were not pressed or otherwise consolidated, there is more of a random alignment of fibers that do not seem to be hydrogen bonded – perfect half-stuff.

Avoiding hydrogen bonding via solvent exchange

Suppose fume hoods and toxic hydrocarbon solvents don't put you off. In that case, it is possible to minimize much of the aligned 'zippering' hydrogen bonding action through solvent-exchange (aka liquid-liquid extraction). Substituting solvents will replace bipolar molecules (water) with aromatic hydrocarbons. Straining your pulp and flooding it with alcohol to exchange one solvent (water) for another (alcohol), then flooding with methyl ethyl ketone to exchange the alcohol, eliminates water from the process without the regular operation of drying. Solvent-exchange produces dry fibers and half-stuff with a more random bonding pattern (i.e., less bonding) to store for future use. While hand-beaten kozo will survive in the refrigerator for some time, it helps have dry pulp and non-bonded fibers on hand when trying to measure out quantities for color matching or making a specific weight of paper.

To avoid the creation of hydrogen bonds when drying paper:

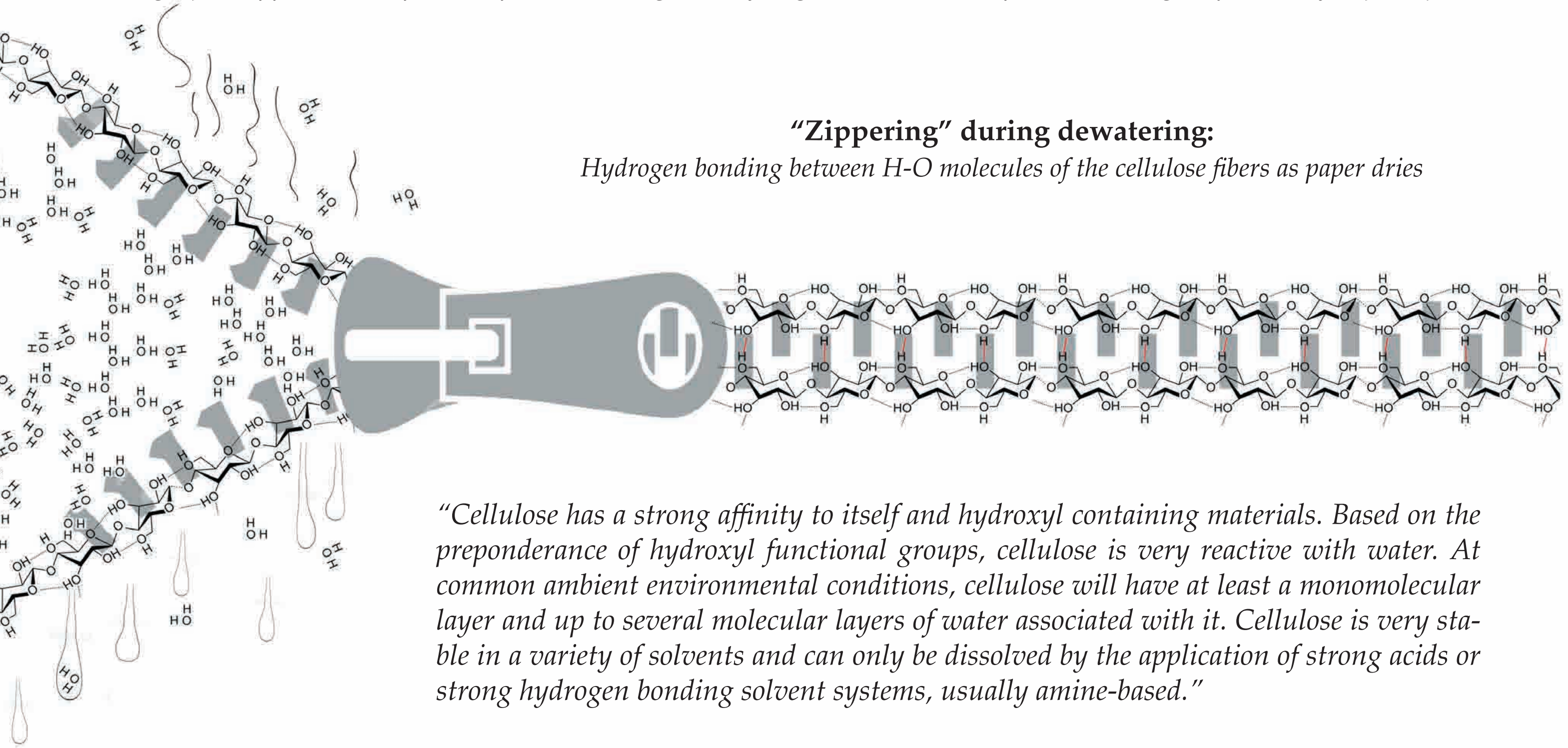
1. Squeeze (or vacuum) water from pulp.
2. Under a fume hood, flood with alcohol and stir.
3. Wearing protective gloves, drain (and vacuum) alcohol.
4. Under a fume hood, add methyl ethyl ketone (MEK), enough to thoroughly soak the fibers.
5. Drain, and allow the MEK to evaporate (flash off).



Water's four hydrogen bonds optimally arrange themselves tetrahedrally around each oxygen molecule.

Warning Note: *Alcohol and MEK are flammable, and their vapors dangerous. Handle with care in a safe, non-sparking (explosion-proof) fume hood.*

Handling a piece of freeze-dried furnish after moistening: note hydrogen bonds have not formed, making the fibers easy to pull apart



"Zippering" during dewatering:

Hydrogen bonding between H-O molecules of the cellulose fibers as paper dries

"Cellulose has a strong affinity to itself and hydroxyl containing materials. Based on the preponderance of hydroxyl functional groups, cellulose is very reactive with water. At common ambient environmental conditions, cellulose will have at least a monomolecular layer and up to several molecular layers of water associated with it. Cellulose is very stable in a variety of solvents and can only be dissolved by the application of strong acids or strong hydrogen bonding solvent systems, usually amine-based."

"Adhesion and Surface Issues in Cellulose and Nanocellulose"

Douglas J. Gardnera, Gloria S. Oportoa, Ryan Millsa and My Ahmed Said Azizi Samir

Freeze-dried newly formed sheets and processed cellulose fibers

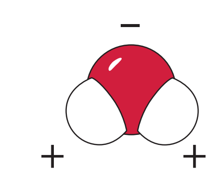
An alternative to a library of half-stuff and old papers for backing or infill projects

Hornification: *a technical term describing the formation of irreversible or partially reversible hydrogen bonding in paper upon drying.*

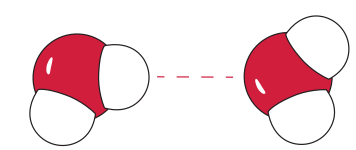
Newly formed sheets of furnish, freshly couched and pressed but not yet dried, are held together by various forces, including fiber entanglement, wet bridges, capillary tensions, etc. In this wet mass of entangled fibers, the hydrogen bonds at the fiber and fibril crossovers (the key to a dry sheet of paper's structural stability) have not yet formed. Additionally, the tubular cellulose fibers have not yet collapsed into the ribbonlike structures we often see via electron microscopy. As water is removed during sheet formation, pressing, and drying, the pulp's fibers "zipper" together due to hydrogen bonding between hydroxyl groups. However, prior to pressing and drying, furnish exists simply as a lovely arrangement of fibrous pulp, which is likely to fall apart if you try to lift it unsupported.

During drying, thanks to water molecules' polar nature and the hydroxyl groups of cellulose, tubular cellulose fibers collapse and electrostatic hydrogen bonds form. This inter-fiber bonding is referred to in technical literature as hornification, a word used to describe something that becomes hard or horn-like. In the case of dried pulp fibers, it describes the stiffening of the structural polysaccharides of the cell wall through an increase of intermolecular hydrogen bonding.[2] Hornification helps to define the structure of the dried sheet, giving it many of its physical characteristics.

__The hydrogen bond__ is one of the strongest intermolecular attractions, but weaker than a covalent or an ionic bond.



Polarity of the water molecule



Hydrogen bond between water molecules

__The dance of water molecules:__ hydrogen bonds between water molecules are continually breaking and reforming. Within a newly formed and pressed sheet, H2O molecules are changing partners millions of time per second, pulling hydroxyl groups on the cellulose polymer into polar alignment as water evaporates.

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2 James L. Minor: "Hornification - Its Origin and Meaning." Progress in Paper Recycling, 1994. *https://www.fpl.fs.fed.us/documnts/pdf1994/minor94a.pdf*

The hydrogen bonds found in paper are **not** easily reversible. Even if a sheet of dry paper is moistened overnight and vigorously stirred in water, it will not readily disintegrate into the fibrous furnish from whence it came. It is far easier and more effective to recycle a sheet back into furnish *before* it dries, either immediately after couching or after pressing. Therefore, the characteristics of a sheet which has never been dried versus the same sheet dried and re-moistened are significantly different: both are flat and wet, but only the previously dried sheet (with hydrogen bonds firmly in place) has the structural integrity to be lifted between your fingers without disintegrating. In a conservation context, where (for example) we may need a sheet or quantity of furnish that can be easily manipulated and distributed into areas needing infill, the inviolable structure of a conventionally dried sheet is not necessarily an advantage.

As you might imagine, a freeze-dried sheet of newly formed paper, once re-moistened, has more in common with a freshly formed and couched sheet than with a conventionally dried and re-moistened sheet, due in large part to the removal of its water molecules by sublimation. **Most crucially, a sheet freeze-dried from wet furnish will revert to pulp if stirred in water, almost as if it had never been dried in the first place. This characteristic enables a wide array of possibilities.**

When repairing or infilling a paper artifact, a leaf caster is a useful tool for distributing fiber into the missing areas of an old document (provided the artifact does not contain water soluble ink - in which case leaf casting is not a suitable approach). Freeze-dried pulp has various advantages when leaf casting. At the edges, where the new pulp overlaps the damaged document, the fibers will hydrogen bond to the old paper. When making pulp for leaf casting, freeze-dried pulp can be mixed with pulps of other values to match a document needing repair, whereas blending (i.e., processing in a blender) a light and dark conventional sheet of paper to make an in-between value will likely result in a speckled or mottled infill.

If one wished to forego leaf casting, traditional papermaking techniques can be used: couch a matching sheet and coax the fibers into the form of a missing area. Conservator Keiko Keyes and I experimented with this approach decades ago – a process with much pormise, but which I now believe to be more trouble than it is worth for conservators without access to a small papermaking studio.

Finding a matching sheet from a library of conventional older papers set aside for infill, cutting, or tearing to an appropriate shape and using paste may seem like a more accessible alternative. However, this approach has its drawbacks. Matching a document's weight, fiber, laid pattern, look-through, and pH for an infill could take considerable time and luck. As I outline in this book, making a paper that matches the weight (g/m^2), color, and fiber content of an antique leaf is not such an impossible task.

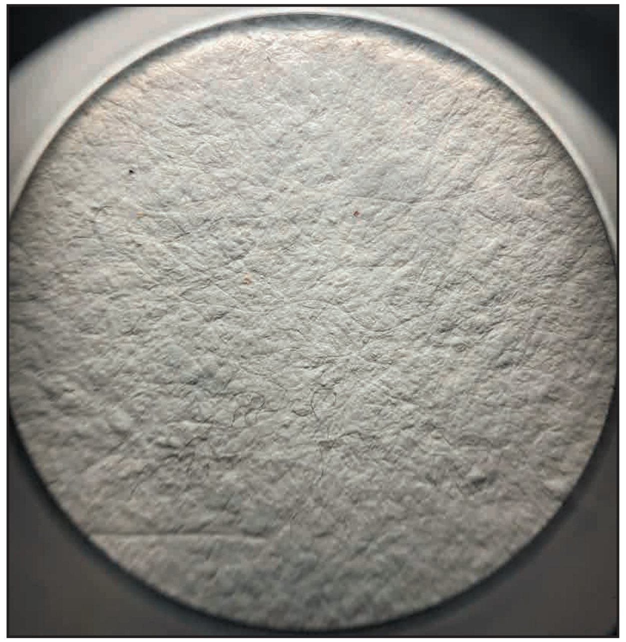
Freeze drying (lyophilisation)

The benefits of postponing hydrogen bonding for conservation applications

I have found that a newly formed and couched sheet can be freeze-dried to prevent the natural process of inter-fiber hydrogen bonding (hornification). In the freeze drying process, newly made (never dried) frozen wet sheets are warmed while under extreme vacuum. As the water freezes in the process of freeze drying. the water molecules expand before sublimating, increasing the distance between the bonding sites of contiguous cellulose hydroxyl groups, effectively preventing the hydrogen bonds from forming. Early results seem to bear out this hypothesis. Re-moisten the freeze-dried sheet, press it and let it dry – only then do hydrogen bonds form and the sheet become paper as we know it.

The dimensional stability of paper is known to improve with age, making older papers potentially desirable for conservation. The gently processed hand-beaten bast fibers used in most Japanese (mulberry) papers usually produce a reliably dimensionally stable sheet. European paper can prove more difficult: modern processing engines quickly hydrate, cut and fibrillate fiber, making such paper likely to expand and contract more than an antiquarian sheet. Nevertheless, for reasons I am still investigating, freeze-dried paper is more dimensionally stable compared to the same sheet couched and dried conventionally. This alone is a huge advantage in conservation. Where conventional half-stuff must be soaked overnight and may prove to be dimensionally active after processing, freeze-dried pulp can be moistened and used immediately, losing about 100 CSF to 75 CSF in the process, making for a more stable sheet. Papers on industrial papermaking[3] suggest, and my tests confirm, that **the addition of cationic starches (retention aid and formation aid) will help buffering agents and fines attach to the (anionic) fibers of the furnish, making for a freer furnish (in my tests, an increase in freeness from 100 to 150 CSF).**

3 Hubbe, M. *Difficult Furnishes*. Proc. TAPPI '99, 1353-1367



When repairing Western papers using infill techniques – feathering and sculpting a matching paper fragment to fill fragile areas of damage such as torn edges – freeze-dried paper seems to have many advantages over the use of a paper library. Freeze-dried paper offers less resistance when moistening and feathering the edges to match the infill area. Once aligned in place, the freeze-dried fragment requires minimal use of paste or methyl cellulose, as the (still active) bonding potential of the hydroxyl groups will assist in a natural paper bond to the edges of the document under repair. After moistening the freeze-dried paper for the first time since lyophilisation, dry the freeze-dried paper and document together under pressure and you will note little shrinkage in the freeze-dried paper (much like using an antique paper, and unlike using a contemporary paper).

All paper dries with a memory: dry a newly formed paper flat and it will tend to be flat throughout its lifetime; dry it wavy and cockled and it will always want to be so. As freeze-dried paper has yet to fully set its shape memory, freeze-dried sheets are impressionable and malleable, ready to take on surface, shape and indentations far more readily than a re-moistened, normal sheet.

On dimensional stability

In general there is not much extant research to date regarding the potential of freeze-drying pulp or half-stuff. Timothy Barrett's comprehensive *European Papermaking Techniques 1300–1800* does reference a few historical instances of frozen half-stuff, quoting Lalande's *Art de faire le papier*: "A well run mill has normally a good supply of 'cobre' or half-stuff, that is to say, stuff which has been broken only and which is kept during the winter in the stuff-chests; the frost gives it a certain degree of perfection; it is even claimed that the Dutch spread their half-stuff on large sheets and expose it to the frost night and day."[4] However, freezing and freeze-drying are of course two very different processes.

A more recent precedent does exist for the idea that freeze-drying pulp preserves internal dimensional stability and prevents shrinkage by inhibiting hornification. A 1997 Tappi Recycling Symposium study measured cross-sectional fiber dimensions before shrinkage due to drying by examining freeze-dried fiber samples.[5] The fact that lyophilisation did not prohibit, but in fact enabled such cross-sectional analysis, suggests that it represents a viable method for preserving fiber stability.

Furthermore, in his study "Dimensional Stability of Paper: Papermaking Methods and Stabilization of Cell Walls," Daniel F. Caulfield provides numerous citations confirming the relationships between freeness, stability, and drying described above. Caulfield writes that "[the] dimensional instability of paper arises ultimately from the moisture sensitivity and swelling of the cell wall."[6] Caulfield restricts his investigation of dimensional instability to "changes within the plane of the sheet of paper (i.e., the x-y plane)," not curling or cockling, since "swelling of a sheet of paper is largely (90%) in the thickness or z direction."[7] Citing J.P. Casey regarding the inverse correlation between interfiber bonding and dimensional stability, he draws the following conclusion regarding restrained drying:[8]

4 Barrett, T., *European Papermaking Techniques 1300–1800*, retrieved from http://paper.lib.uiowa.edu

5 Fjerdingen, H., Houen, P. J., *On the Effect of Recycling on Cross-Sectional Shapes and Dimensions of Sulphate Pulp Fibres*, 1997 Recycling Symposium Proceedings.

6 Caulfield, D.F., *Dimensional Stability of Paper: Papermaking Methods and Stabilization of Cell Walls*. USDA Forest Service Forest Products Laboratory, Madison, WI.

7 Crook, D.M. and W.E. Bennett, *Effect of Humidity and Temperature on the Physical Properties of Paper*, British Paper and Board Industry Association, 1962, cited in ibid.

8 Casey, J.P., *Pulp and Paper Chemistry and Chemical Technolo-*

Harvested, stripped, soaked, scraped, cooked, and hand-beaten kozo. Once freeze dried, if kept dry, it can be stored for decades. When re-moistened, it's right where you left off – ready for more beating or simply to be stirred into a bucket of water to make furnish.

Beating or refining pulp is the most effective means of improving interfiber bonding and thereby increasing both the density and strength of a sheet of paper. But by so doing, the dimensional stability of the sheet is reduced. [...] ***Fiber orientation and restraint during drying are related and probably have the largest effect on dimensional stability. If paper is restrained from shrinking during manufacture, its dimensional stability is improved.*** *The effects of restraint during drying can easily overcome the effects of fiber furnish, beating, and fiber orientation.* [9]

Caulfield goes on to say that in the case of unrestrained sheets, dimensional movement increases proportionally relative to freeness. However, "if the sheets are dried with increasing levels of restraint to prevent some of the initial shrinkage, the dimensional swelling on subsequent exposure to moisture is markedly reduced and the effect of freeness disappears."[10]

In tests described in *Cinquecento Paper Textures* (free for download at magnoliapaper.com), I have found that constrained drying – even sheets hung in spurs, constrained only by the proximity of neighboring sheets, makes for a more dimensionally stable paper.

Overview: benefits of freeze-dried furnish (half-stuff or sheets) for paper conservation

1. Matching weight, color and content: since freeze-dried sheets are dry, color matching by eye or spectrophotometer is possible (wet paper pulp is impossible to match). Making a 7.5 cm square sheet and storing it with the fiber makes for easier color matching. Freeze dried paper is about one shade lighter (L value -1) than a free-dried sheet that has been remoistened and dried; the fluffy texture of the freeze-dried sheet refracts more light than a consolidated sheet. Weighing and calculating the GSM is also easy.

2. Cutting a traced shape from freeze-dried pulp is likewise equivalent to cutting a normal sheet of paper.

3. Freeze-dried paper has less resistance when moistening and feathering its edges to conform to a desired shape, as not all hydrogen bonds have formed.

gy, Vol III, Interscience Publ. Inc., New York, 1967, cited in ibid.

9 Caulfield, p. 89; my emphasis.

10 Fahey, D.J. and W.A. Chilson, *Tappi* 46 (7) 393, 1963, cited in ibid.

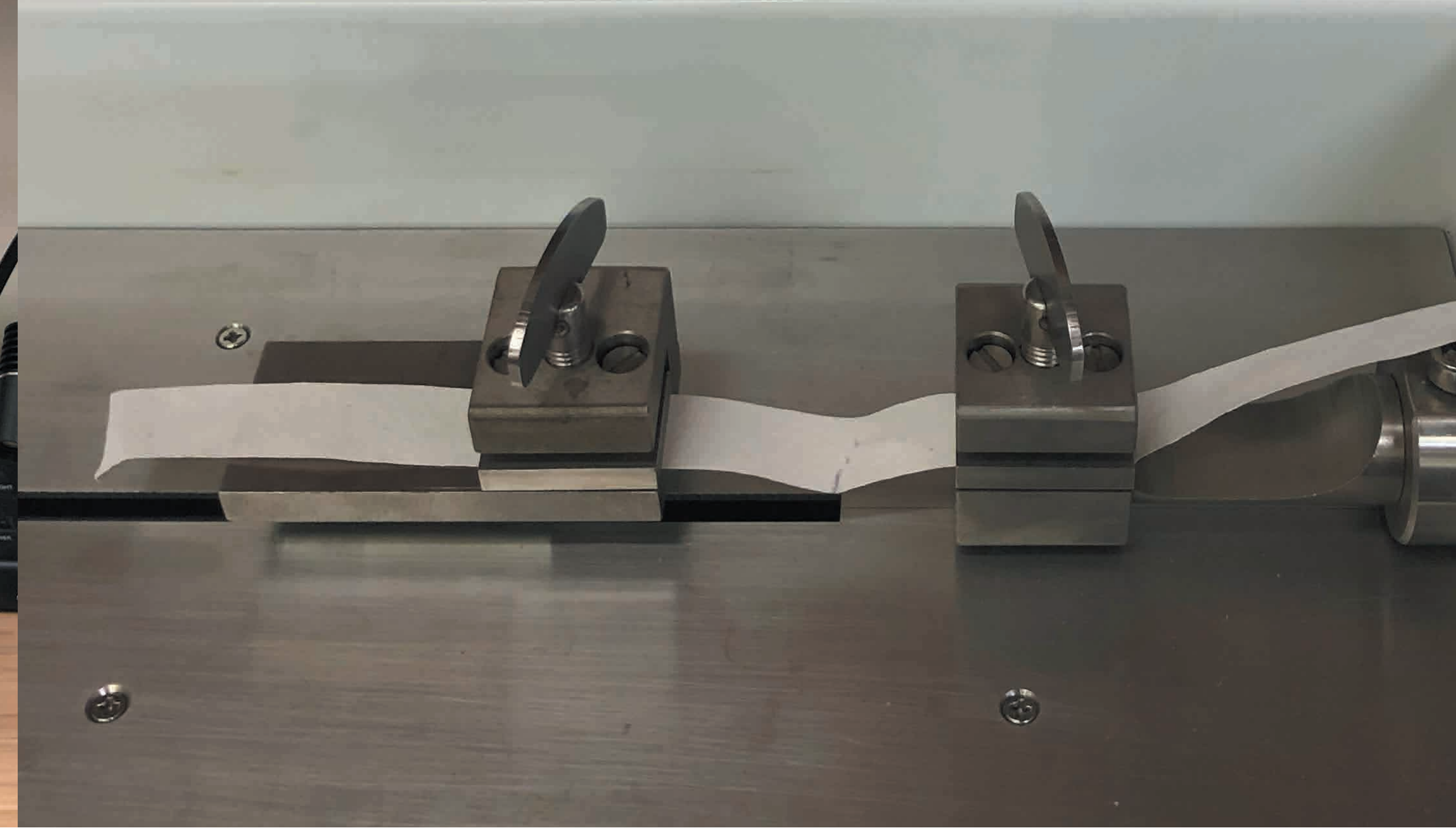
4. Edge pasting uses less paste – immediately after feathering, positioning the fragment in contact with the document allows the moist, fibrous edges of the freeze-dried pulp to bond to the edges of the document without the use of much, if any paste.

5. Freeze-dried pulp is a known quantity (literally) – it is difficult to ascertain the content, pH, impurities, etc., of a sheet selected from a library of older papers set aside for infill. By contrast, newly made, freeze-dried sheets of pulp can be documented and classified based on fiber content, weight and additives, buffers, antioxidants, laid screen pattern spacing or wove pattern – making the development of a new library of freeze-dried sheets of varying predetermined characteristics an exciting prospect.

6. In leaf casting applications, freeze-dried half stuff is superior to conventional half-stuff or recycling of paper. Freeze-dried pulp can be blended instantly and incorporated into the casting process using techniques reminiscent of the original papermaking methods used to form the sheet needing repair. Conventional half-stuff requires soaking for hours prior to blending (it is often recommended it be soak overnight). Freeze-dried furnish hydrates instantly.

7. Dimensional stability and felt-hair marks can be preserved: minimal shrinkage means that the resulting paper will possess significant dimensional stability. If felt-hair marks are desired, a coarse felt can be used and the marks will be preserved in the freeze-dried furnish even after hot pressing; more generally, any desired surface texture can be maintained. Recent freeness tests in our studio indicate that freeze-dried furnish is significantly freer (from 75 CSF to 120 CSF) than the same pulp before freeze drying – a freeness more in keeping with the furnish used in the manufacture of older papers.

Haida HD-1512 Horizontal Tensile Tester at Magnolia's paper studio



Horizontal Tensile Tester in action: clamps holding strip as it is tested

Tensile strength as a measure of freeze-dried pulp's utility

Tensile strength measures the force required to stretch and pull a strip of paper to the breaking point. Tensile strength is a fundamental measurement of paper strength[11] and is a component of the more complex tear, burst and fold strength tests also used in the paper industry. Per the TAPPI standard, "tensile strength is indicative of the strength derived from factors such as fiber strength, fiber length, and bonding."[12] Put simply, tensile strength (when measured according to standard protocol) offers a reliable measure of paper's permanence and some of its key mechanical properties.[13]

11 Casey, J.P. *Pulp and Paper: Chemistry and Chemical Technology*, Third Edition, Vol III, Wiley-Interscience: p. 1786
12 TAPPI T 494 om-01: Tensile properties of paper and paperboard, June 13, 2006.
13 Caulfield, D.L. et al., "Paper Testing and Strength Characteristics," *TAPPI* 1988, TAPPI Press: 31-40

The standard strip length for testing tensile strength in machine-made paper is 200 +/- 10 mm; different lengths can be used, but may introduce the possibility of interference by factors such as clamp alignment within the tester.[14] In the case of hand sheets (as in the tests herein), the standard strip size is 100 mm. Hand-driven testers exist, but motor-driven testers are generally preferred for their consistency of load application. Tensile strength may be affected by variables including environmental humidity and grain/"machine" direction when testing, the latter due to a greater alignment of fibers in one direction. As a result, it is useful to conduct tests tearing in both directions and then average the results.

Ultimately, the most important factor relative to tensile strength is the amount and quality of fiber bonding.[15] Therefore **tensile strength tests can serve as a useful measure of the hydrogen bonds that have taken place in a given sample**. Comparative tensile strength tests of two air-dried linen and hemp handmade papers that were freeze-dried prior to drying indicate that hydrogen bonding is about 50% less in the re-hydrated and dried freeze-dried sheets than in the normally dried sheets. (Sizing can compensate for loss of inter-fiber bonding.) This suggests that freeze-dried furnish has great potential to be stored and used in conservation projects long after it was first measured out and blended.

14 Casey, p. 1787
15 *Ibid.*

When traditional furnish is left to air-dry, it becomes hard as a rock and quickly loses its utility, due to the formation of hydrogen bonds between fibers. But **if the furnish is freeze-dried, this initial formation of hydrogen bonding is inhibited** and the furnish can be stored until needed. Once re-moistened, not only does it behave identically to a normal furnish in studio or conservation applications, **it creates a sheet possessing tensile strength that is measurably equivalent to one formed from traditional (not freeze-dried) pulp**.

The table at right offers some encouraging empirical confirmation of this hypothesis.

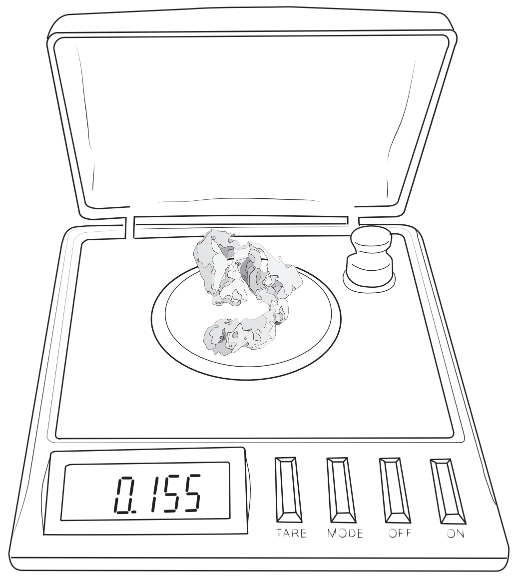
Bleached Abaca half-stuff:
Test weight ≈ 100g/m²

	Force
Not retted, not cooked (contains lignin) before freeze-drying:	2.36kg
Retted, not cooked (contains lignin) before freeze-drying:	4.32kg
Retted, alkali cooked (not beaten)	6.19kg
Retted, cooked, beaten & freeze-dried	5.15kg
A linen and hemp freeze-dried furnish:	6.85kg

For comparison, a US dollar bill with a weight of 90 g/m², made from linen & cotton rag, has a tensile strength of 15kg pulling with the grain of the paper and about 7kg pulling against the grain. A common 78 g/m² copy paper will have reading from 3.5kg to 7.5kg. A rather heavy 280 g/m² cotton printmaking paper like Rives BFK has a tensile strength from 8kg to 13kg.

III

Describing the weight of paper
in grams per square meter



Weighing small quantities of dry pulp

Weighing a sheet of paper to determine paper's weight expressed in g/m²

Using PaperWeight app to determine a paper's weight, expressed in g/m²
Magnolia PaperWeight is now available on the Apple App Store

Magnolia PaperWeight
Apple App Store download

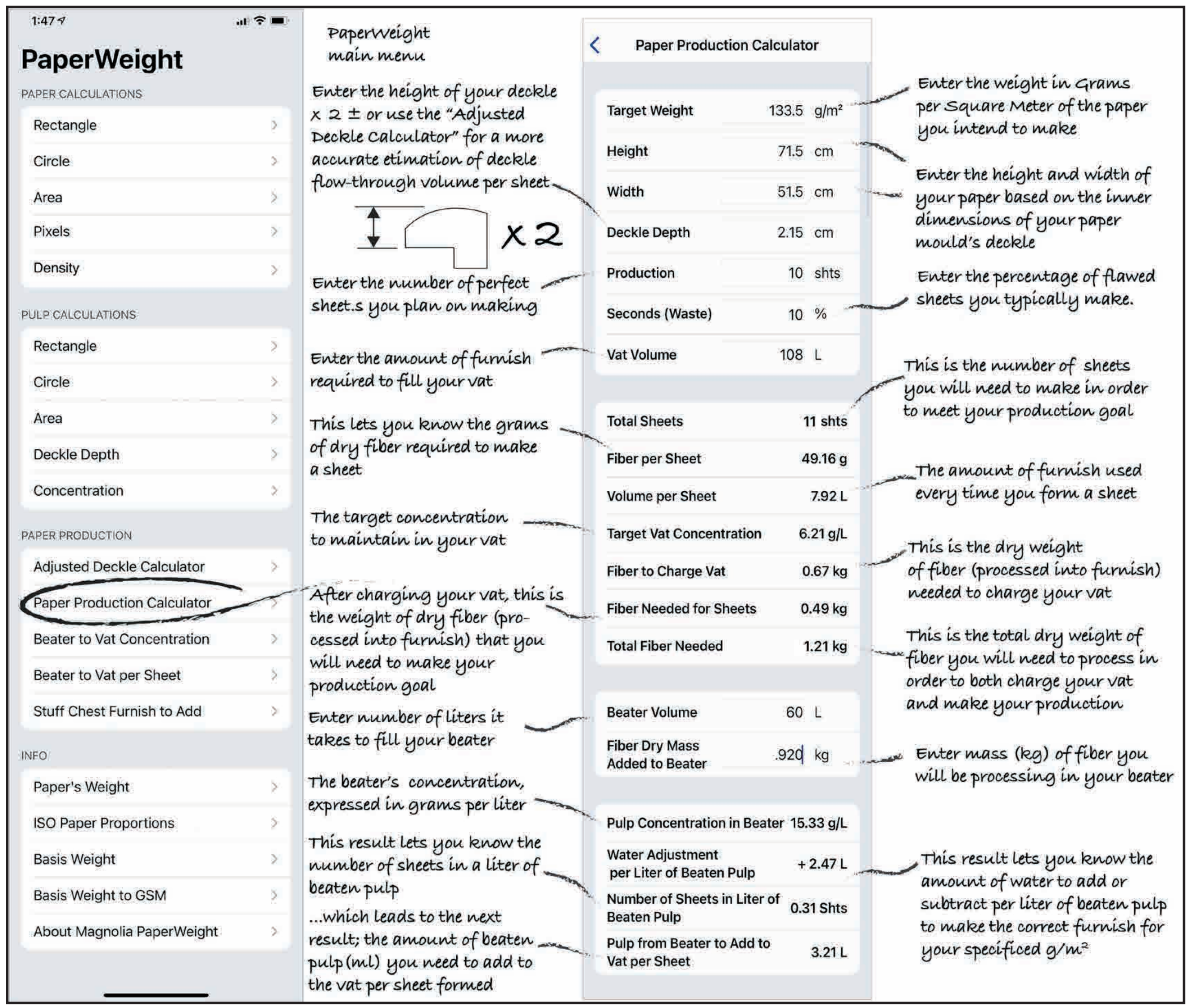
Describing the weight of paper
in grams per square meter

When a sheet of paper is described as lightweight, medium weight, or heavyweight, these general terms really refer to the sheet's grammage. Using a scale and a ruler, grammage can be conveniently and accurately measured in grams per square meter, GSM, or g/m²; this measurement represents the weight of one square meter of a given paper.

Describing the weight of any paper in Grams Per Square Meter requires some data and a calculation. This app makes the calculation easy, but does require the use of a scale and a ruler.

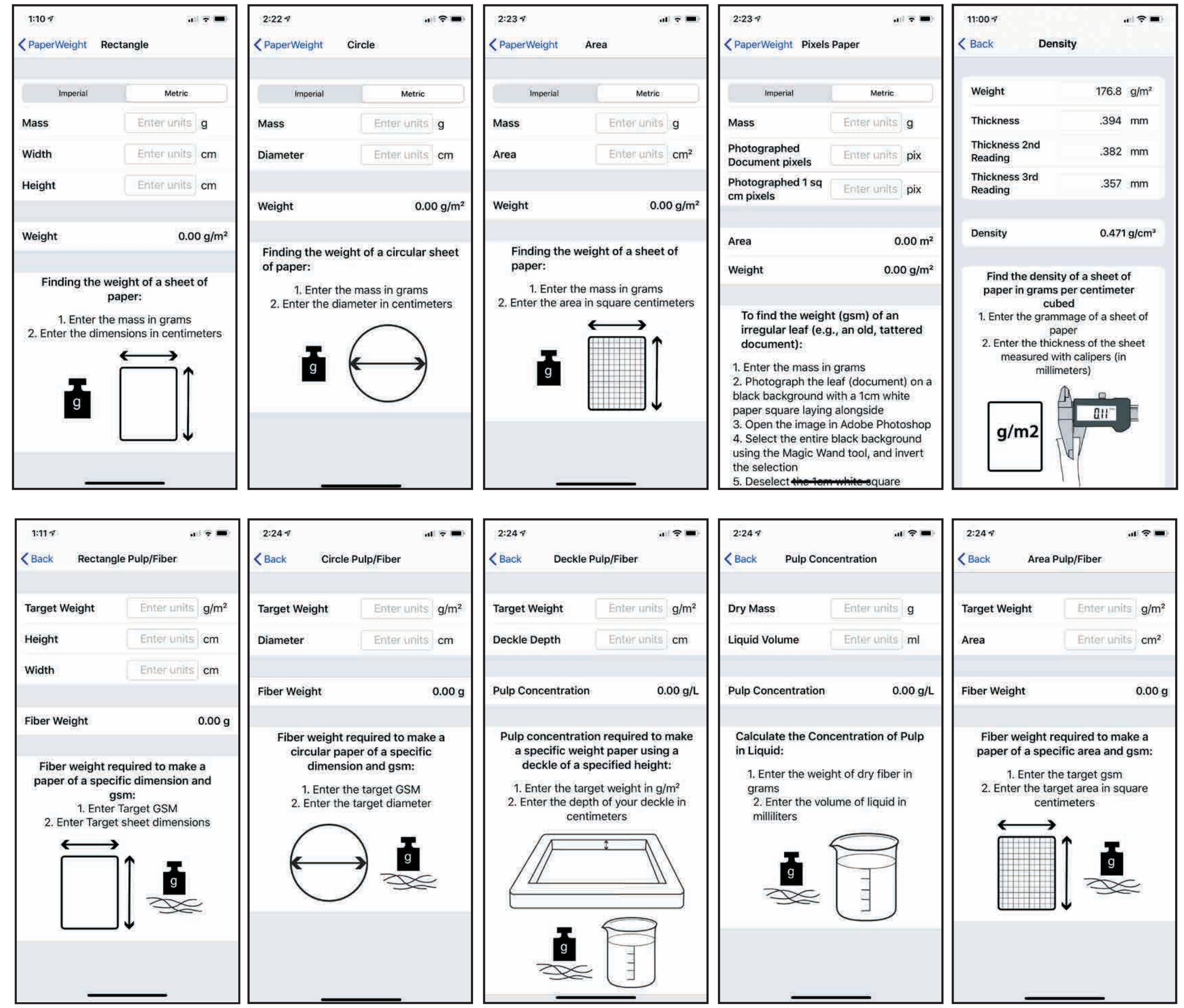
For papermakers and conservators, determining the weight (g/m²) of a leaf of paper provides the data necessary to calculate the pulp needed to create a paper of the same weight. For example, in the case of a paper conservator wishing to make paper for an infill, knowing the document's weight to be repaired is critical when determining the quantity of dried fiber necessary to form a matching sheet.

Magnolia Paperweight is available for download at the Apple App Store, thanks to the programming efforts of Nicholas Price and Alex Shepard.



Using the *Paper Production Calculator* found in the *Paper Production menu grouping (circled).* In this example, we plan on making 50 sheets of 18 x 24 inches (46cm x 61cm) paper (with 20% seconds), with a grammage of 120 g/m².

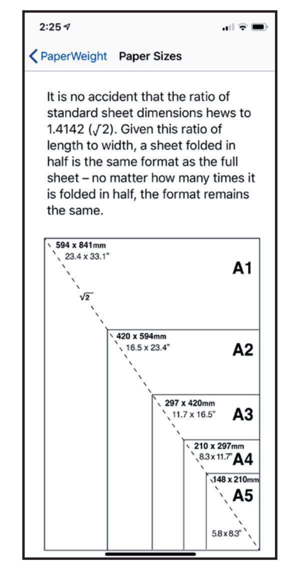
Magnolia PaperWeight:
Weight (grammage) and fiber calculator screens



Designed for hand papermakers, paper conservators, artists, and printmakers who work with paper, the *PaperWeight* app is an effective tool for paper analysis, documentation of paper artifacts, quality assurance, calibration, and papermaking preparation.

With *PaperWeight*, you can quickly and efficiently:

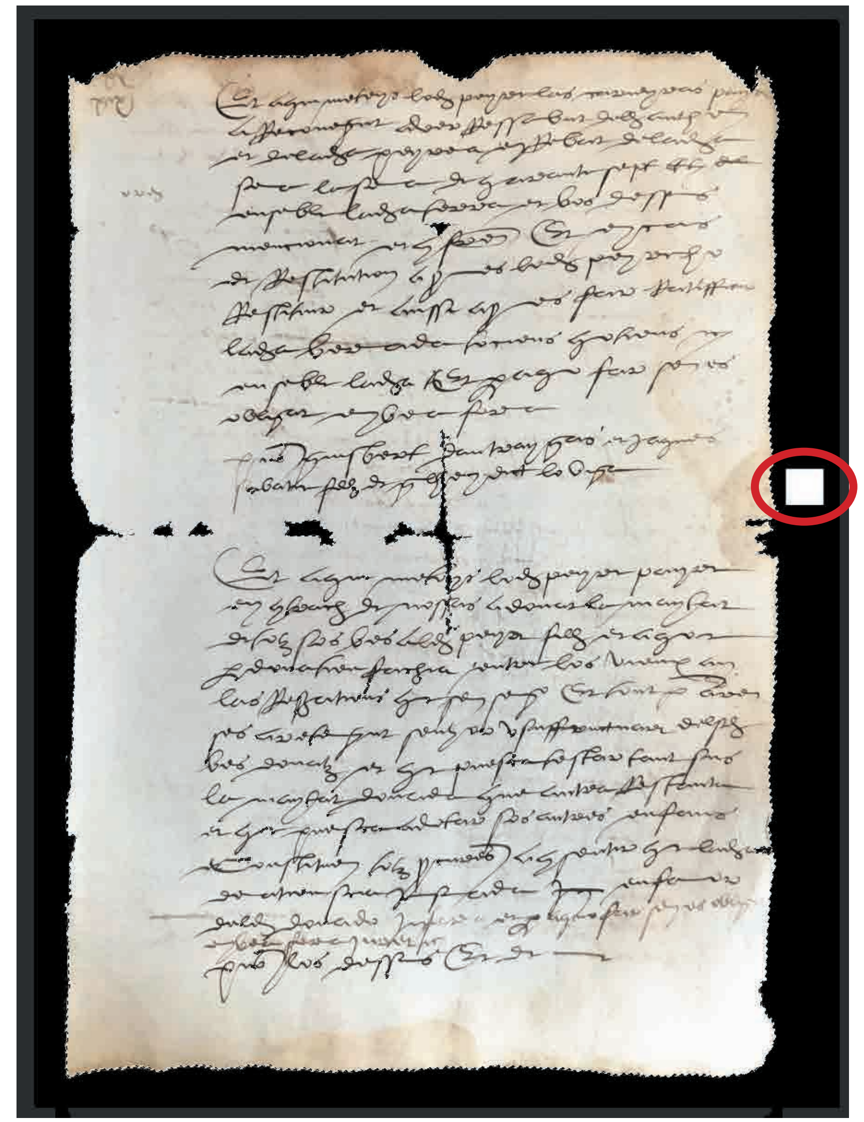
- **Find a paper's grammage** expressed as grams per square meter (GSM or g/m²); enter the paper's mass and dimensions – rectangle or circular sheets
- **Determine the amount of fiber needed** to make a sheet of a predefined size and weight
- **Discover the weight (g/m²) of an irregular**, torn, fragmented leaf of paper
- **Find the concentration of pulp (g/ml) required** to make a paper of a specified weight by entering the height of a paper mould's deckle



The previous, web based version, of *PaperWeight* can be downloaded at www.magnoliapaper.com or https://studio.code.org/projects/applab/sxTKu3jShSOxDjsMHmhR_YKZKe8nOzmW2_3qSO_zCaM

IV

Calculating the Square Centimeters of an Irregular Sheet



Determining the size of an irregular sheet

To find the weight (gsm) of a document, we must first determine its size in square centimeters (sq cm). If the document is irregular, with holes and missing parts, discovering the sq cm can be challenging for even the most dedicated mathematician. This Photoshop technique greatly simplifies the process.

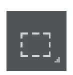
The steps:

1. With a digital camera or smartphone, photograph the document on a black background; be sure to include a 1 cm square piece of white paper in the border. (See example at right)

2. Open the photo in Photoshop.

3. Select the document: use the **Magic Wand** tool to select the black area surrounding the document and any black showing through holes in the document.*

Next, add to the selection the 1 cm white square using the **Marquee** tool. (To do this, hold down the Shift key while you drag a square around the 1 cm white square.)

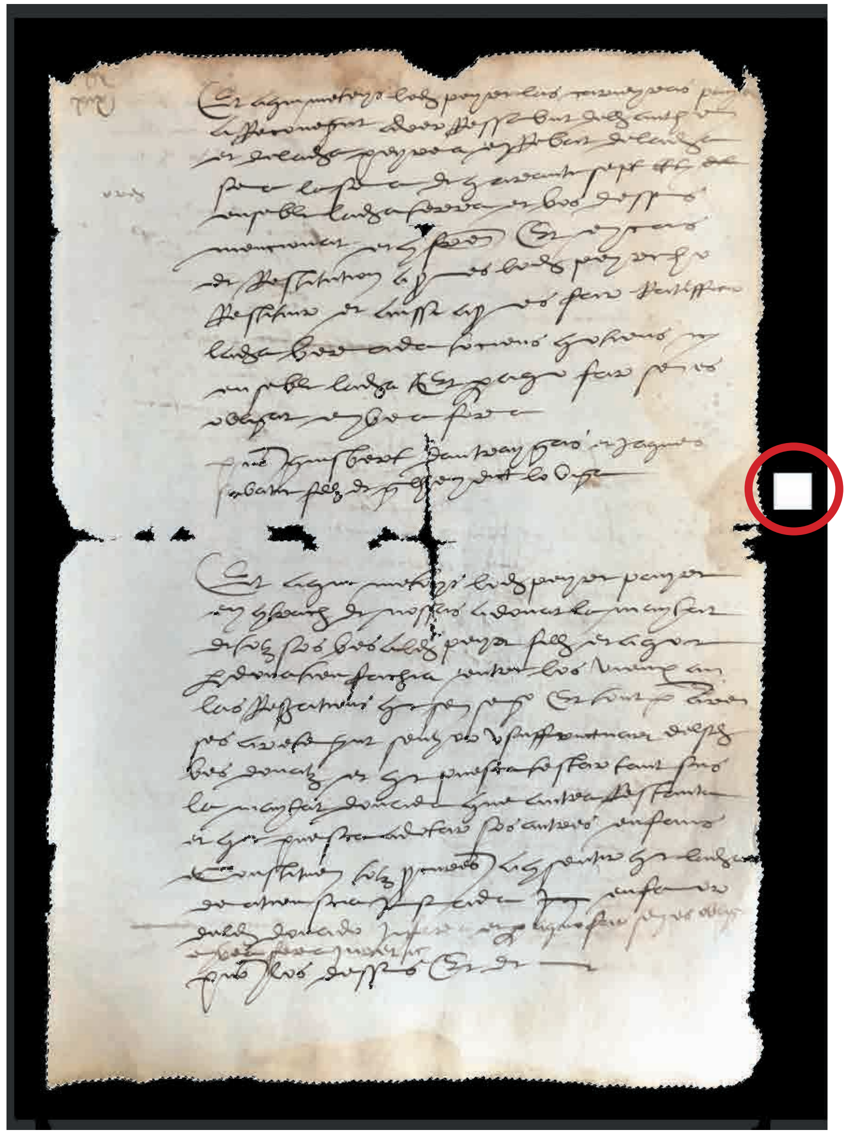


4. From the main menu, choose **Selection/Inverse** to invert the selection so that only the document is selected.

At this point, a marquee ("marching ants") should be moving around the perimeter of the document – holes and all.

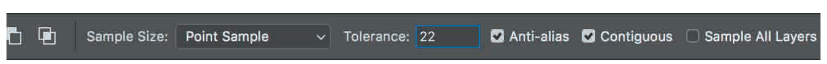
5. Next, open the **Histogram** palette (from the main menu, choose "**Window**" and note if there is a check mark before

Note: the *Magnolia PaperWeight* app makes this calculation simple: Download the app from the Apple App Store and use menu option: ***Pixels***.



iPhone 7 photograph of a document on a black background with a 1 cm square piece of white paper in the border. Note marching ants (marquee) dots around the document but not the 1 cm square (Step 3).

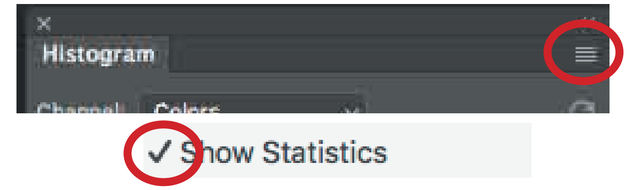
*Magic Wand Palette Settings:**



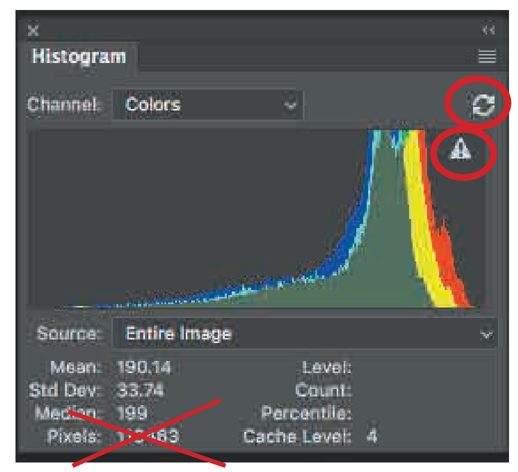
Photoshop's Magic Wand selects pixels based on tone and color. With Anti-alias and Contiguous checked, choose a tolerance that selects all the black while not selecting into the document. Increasing or lowering the tolerance will make the wand choose a larger or smaller range of values. Click areas while holding down the Shift key to add to a selection; click areas while holding down the Option key to remove from a selection. Command+D deselects all. Alternately, if the black is sufficiently different than anything in the document, uncheck Contiguous and all blacks will be selected with one click.

Histogram; if not, click on **Histogram** and the Histogram palette window will appear).

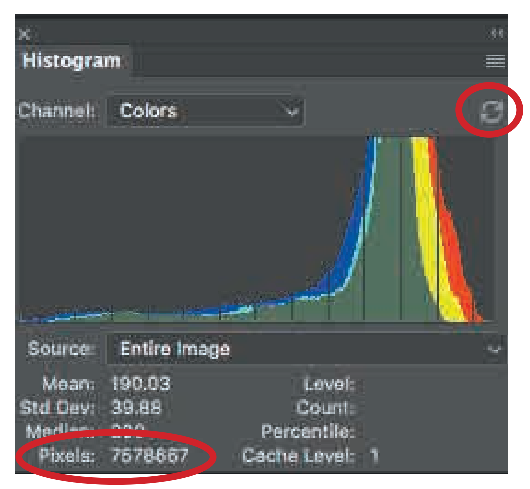
6. Click the pull-down menu of the Histogram palette and click on Show Statistics, expanding the palette.



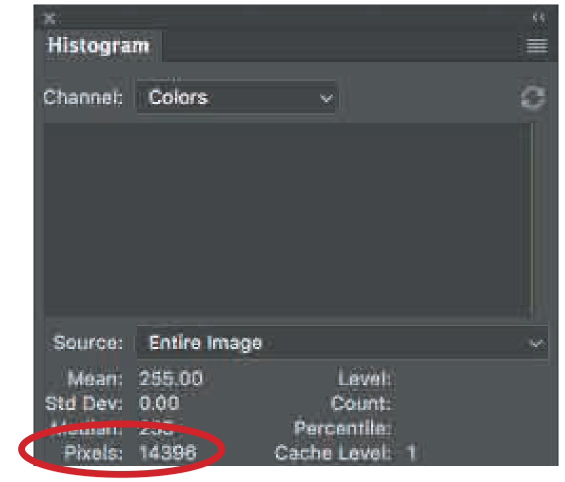
7. If an exclamation mark is visible in the upper right had corner of the **Histogram** window,  this indicates that the pixel count is not accurate and the **Refresh** button  must be clicked to get an accurate pixel count. This step is critical.



Take notice and write down the accurate pixel count; in this case, pixels = 7,578,667 (below):



8. Next, deselect the document (Control+D on Windows or Command+D on a Mac). Now select the 1 cm square using the **Marquee** tool or the **Magic Wand** tool and note the pixel count:



In this case, the 1cm white square = 14,396 pixels.

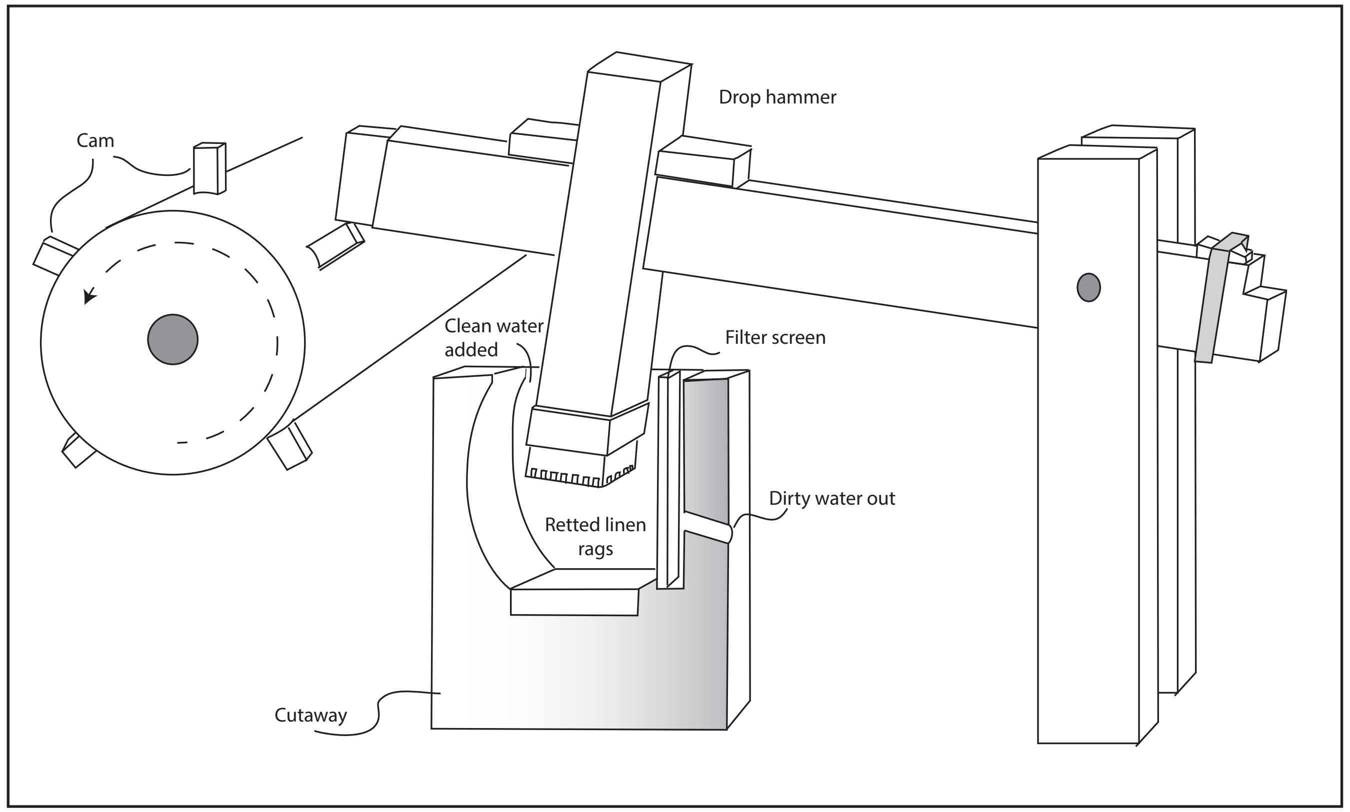
9. Divide the number of document pixels by the number of pixels in the white sq cm to find sq cm for the document.

In this example:
Document pixels to sq cm calculation:
7,578,667 ÷ 14,396 = 526.66 sq cm

Now we have the square centimeters of the document. For the formula we also need to measure the mass of the document. For this I use a balance beam. The mass of the document is 3.1 grams.

Now the accurate weight (gsm) can be discovered:
(mass ÷ area x 10,000 = gsm)

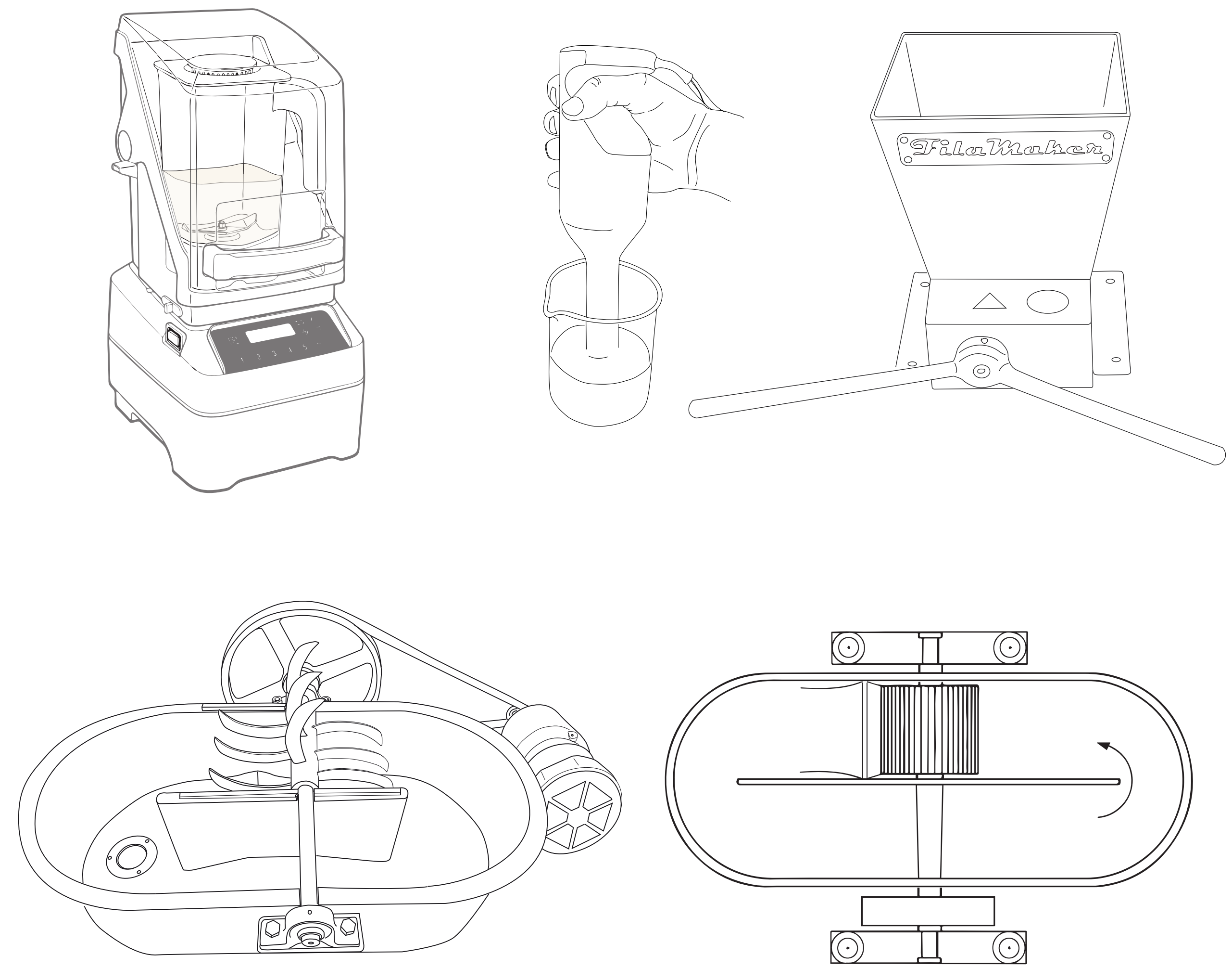
3.1g ÷ 526.66 sq cm x 10,000 = 58.86 gsm



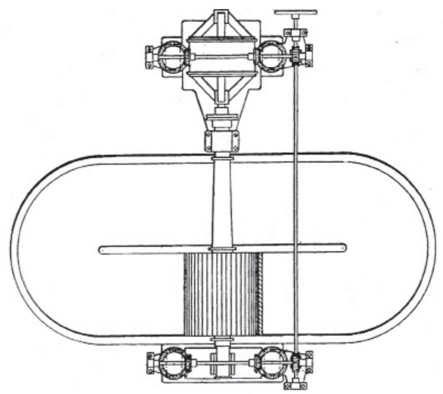
Papermaking drop hammer diagram (see Stamper Mill, p. 31)

V

Processing Paper Fiber



"Paper is made in the beater"



Hollander Beater (beating engine) for processing fiber.

Hydration and fibrillation occur during fiber processing, when the heavy hammers of a stamper and the fly bars of the beating engine pound onto wet shards of linen and hemp rags, causing the fibers of the cloth to stress, fray, and swell with water. Various degrees of hydration and fibrillation are responsible for producing the wide variety of papers we have come to enjoy. Expertise and experience at the processing stage will confirm the axiom that "paper is made in the beater" rather than during sheet formation at the vat: it is at this stage, as fibers are hydrated, fibrillated, separated and made shorter in the beating engine, where the characteristics of the finished sheet are actually determined. While shorter fibers articulate laid lines and are desirable in some watermarked paper, folding endurance, tensile and tear strength are eventually diminished by prolonged processing.

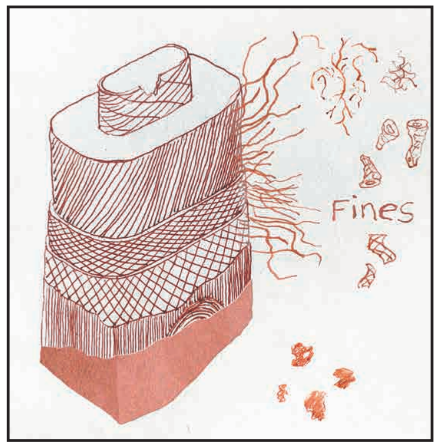


Illustration of fibrillation and fines (from top: fibrils, cut cell ends, and flaky granular material) being released from a fiber and fiber wall.

Processing creates fines and abrades cellulose fibers causing fibrillation so that frayed fibrils extend from the main fiber, increasing the fiber's surface area, and therefore its bonding potential. Increased processing (longer beating times) creates more fibrillation, "wetter" pulp, and harder, more rattly paper with more tensile and tear strength in the finished sheet. However, at a certain point, extended beating weakens the sheet, makes a progressively translucent paper and a paper with less dimensional stability.

Blender modifications

Not always having access to laboratory beaters or stamper mills, most small-scale paper studios rely to some extent on kitchen and commercial food processors and blenders. Unfortunately, the standard thin, sharp blades of this type of equipment catch the fibers, creating knots and tangles; they can also harm cellulose fibers by shortening and cutting the fibers, thereby exposing oxidation sites which weakens the paper and shortens its life expectancy (but cutting also happens in a beater).

In a series of experiments, I substituted the knife-sharp blades of a commercial blender for a bladeless device with hydropulper-inspired vanes. This durable plastic rotary propeller, created using a 3-D printer with PLA filament, hydrates and fibrillates without noticeably cutting or entangling the fibers.

By design, kitchen blenders are made to cut, pulverize, whip and chop ingredients for our culinary pleasure. Their sharp cutting blades are always the leading edge of their (counter-clockwise) rotation. A simple modification to the blender blade assembly of a Hamilton Beach commercial blender disables this cutting edge: simply disassemble, invert, and reassemble the blades so that the cutting edge is the trailing edge and the blunt edge is the lead edge. This easy switch (brought to my attention by artist Guy Diehl) potentially produces more "beating" and less cutting during processing. Freeness tests done with this inverted blade produce results comparable to the hydropulper blade.

Pulp & furnish preparation for blender processing

As previously described, it is possible to **predetermine the grams of raw material** needed to make a specific weight (gsm) paper. For example, to make a 60 gsm sheet for a 5.7 cm diameter paper (2.25 inch) we can calculate using this method that 0.15 grams of dry fiber will be needed. (i.e., processed abaca, flax, or cotton linter, or a combination of the three). Dry half-stuff fibers are best if well hydrated before blending.

Prior to blending, always **soak fibers for at least one hour**[16] – Soaking will increase the tear and tensile strength of the finished sheet. Soaking overnight is recommended. Next add a few grams of $CaCO_3$ and/or $MgCO_3$ as buffering agent and antioxidant. For a more **opaque** and harder paper, add kaolin, (aka China clay) and or white pigment (titanium dioxide). Retention aid can be added at the end of blending to attract clay to fibers, thereby losing less of your additives in the "white water."

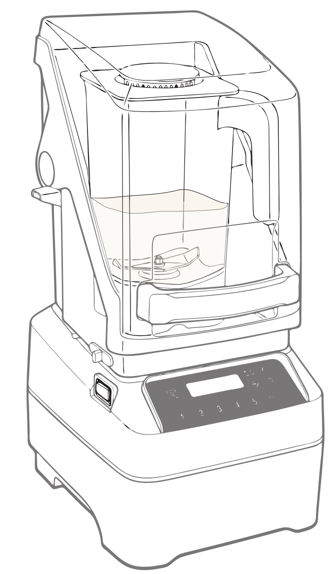
Blend for 2 to 3 minutes in a blender with blades reversed (see next page). After blending, add 10 ml to 25 ml of tororo-aoi (PNP formation aid) for slower drainage, smoother paper formation and a well-formed sheet. Briefly blend again with added formation aid (1 second), decant, and stir or shake vigorously to break up the knots settle air bubbles caused by blending.

16 ***If soaking overnight is not an option use freeze dried furnish.***

1 **Select & weigh fiber:** Use the PaperWeight app to calculate the weight of fiber needed for a specific gsm paper.

2 **Soak the fibers overnight before blending to increase the tear and tensile strength of the resulting paper**

3 **Add water and any additives, then blend until fibers are separated.***

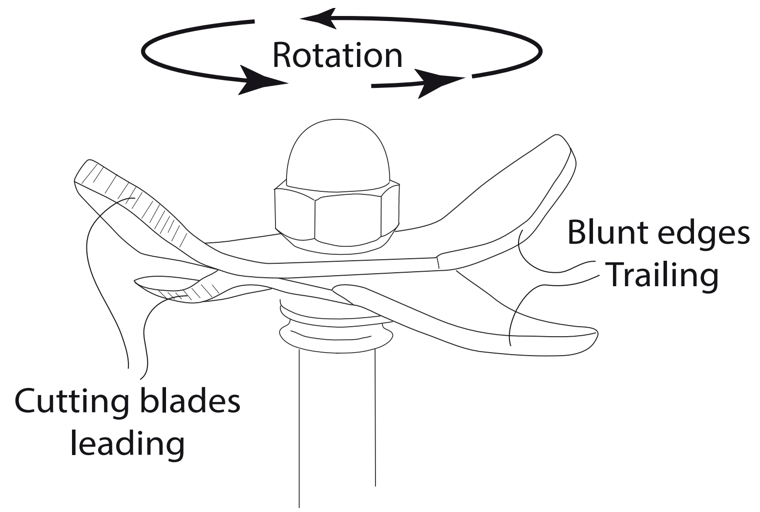


Use caution and be safe with the spinning blades of mixer. Use a GFCI outlet (Ground Fault Circuit Interrupter) to avoid electrocution.

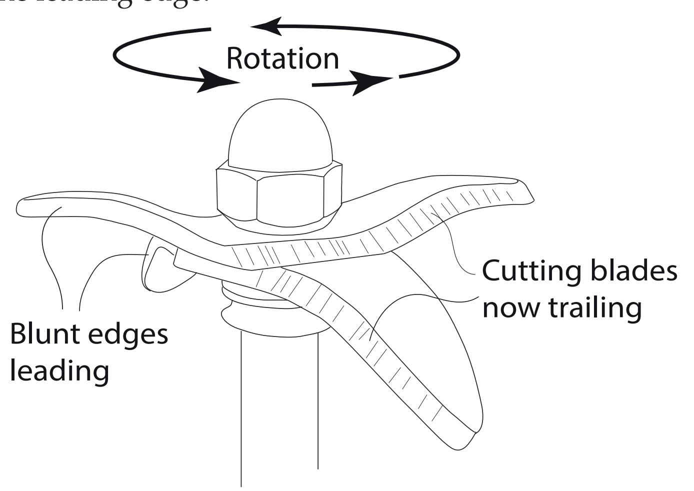
****Blender Notes:*** *In a freeness test of flax and abaca pulp processed in a kitchen type blender, we found that 5 minutes of blending (whipping) reduced freeness from 400CSF to 350CSF and another 5 minutes blending (total 10 minutes) reduced freeness another 50ml to 300CSF. Folding strength rose in the first 5 min and then diminished after 10 min of blending. One strategy to make a kitchen blender more like a commercial hydropulper is to change out the blades for a flat plate with pulp impeller vanes for more hydration and fibrillation with less cutting or if the blender model design permits, detach, invert the blades and reassemble (see opposite page).*

Hamilton Beach blade reversal

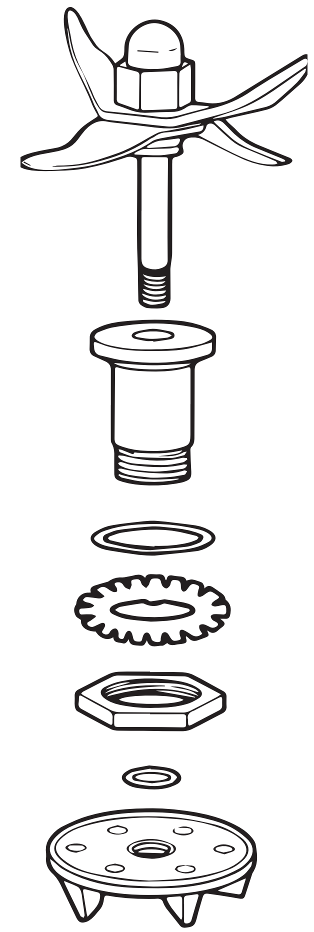
Standard, default assembly:

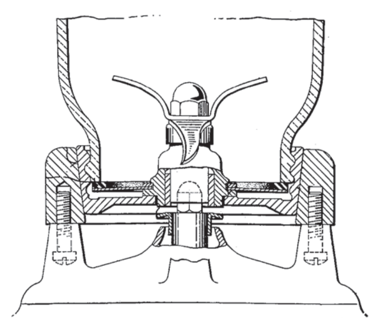


Reversing blade orientation: Inverted blades make the blunt edge the leading edge:



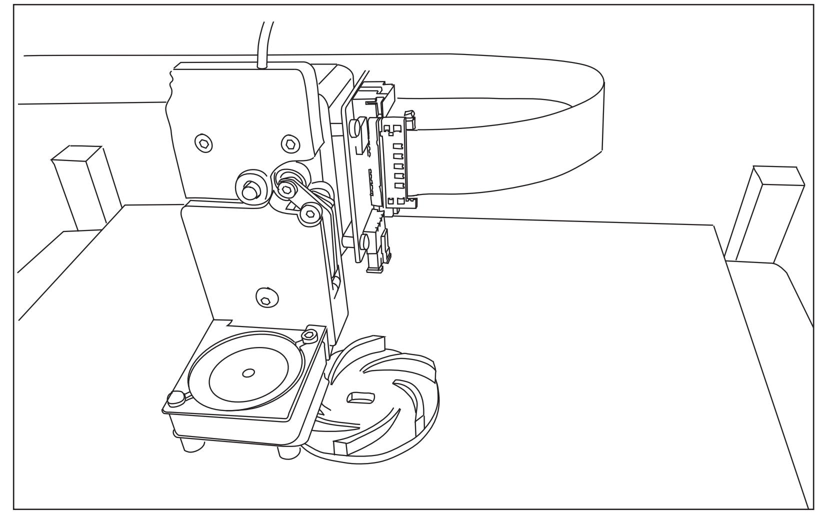
Hamilton Beach commercial blender blade assembly



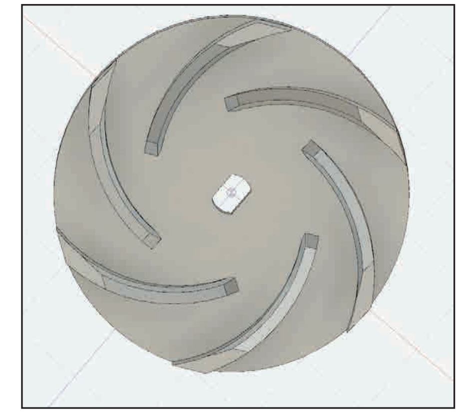


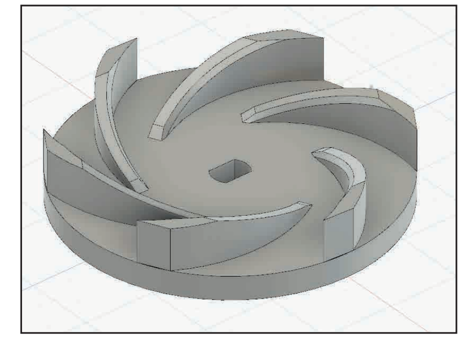
Invert blender blades for less cutting action

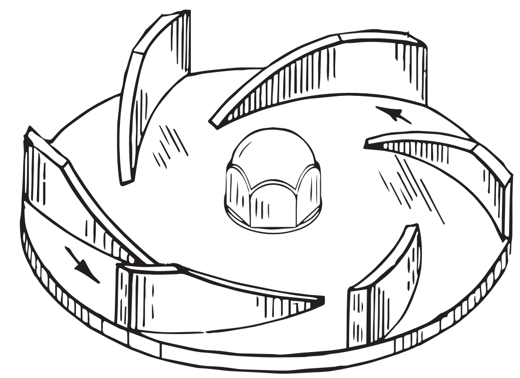
Hydropulper-inspired blender blade



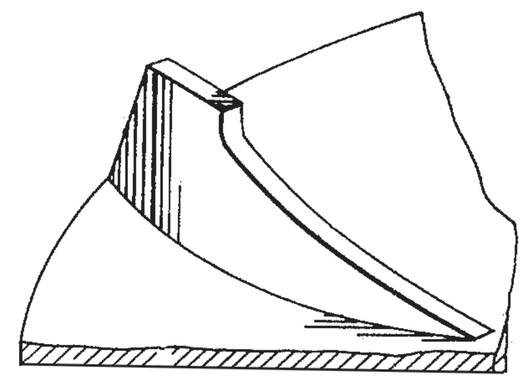
Fabricating hydropulper-style blade on a 3-D printer



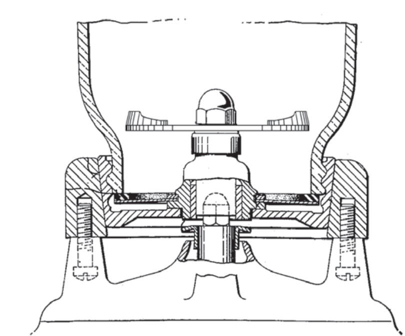




Hydropulper modified blender blade



Hydropulper-style blade (detail)



Blender modification with pulp impeller vanes

An STL file for this design can be found at: www.magnoliapaper.com

Jacques Brejoux and his extraordinary wooden stampers at Le Moulin du Verger in Angouleme, France

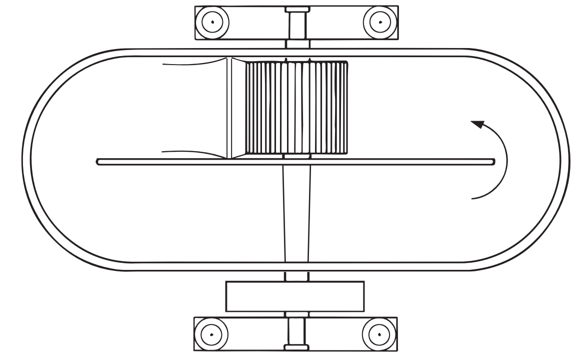
Processing Linen and Hemp

In the fall of 2018, I had the great fortune to visit Jacques Brejoux at his 500-year-old paper mill in Angouleme, France. Jacques uses a series of custom-built, formidably-sized wooden stampers, moving in an asynchronous fashion and dispatched by a large roll similar to the inside of a music box, where the hammers are raised by a cam and allowed to drop. This cinquecento-style processing technology is the unmatched standard which I have attempted to recreate in my paper studio.

There are many factors and circumstances that brought about the characteristics of 15th c. paper. It was manufactured from linen and hemp rags that were sorted, cut, retted (composted) and rinsed (washed) as they were hammered into a “free” furnish, (not “wet” and over-processed). Once formed, pressed and hung to dry, the sheets were sized in a dilution of hot animal skin (hide) glue. The resulting paper was durable, fairly dimensionally stable, flexible, had a nice rattle, and in most cases, the sheets had beautiful “look-through” displaying lovely watermarks of the day.

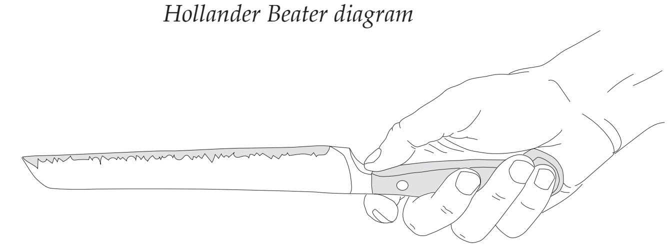
To recreate such a paper one needs to ret, (compost) linen and hemp rags. The retting breaks down the fiber bundles, shortening beating time so they are not overly wet when processed (highly hydrated and fibrillated) in the stamper mill. Retting and beating also shorten some of the fibers, yielding an articulated look-through. While the drop-hammer pulverized the pulp, a trickle of water was introduced to rinse (wash) the pulp, removing dirt, grime and “fines” further increasing freeness. To further speed drainage, the vats had wood-fired heaters to warm the furnish, again allowing for faster sheet formation.

Today it is nearly impossible to find linen and hemp rags that are not tainted with optical brighteners (rendering them useless for fine art papermaking). For non-optically brightened linen we must turn to the cuttings from eco-responsible garment manufacturers. Although these new fabric scraps were disliked by Renaissance papermakers, as they increase retting times tenfold, we must make do. Linen (flax) and hemp fibers hydrate and fibrillate easily; Hollander beaters and other processing equipment tend to make them overly wet. Flax and linen half stuff is available but still requires retting.



Hollander Beater diagram

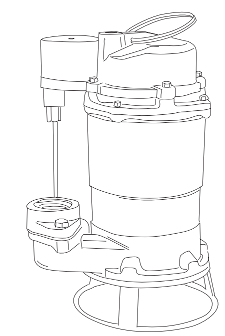
In addition to beautiful felt hair marks, Renaissance papers generally had lovely look-through, showing watermarks (an emblem of the vat man) and laid patterns when held to the light. To achieve this attribute, a percentage of the furnish must be comprised of shorter fibers. To accomplish this in a Hollander beater without over hydrating requires well-retted linen and hemp scraps.



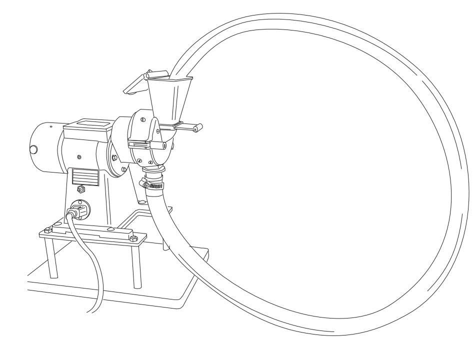
Checking pulp fiber length on the edge of a knife

Process: Cut linen and or hemp scraps to 6 cm squares and compost. After 8 months to a year or two of composting, when the scraps have weakened to the point that they can be pulled apart, wash the scraps. Cooking in soda ash or sunlight bleach in a dilute hydrogen peroxide bath is optional. Fill a Hollander beater with warm water and slowly add the cleaned scraps while applying light pressure (beater roll to bedplate). Slowly increase the pressure to “break” the cloth scraps down to half stuff. When you see that the threads have unraveled and turned to pulp, beat your fiber hard (to shorten the fibers). Avoid over-processing; do not make the “stuff” too “wet”. Make the beater “sing” and remember to wear ear protection. Test the fiber length with the edge of a straight knife from time to time while processing. Lift a knife through the pulp (sharp edge up) and have a look at what catches on the cutting edge; this way you can watch the fibers in the pulp shorten while processing. Fibers shorten faster with less hydration in a less viscous suspension. Therefore, for a good look-through, use more water and less half stuff.

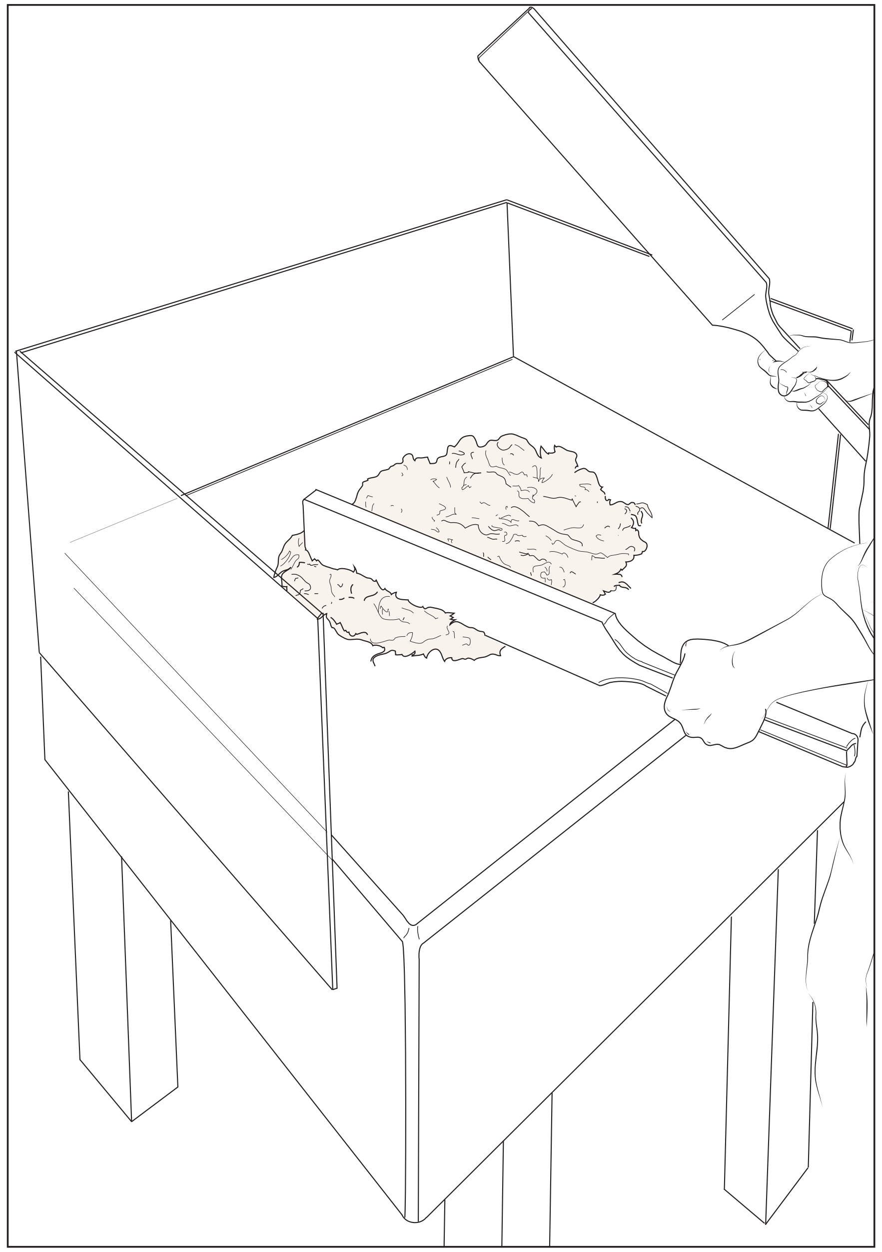
Failed attempts to approximate a stamper mill



Grinder mill: In my quest to find unconventional beating engines that might more closely approximate the stamper engines of the past, I tested a BURCAM 400700P 3/4 Hp Sewage Grinder Pump. I believe this is a somewhat viable processor for de-fibering half stuff for the creation of a dimensionally stable finished paper. It may also possibly be useful for making cotton pulp for casting. The lack of hydration using this recirculation “grinder pump” was not sufficient to produce viable hand-formed sheets. The pump did clog from time to time.



Glen Mills Culatti MHM-4 Micro Hammer Cutter Mill: Another possible candidate as a laboratory pulping processor, this hammer mill is designed to crush aggregate material into smaller pieces by the repeated blows of small hammers. I attached a 1” interior diameter hose to the output and looped it around to the input hopper in a five-foot circumference. Testing with water, the hammering action acts like a pump, moving 1 liter of fiber and water fast and efficiently around the five-foot loop. Unfortunately, the tiny micro hammers, while suitable for crushing grains, proved insufficiently powerful for processing pulp. Ultimately, my conclusion regarding both devices: Not ideal and not worth the effort.



Beating kōzo on a solid butcher block table: flatten the pile of cooked bark with alternating blows of the beating paddles, then gather the flattened mass and rotate it 90° to ensure all bark is evenly pounded.

Cooking and hand beating kōzo bark

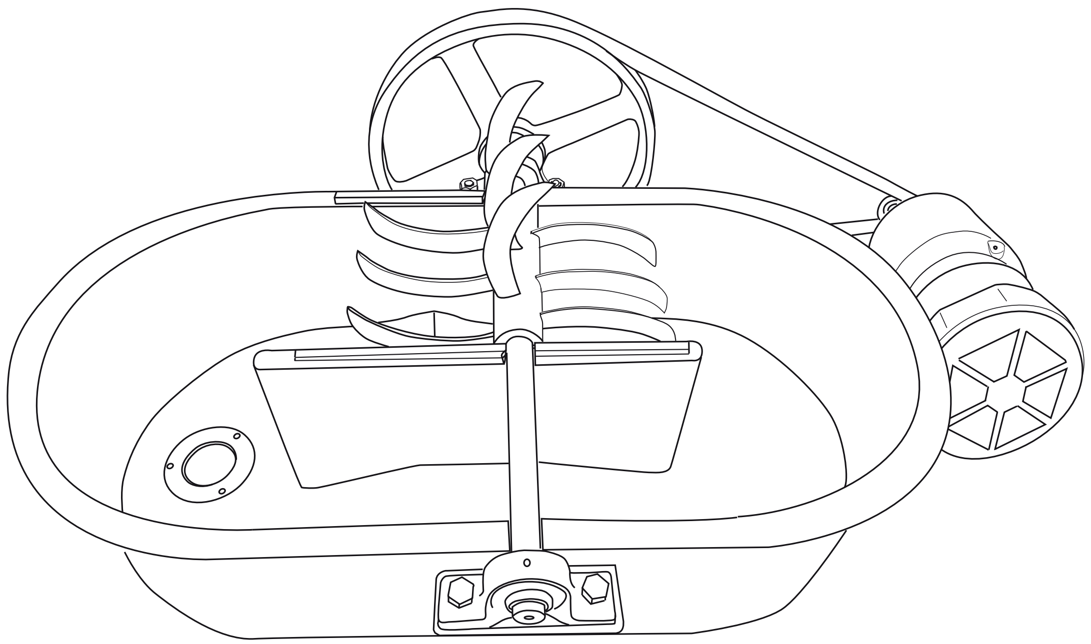
Cooking and cleaning kōzo bark to a large extent determines what the finished paper's characteristics will be. Bark cooked with more or stronger chemicals for a longer period at higher temperatures will produce a softer more opaque paper. Bark processed with a minimum of chemicals for a shorter time will produce crisper and stronger paper. These processes call for the use of soda ash, a caustic substance which requires careful handling.

1. Soak kōzo bark overnight in fresh water to soften fibers, then drain.
2. Fill a stainless steel or enamel pot with water and bring to a boil. Never use an aluminum vessel as it will react with caustic solutions.
3. Slowly stir in approximately 4 to 8 ounces of soda ash per pound of dry bark.
4. Carefully add bark to the boiling water.
5. Bring mixture back to a boil and simmer immediately.
6. After two to three hours of cooking, test a length of bark to see if the fibers will separate. If by pulling on a short, narrow piece of bark it separates with a slight tug, the bark is done. If not, continue cooking and test every 15 minutes. The longer the cooking time and the easier the fibers pull apart, the softer the resulting paper.
7. Rinse cooked fibers by pouring them into a colander and flushing with water until the runoff is clear.

The cooked, rinsed and cleaned kōzo must next be beaten to further break down the bark. As this breakdown occurs, the fibers separate. This enables the fibers to disperse when stirred into water. It is a somewhat noisy process. Thick, firm beating surfaces help minimize the din.

1. Select a quantity of pulp equal to that needed to make a loaf of bread. Squeeze out the excess water and place the pile on a sturdy and not-too-cherished surface.
2. Pound the pulp using a beating stick, wooden mallet or the like.
3. As each blow strikes the bark, notice how the impacted strands expand under the force. If this does not occur, the blows are not sufficiently forceful.
4. After flattening the pile of pulp with consecutive blows, push pulp back together, rotate 90 degrees and continue beating. From time to time, invert the pile and fold in the ends.
5. Continue beating for 10 to 20 minutes.

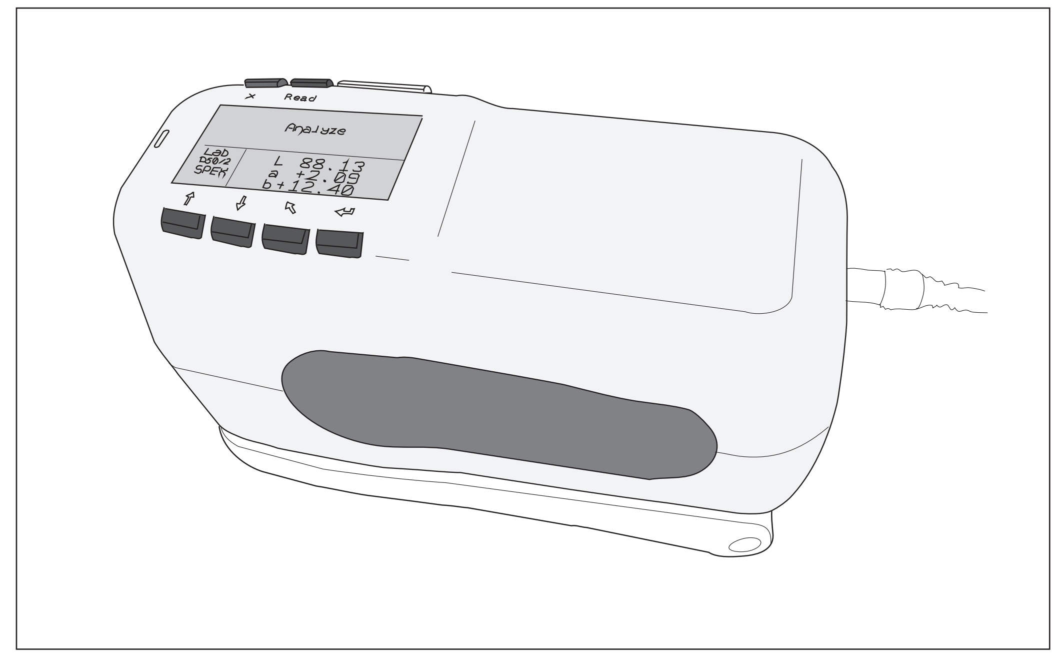
Safety: Alkali chemicals such as soda ash can burn the skin and eyes, and should always be added to water and not the reverse, as spattering can occur. It is also a good idea to wear rubber gloves, a vinyl or rubber apron, and safety glasses when handling such chemicals. Even in a diluted state these chemicals have a drying and cracking effect on the skin, so **wear rubber gloves**. Caustic soda (NaOH) is not recommended: it is dangerous to handle and very harsh on the fibers.



Naginata beater *used to separate cooked kōzo, mitsumata and gampi – a modern day machine designed to defiber paper mulberry.*

VI

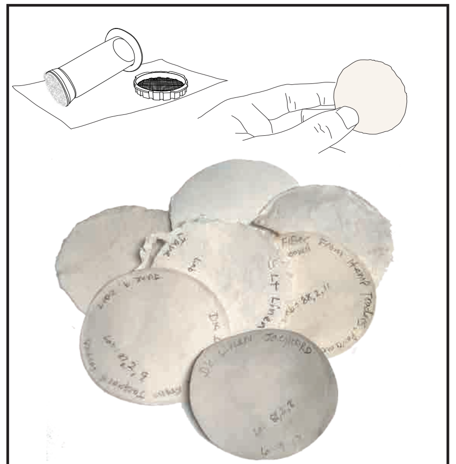
Paper Color Matching



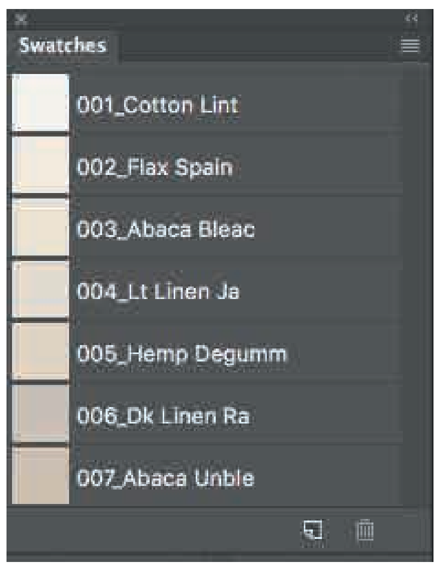
Calculating & blending half-stuff to visually match a target paper color

Spectrophotometer Settings: *On the X-Rite Sphere spectrophotometer, I use D50-2 (a human viewing color in a 5000° light at a 2° angle-of-view). "Analyze" is selected in the menu of the device; "Spectral highlight" is off. I set the preferences to average 3 sample reads to get a more accurate Lab result.*

Whereas Lab color is designed to approximate human vision and is device-independent, RGB is the color space for computer monitors and CMYK is the color space for process printers; hence my use of Lab.



Paper color test sheets made from natural fibers with the addition of MgCO3, CaCO3 and formation aid (made with an AeroPress)



Expanded Photoshop Swatches palette with seven colors of pulp

Creating a paper of the same color (value and hue) of a target sheet is often done by trial and error or in-painting/tinting after the fact. To make a paper with a more accurate infill paper color, a spectrophotometer and Photoshop can be used to calculate the relative percentages of available dry pulp (half-stuff) needed to create a specific paper color when blended.

Note: *For these tests the half-stuff pulps were sourced from handmade paper suppliers. Additionally, I found various sources for raw fiber and textile cuttings that I processed into dry half-stuff; shredding, retting, cooking in soda ash, washing and beating/breaking in a Valley Iron Works beater. Additives: MgCO3 and CaCO3 were added during breaking. I made the furnish in an inverted-blade-blender for 2 to 3 minutes and added formation aid prior to sheet formation.*

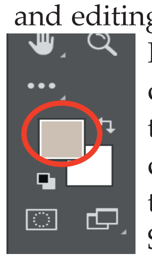
X-Rite Sphere Spectrophotometer

(1) Make and document test pieces of paper from available pulp half-stuff you have on hand. (Use the efficient AeroPress techniques for making small sheets). With the spectrophotometer set to "Analyze," measure the Lab values of each test paper.

Fiber	L	a	b	
Cotton Linter	97	0	3	
Flax - Spain	94	1	6	
Abaca Bleached	92	1	8	
Lt Linen	90	1	7	
Hemp - Degummed	88	2	11	
Dk Linen	81	2	8	
Abaca Unbleached	81	3	11	

Documented Lab values of the sample sheets

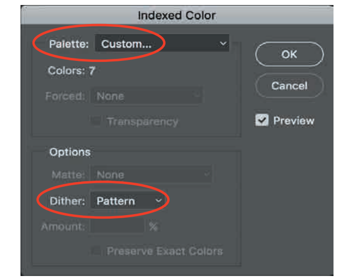
(2) In Photoshop, delete old swatch colors and make a new Swatch Palette propagated with the Lab values of colors obtained from your sample sheets. Swatch colors are made one at a time by clicking on the Tool Palette foreground color and editing the Lab values in Color Picker. When you add a color to swatches it will be the foreground color you created. When all colors have been named and added to Swatches, click the palette menu and choose Save Swatches. Save as PulpPalette.aco



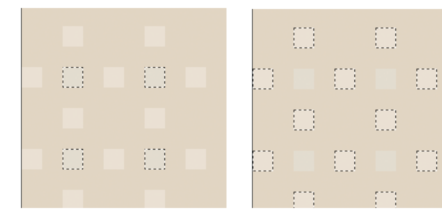
Swatches palette: "Pull Down Menu" & "New Swatch" circled

(3) Use the spectrophotometer to measure the Lab value of the target sheet, sampling from non-image areas where the paper is not stained. Within Photoshop (in 8-bit RGB mode) make and fill a 10 pixel x 10 pixel rectangle with the Lab value of the target sheet. *Note: In a 10 x 10 pixel square there are 100 pixels; although this small size is sufficient for our purposes, a 100 x 100 pixel document would be more accurate, giving 2 decimal places in your pulp-blending percentage formula.*

(4) Next, select from the main menu: Image > Mode > Indexed Color. To load your Pulp Palette use the pull-down menu: Custom > Load; find your PulpPalette.aco that you made of your pulp colors. Within that dialog box, change the settings to: Dither = Pattern, Forced = None and click OK. Photoshop will choose the closest colors in the PulpPalette.aco to render your target color.
Note: The more colors of pulp in your palette, the more accurate your result. Photoshop's limit is 256 colors (8 bit).



(5) Your small square is now "indexed" into the colors of your PulpPalette.aco. Zoom in so you can see the pixels. In this test, Photoshop chose three of the seven colors of pulp to best match our target color: Hemp, Bleached Abaca and Lt Linen Rag. *Note: To discern which fiber type a pixel value represents, open the Info Dialog box (from the Window pull-down menu). From the dialog's pull-down menu select Palette Options and set the CMYK space to show Lab values instead. Now, when you mouse over a pixel, you will see a Lab value of a pixel which you can compare to your master pulp list.*

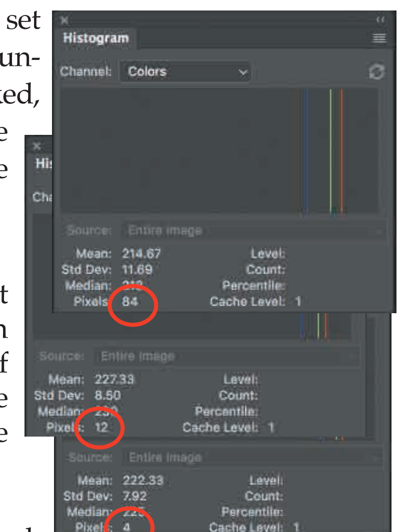


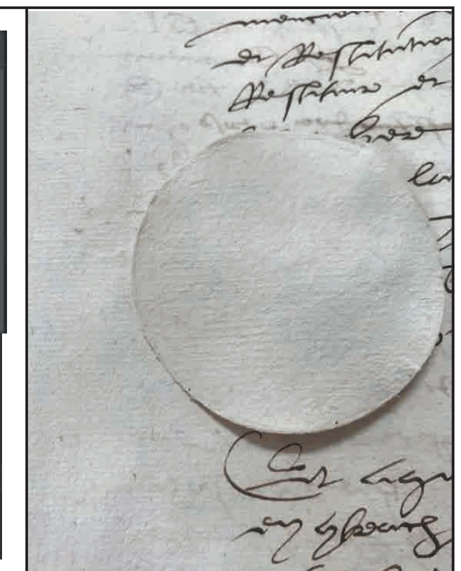
Lab values: 88, 2, 11 = Hemp (84)
92, 1, 8 = Abaca bleached (12)
90, 1, 7 = Lt. Linen Rag (4)

(6) With the Magic Wand Tool set to a tolerance of 1, Anti-alias unchecked and Contiguous unchecked, choose one of the values with the magic wand. All colors of that value will then be selected.

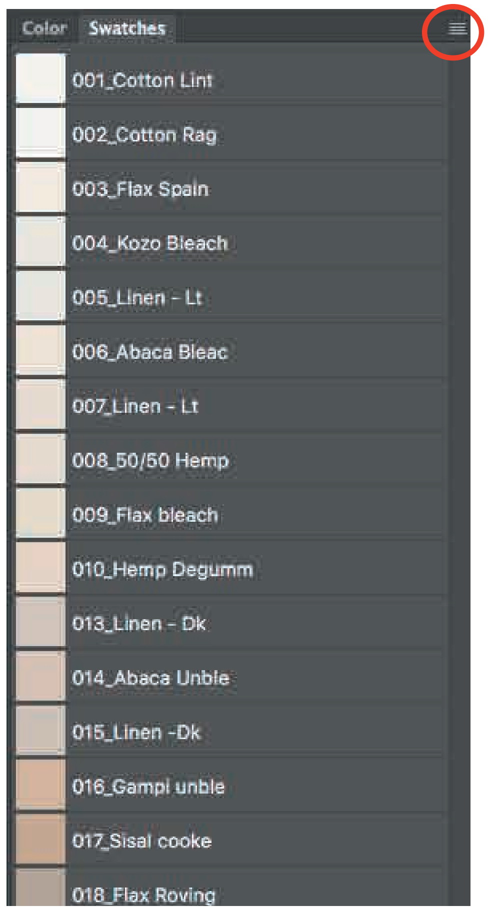
As you select each of the 3 different sets of color pixels, the Histogram dialog box will show the number of pixels selected, which represents the percentage of pulp that should be used of each fiber type.

For this test, the fibers will be blended in the following proportions:
84% Hemp • 12% Bleached Abaca • 4% Lt. Linen





The result of this test: AeroPress laid paper made in test proportions, photographed on our target page from a 1547 manuscript.



Expanded Photoshop Swatches palette in Large List view

Swatches palette in Small Thumbnail view
Cotton linter, cotton rag and sisal have been set to black to prevent them from being chosen.

Making subsets of pulp color palettes:
When working with a more extensive pulp color library, colors representing unwanted fibers may be turned off to eliminate the selection of those fibers. For example, when making a 16th century paper repair, the bright whites of cotton rag and cotton linter might not be desirable. Since we are indexing to a palette of available colors, we must remove the unwanted color(s) from the palette and then re-index, per the steps below:

1. In the Swatches palette drop-down menu, choose “Replace swatches” and select your saved pulp color palette. Be sure you are viewing swatches in list view: in the Swatches palette drop-down menu, choose “Small Thumbnail” or “Large List” view. If you labeled your colors, the name of each fiber will appear alongside its swatch color in “Large List” mode.

2. Open Preset Manager from the Swatches palette drop-down menu.

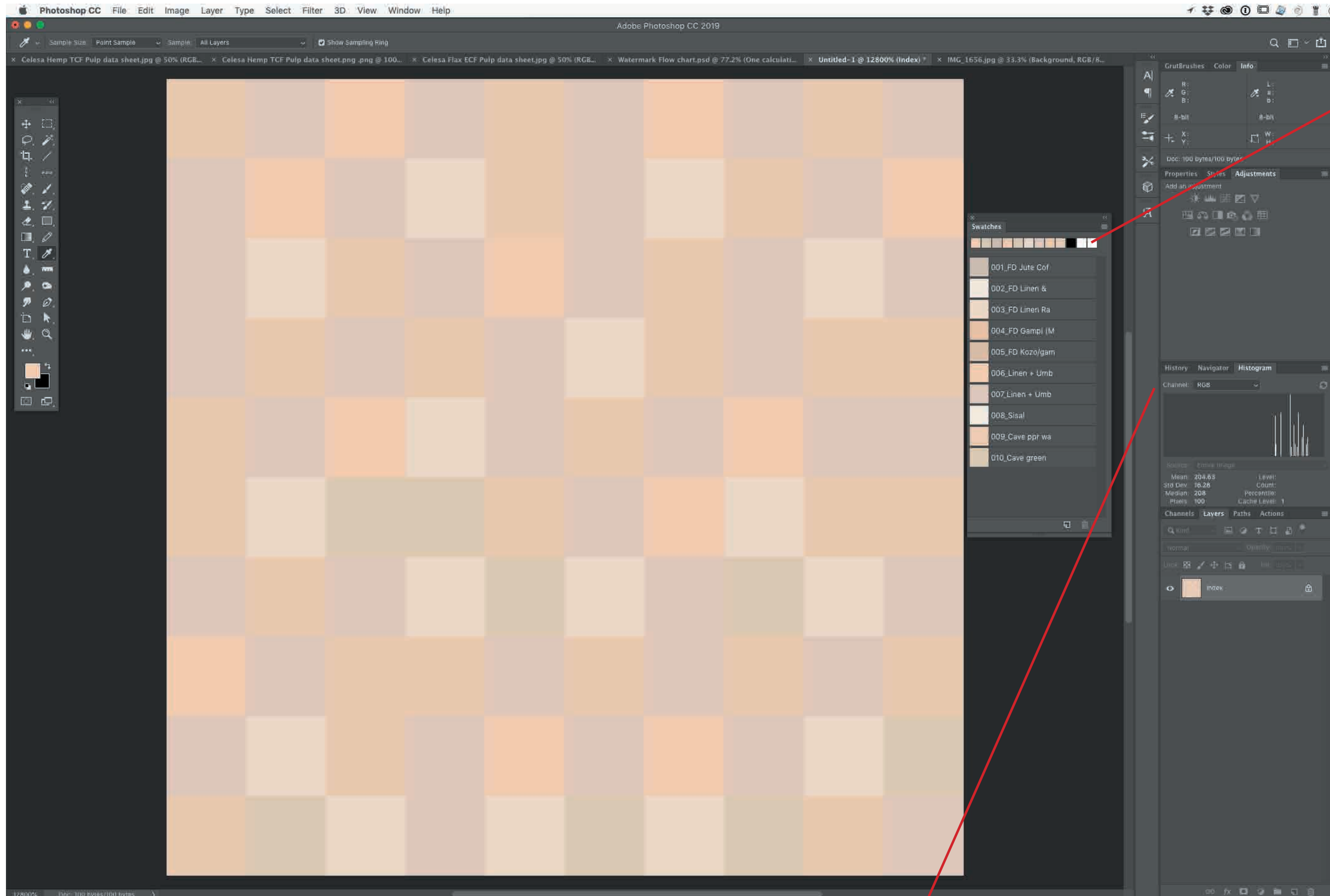
3. Within this dialog box, right-click (control-click) on the swatch and delete the undesirable fiber color(s). Alternatively, set their Lab value to 0,0,0 (black).

4. Select “Save swatches” from the Swatches palette drop-down menu. Take note where you are saving and choose a unique name, noting removed fiber(s).

	Magnolia Pulp Swatches				6/24/17
	Description	L	a	b	Color
1	Cotton Linter	97	0	3	
2	Cotton Rag Bleached (Cheny)	96	0	2	
3	Flax Spain	94	1	6	
4	Kozo Bleached H2O2	93	0	5	
5	Linen - Lt RL Marin	93	0	4	
6	Abaca Bleached	92	1	8	
7	Linen - Lt Jacquard	90	1	7	
8	50/50 Hemp dg, Lt Linen Jacq	90	1	8	
9	Flax bleached Cave ppr 1/4" cut	90	0	9	
10	Hemp Degummed	88	2	11	
11	Jute Mexico Coffee Bag	87	2	10	
12	Kozo Unbl solvent exchange	84	3	12	
13	Linen - Dk Rag jacquard	81	2	8	
14	Abaca Unbleached	81	3	11	
15	Linen -Dk RL Marin	80	2	9	
16	Gampi unbleached	77	4	17	
17	Sisal cooked hand beaten	73	4	17	
18	Flax Roving Cooked	69	2	10	

Example: an AeroPress test sheet reveals the need to remove Sisal (color 17) from the palette:
In the test on the left (paper disk), my sisal half-stuff (made from retted coffee-bean sacks) was part of the color formula but added many speckles that were not appropriate for the project. After removing that swatch and re-indexing to the limited palette, I had a new recipe with which to work, sans sisal. Photoshop compensated by adding more and less of other swatch colors, resulting in a color blending formula that was nearly perfect.

Case study: color matching from a library of freeze-dried pulp

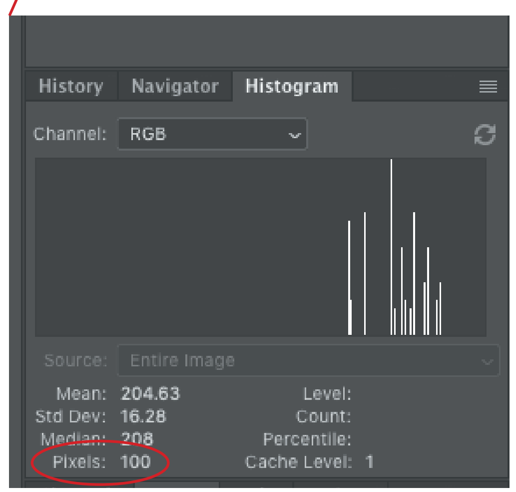


Photoshop screen capture showing the target Lab value of the book paper indexed (100% dithered) into a pulp library of 10 colors of freeze-dried pulp

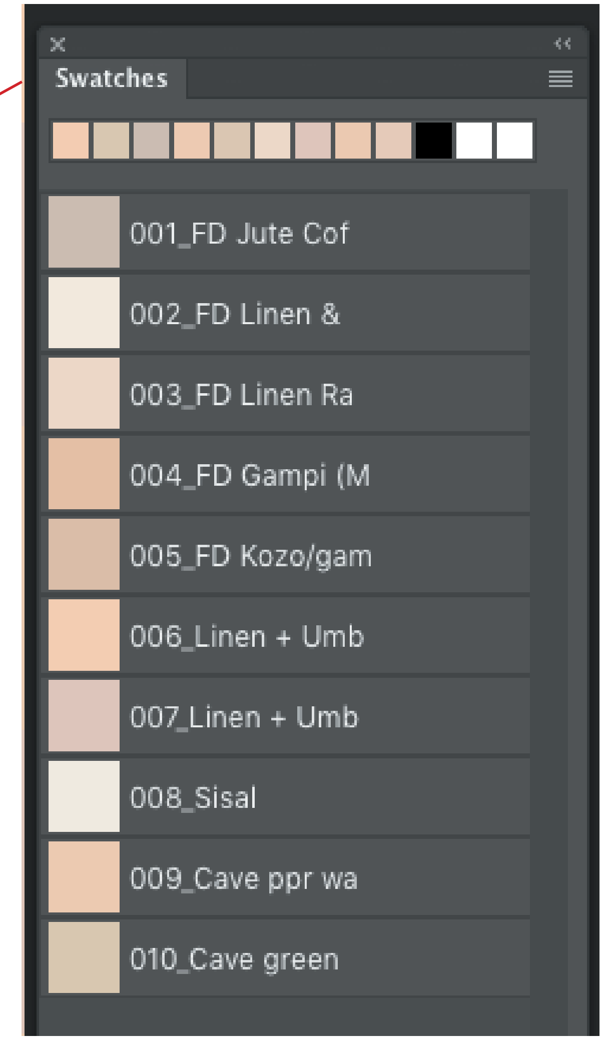
In this case, we sought to match the color of an antique book leaf (see p. 113 for the full case study). After surface cleaning of the leaf to be repaired, sphere spectrometer readings were taken to find the paper's average Lab color value (our target value). Having already prepared a library of ten colors of freeze-dried pulp from various fibers, the target value of the book paper was digitally indexed (100% dithered) using Photoshop to determine which colors from the library, and what ratio of each one, would yield the desired color.

Calculating fiber percentages to match book leaf paper color

The 10 x 10 pixel document (above) started as the target color (Lab 85, 3, 14) and was indexed into pulp library colors. Each pixel value was then selected one at a time and the number of pixels of each selected value was noted (below). The number of pixels selected can be found in the Histogram palette. The five different colors in the indexed image represent a combination of five pulps from our library of freeze-dried pulps in specific amounts. The number of pixels of each color (representing a different freeze-dried pulp) in our 100 pixel (10 x 10) document can be put to practical use as a percentage of the total: i.e., if 38 pixels are indexed to a particular color of freeze-dried pulp, we know that we need a mixture containing 38% of that color.



The Histogram palette showing, among other things, the number of pixels selected



Swatches (Lab values) in our freeze-dried pulp library

Here, calculations suggested the following pixel values and percentages for each indexed pulp type:

Lab: 83, 4, 10 (38 pixels) 38% linen – umber
Lab: 86, 5, 19 (11 pixels) 11% linen – ochre & umber
Lab: 83,1,16 (8 pixels) 8% Cave paper – green tint
Lab: 85,4,18 (27 pixels) 27% Cave paper – warm
Lab: 89,2,11 (16 pixels) 16% linen rag

Selections from each of the five freeze-dried pulps were weighed out in exact quantities on a small scale and then blended together in water with just enough formation aid to flow smoothly. Using two grams of dry fiber per liter of water made it easy to calculate the fraction of fiber (g) we needed for the small infill.

A quick calculation in *PaperWeight* indicated the small grammage needed to make the fill.

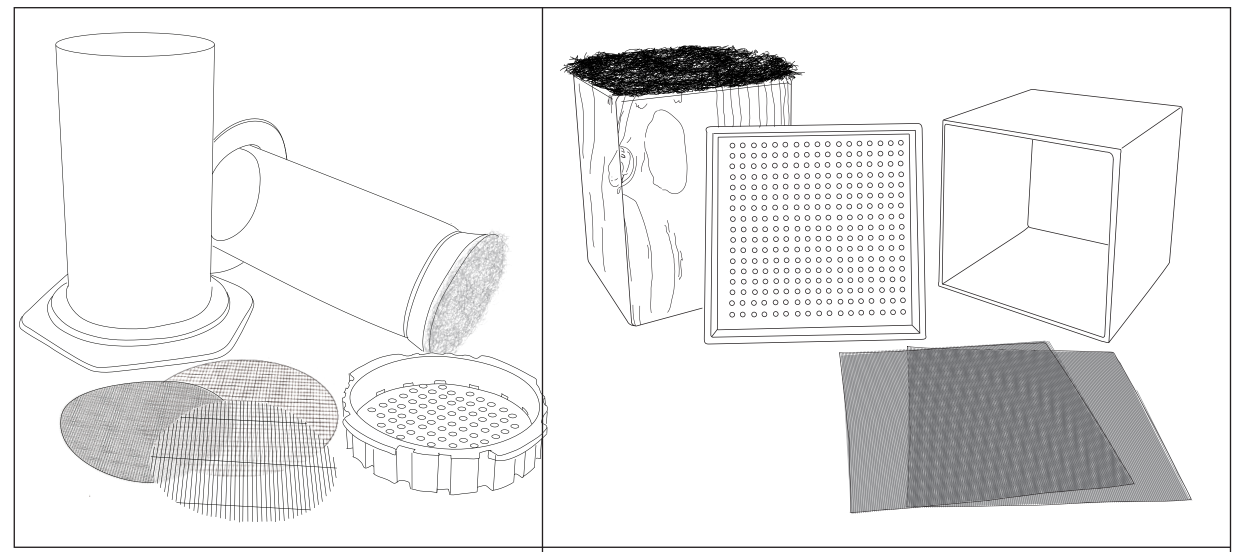
Weighing the freeze-dried pulp in the percentages suggested by the Photoshop indexing dither

Color matching: looking into the blender at a selection of five freeze-dried pulps that accurately matched the book paper's Lab color value. (I'm amazed that this actually works...)

VII

Making paper with a 3-D printed deckle box

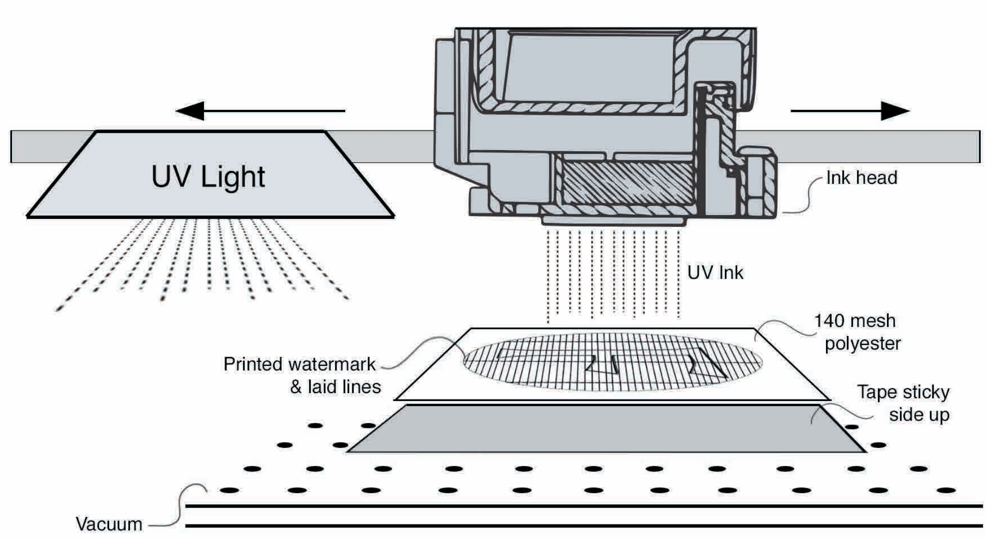
and an Aerobie® AeroPress®

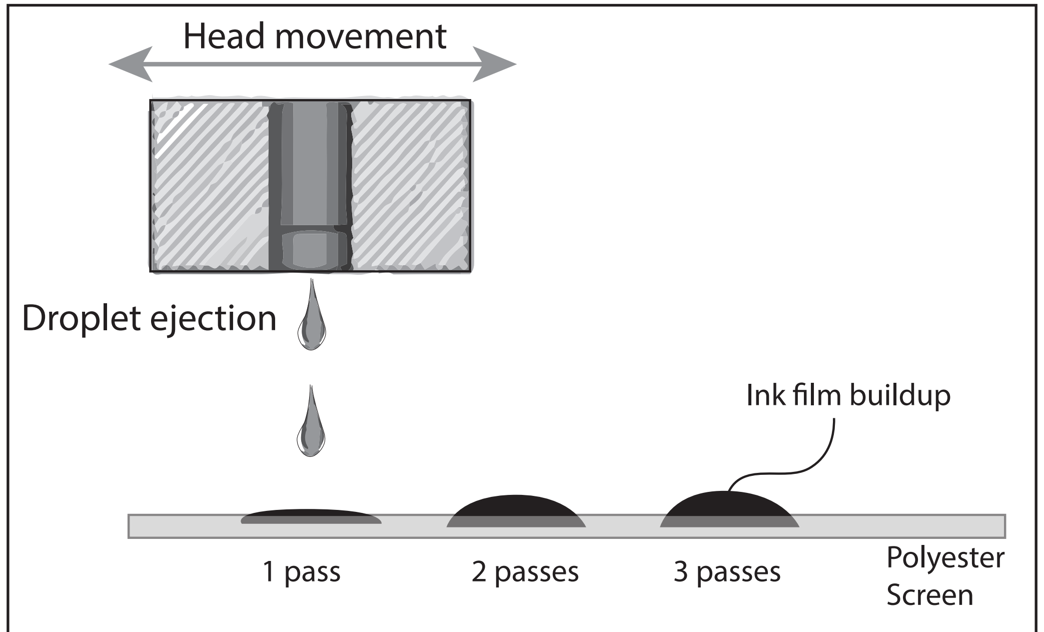


Modifications & screen/felt preparation

When making handmade paper at smaller scale, it is possible to make custom watermarks and laid screen patterns on wove screen surfaces using silkscreen or UV inkjet printing. We design our laid lines and watermarks using Photoshop, creating files at **300 ppi** and printing them on **86 mesh polyester**. For improved results, we printed each file multiple times to build up ink thickness (possible using a UV printer). Between printing passes, we modified the Photoshop file, reducing line thickness so that the ink build up was pyramidal, mimicking wire curvature.

Watermarks & Laid screen printed on a UV Inkjet printer:

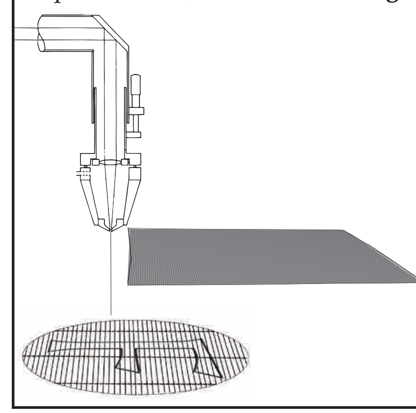




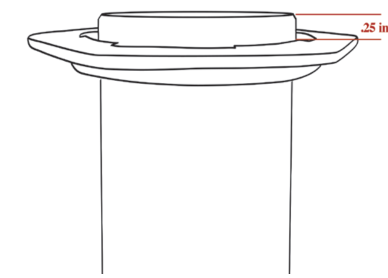
Wove screen: To make wove paper, use 38 mesh polyester screening; use two of these for wove paper to interrupt the pattern of holes in the end cap. Copper or brass screen may also be used.

Laid screen: A laid pattern or watermark can be made by using a UV acrylic printer to print a pattern onto a 86 mesh polyester screen used in silkscreen.

Laser or hand cut the perimeter of the screens: for UV printed circular screens, to a **6.3cm diameter;** for Deckle box square screens, to an **8.3 cm rectangle.**



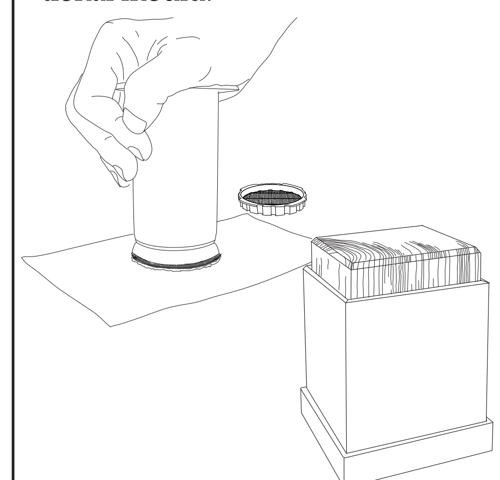
For the AeroPress, the Deckle Cylinder lip must be sanded to accommodate two or three layers of screen. Use a sanding block and take 0.03 or 0.04 of an inch off the top plane of the lip to hone it down to 0.635 cm stand-off (0.25 inch proud). Too much sanding is better than too little.



Affix a 5.7cm diameter felt to AeroPress (or a 7.6 cm square of felt to Deckle Box) using a minimal amount of spray cement.

Felt: Use 50 to 60 micron fleece to approximate a 16th-century texture. Use 20 to 30 micron fleece felt to make a paper with a smoother surface texture. (Woven felts with finer fleece became common in the 18th century, eliminating the felt-hair textures of earlier centuries when papermakers used a non-woven, coarser fleece felt.)

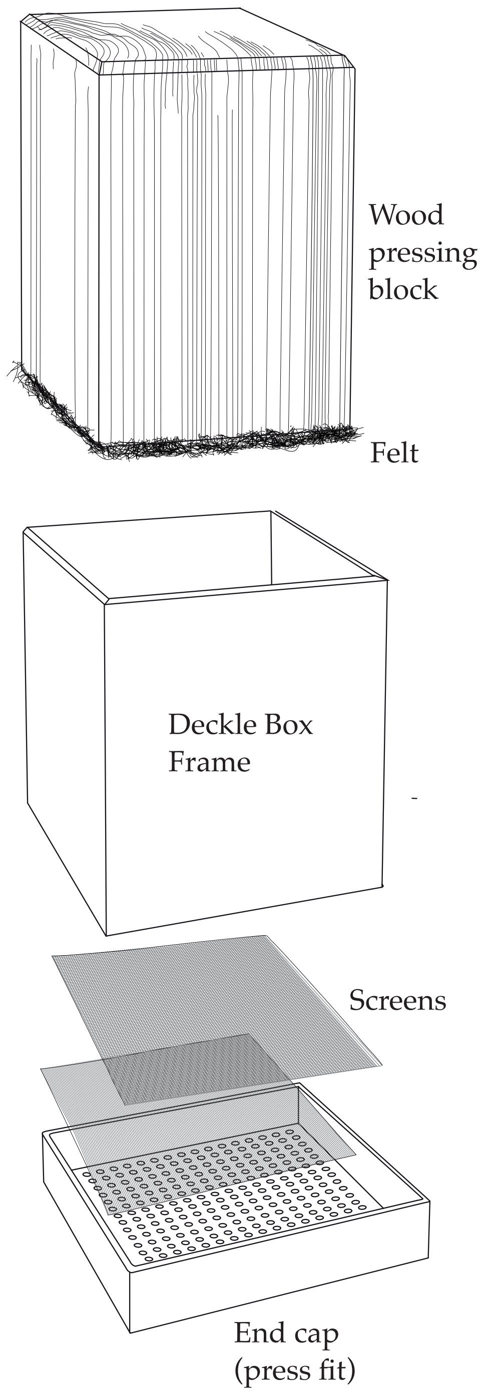
AeroPress and Deckle box instructions are very similar, besides the fact that the AeroPress is cylindrical and the Deckle Box is rectangular. That said, **it is easier to form an even sheet using the deckle box**, as the waves created are linear and have more in common with a traditional mould.

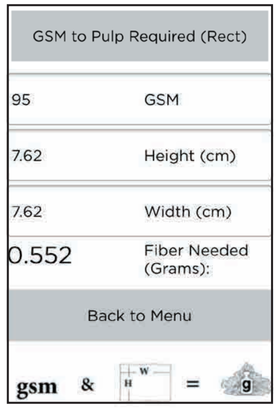


Forming a square sheet of paper using a 3D printed deckle box

6.7cm (3 inch) square

Small Deckle Box parts
6.7x 6.7 cm (3 x 3 in)

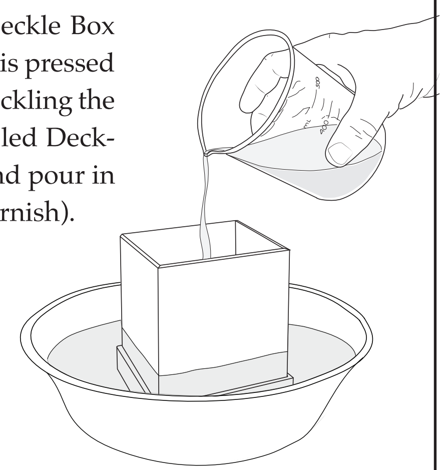




(1) Using the app *PaperWeight*, this small deckle box allows us to make a 7.6 cm square sheet of paper of predetermined weight, content, color and texture by virtue of the confined elongated deckle frame which has a volume of about 500ml. Here I demonstrate making a 95 gsm (g/m2) sheet. In the app (left), I entered my desired paper weight and the dimensions of the deckle frame to find the amount of dry fiber needed to blend my furnish.

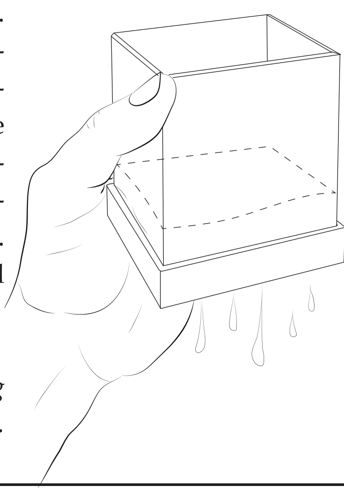
(2) Insert screens into the end cap then rinse in water so the screens lay flat. Inserting Deckle Box Frame; check that the frame is pressed all the way down and not buckling the screens. Submerged assembled Deckle Box in an inch of water and pour in measured, blended pulp (furnish).

Alternately, place assembled box on a flat surface, and while pressing downward, add water to cover screen, then add furnish.



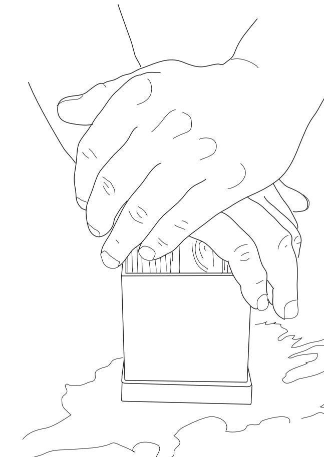
(3) Lift deckle box from the shallow basin and shake side to side and front to back as the water drains, "weaving" fiber alignment into a cross pattern. Shaking in only one direction creates a unidirectional fiber alignment – a "grain" direction in the finished sheet. After 5 to 10 stronger shakes, finish with a few seconds of gentle shakes (vibrations). Wait 15 to 30 seconds for final drainage with no shaking.

Note: Drainage time varies according to furnish hydration and paper weight.



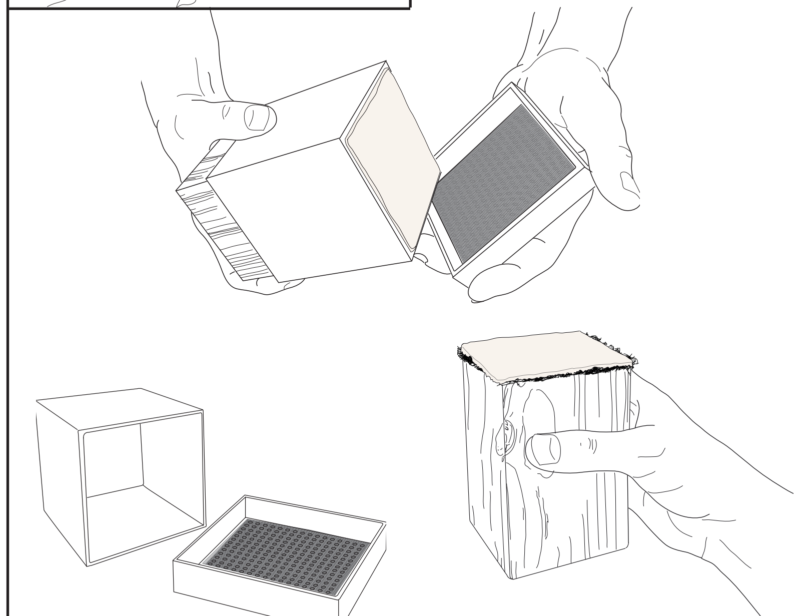
3D print file for deckle box is available as free download at: www.magnoliapaper.com

Couching & pressing using deckle box and felt tipped block

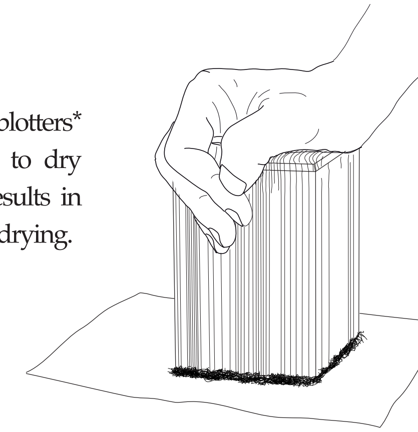


(4) Insert felt tip block and press hard, compacting the fibers and squeezing out water. Apply as much pressure as possible.

(5) Invert and remove end cap and screens. Leaving the newly formed paper on the felt.



(6) Press the moist sheet onto blotters* multiple times, switching to dry blotters - more blotting results in less time with evaporation drying.

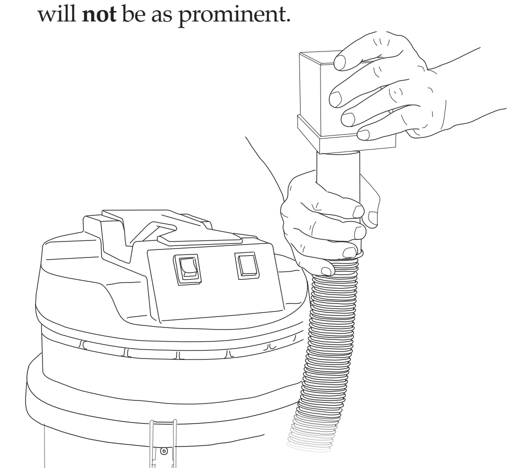


4b. To retain felt hair marks:
Press felt tip block into newly formed sheet early, just **before** the sheet completely drains (and air dry unconstrained). For 16th century papermakers tasked with making 2000 sheets a day, draining the sheet even five seconds longer than necessary was a luxury they could not afford. Couching and pressing early allows us to mimic their hasty technique, which unintentionally yielded sheets with galaxies of felt hair mark texture.

After pressing, remove the screens carefully, leaving the paper on the felt of the block. Use blotters to partially dry the paper on the block felt, giving the fibers a chance to solidify the felt hair marks into the paper prior to a hot iron for speed drying.

To maximize felt hair marks:
- Use linen/hemp-based rags
- Ret until rags can be hand torn
- Hydrate minimally to a freeness of at least 400 to 500 CSF
- Couch onto coarse heritage felts
- Press in a hydraulic press
- No pack pressing
- Air dry individually, unconstrained (lift from felt then set it back on the same felt – let dry on the felt demp felt overnight)

6b. Optional: To speed drainage, vacuum with wet-dry shop vac. If this is done prior to plunger pressing, texture from the felt will **not** be as prominent.



**Any neutral pH material is suitable: suggested blotters include Pellon, Evelon, Zorbix, or a neutral pH paper*

Forming a circular sheet of paper using a modified AeroPress

5.7cm (2.25 inch) diameter

1. Use two of the coarser 38 mesh polyester backing screens as the bottom screen; insert this into the **End Cap.** This separates the forming screen and keeps the end cap from leaving a polka-dot pattern that will be visible in your sheet when held up to light. For **wove paper**, use two 38 mesh polyester screens simultaneously; for even smoother wove paper, combine two coarse screens with the finer 86 mesh screen.

2. With the two or three selected screens inserted, twist the end cap onto the **Deckle Cylinder**. (If it does not twist on, more sanding of the lip is required.) Check to be sure that the screens did not bulge; if so, they may need trimming. A bulge in the screens will make a uneven sheet.

3. Submerge assembled deckle cylinder into an inch or so of water before adding the furnish. The layer of water acts as a buffer, allowing the furnish to disperse evenly.

4. Pour pulp (furnish) from a distance to facilitate even distribution of the pulp. You can lift the **Deckle Cylinder** out of the water as you pour.

Note: The diameter of the finished paper is about 5.7cm depending on shrinkage. Therefore, 0.25 grams of dry fiber will make a 102 gms (g/m^2) weight paper. Use the app PaperWeight at www.magnoliapaper.com to calculate other weights.

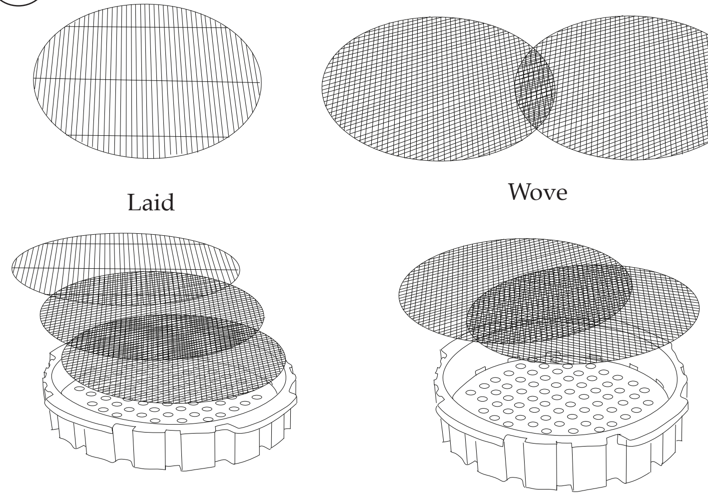
When making small sheets by hand, one might wonder if sponging or a hand-operated coffee maker can provide enough pressure to press a newly formed sheet. Here are some comparisons:

20-Ton Hydraulic Press
20 tons = 40,000 pounds
22 x 30 inches = 660 square inches
40,000 ÷ 660 square inches = **60.6 psi**

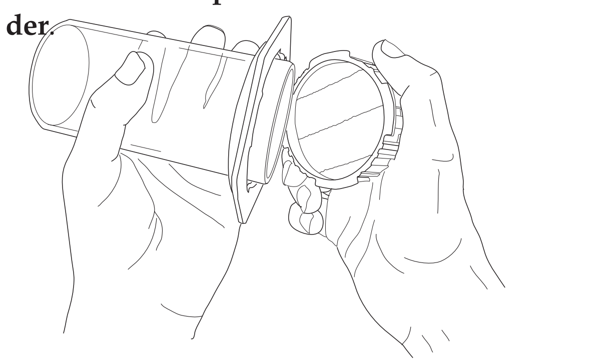
Vacuum table
Many papermakers use a vacuum table to remove water and press paper. If it were possible to pull a perfect vacuum at sea level, their psi = 14.7 psi (or 29 in Hg [inches of mercury]). Using Magnolia's vacuum table we are able to achieve 23 in Hg = **11.3 psi**

AeroPress:
A 2.25 inch diameter circle = 3.97 sq. in.
90 pounds hand pressure ÷ 3.97 sq. in.
= **22.6 psi**

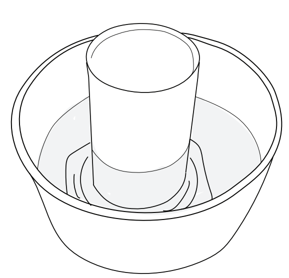
1 **Select Screens** to make wove, laid or watermarked paper.



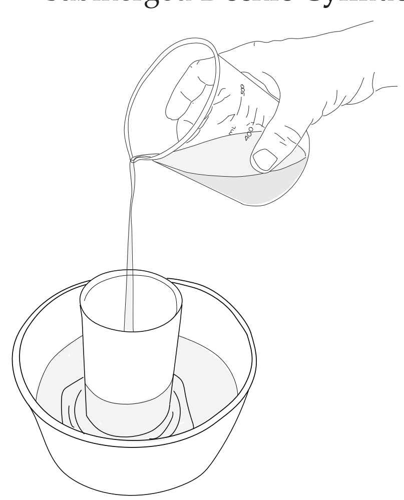
2 Twist the **end cap** & **screens** onto the **Deckle Cylinder**.



3 Submerge the assembled **Deckle Cylinder** into an inch of water.



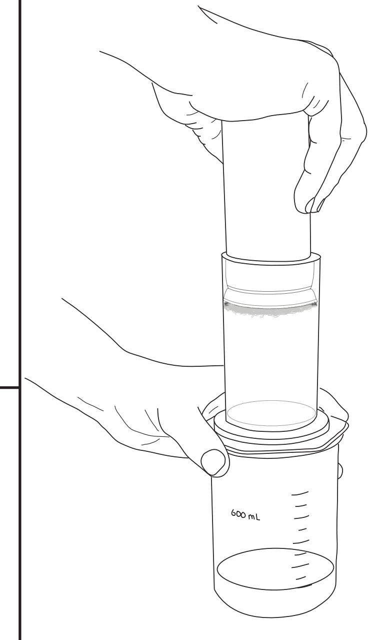
4 Pour blended pulp into the submerged **Deckle Cylinder**.



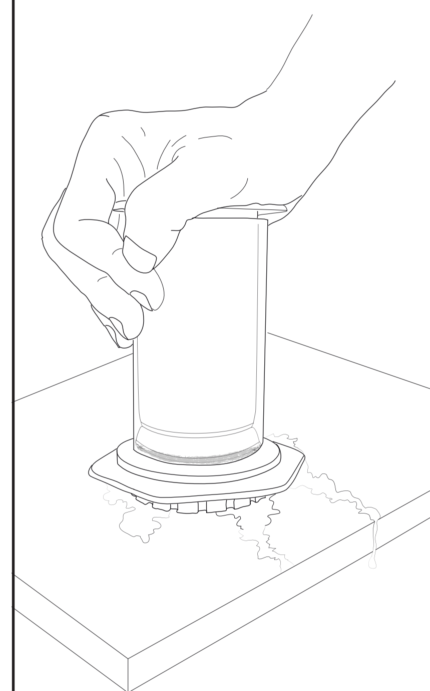
Couching & pressing using an AeroPress

5 Allow water to drain from pulp.

6 Insert **Plunger** into **Cylinder**, and press very slowly.

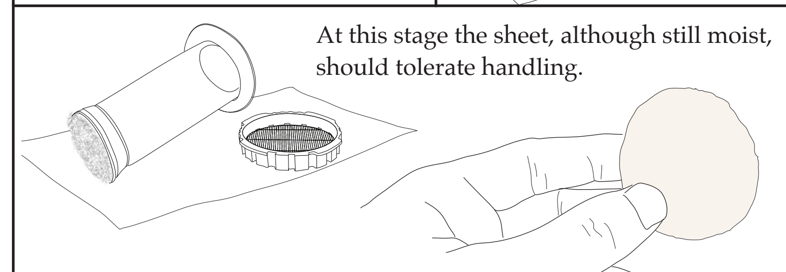


7 Continue pressing on a sturdy surface.

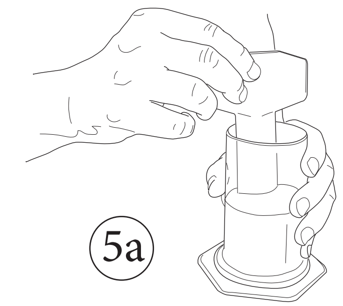


8 Remove the **End Cap** continue pressing with cylinder onto a blotter.

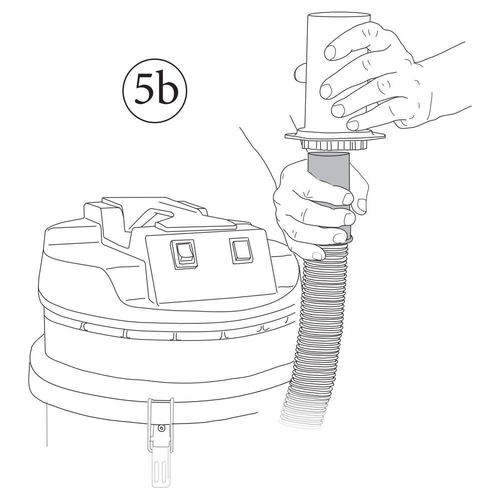
At this stage the sheet, although still moist, should tolerate handling.



5, 5a. Drain and stir with AeroPress provided stirring device as deemed necessary.



5b. Optional: Vacuum with wet-dry shop vac prior to plunger pressing for faster drainage and texture variation.



6. Slowly press the **Felt-tipped Plunger** down against the pulp. Too much pressure too fast creates ridges in the paper.

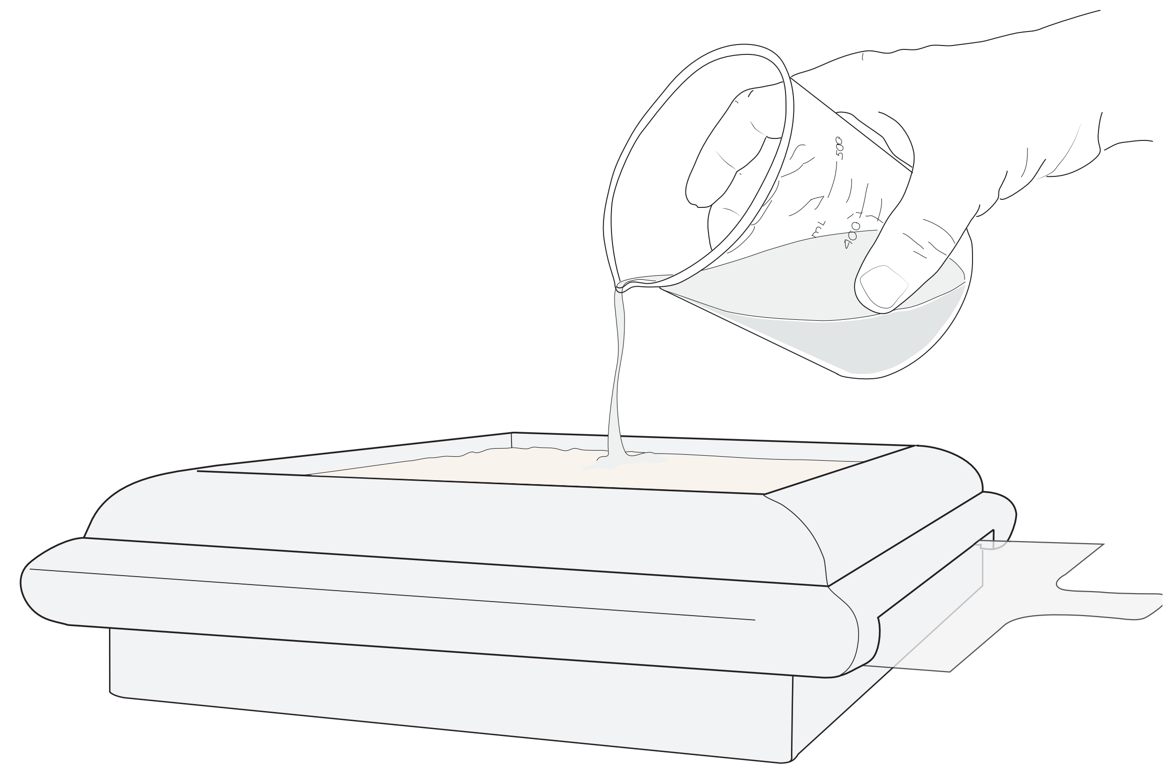
7. On a sturdy surface, continue pressing as the **Felt-tipped Plunger** squeezes water from the newly formed sheet. For most types of paper, apply as much pressure as possible.

8. Unscrew and remove the **End Cap** and screens from the partially pressed sheet. Press the wet paper directly on a felt or blotter. Carefully move to another location on the blotter and press again; this step may be repeated multiple times to remove more moisture. Then, leaving the paper on the blotter, remove plunger from cylinder and if necessary press again.

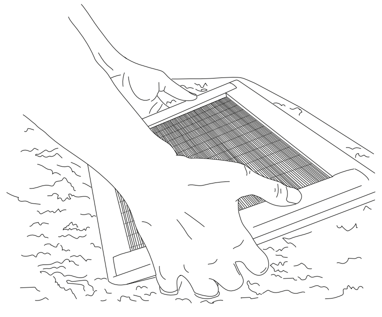
VIII

Sheet Formation on Ribbed Mould without a Vat

with a predetermined quantity of furnish



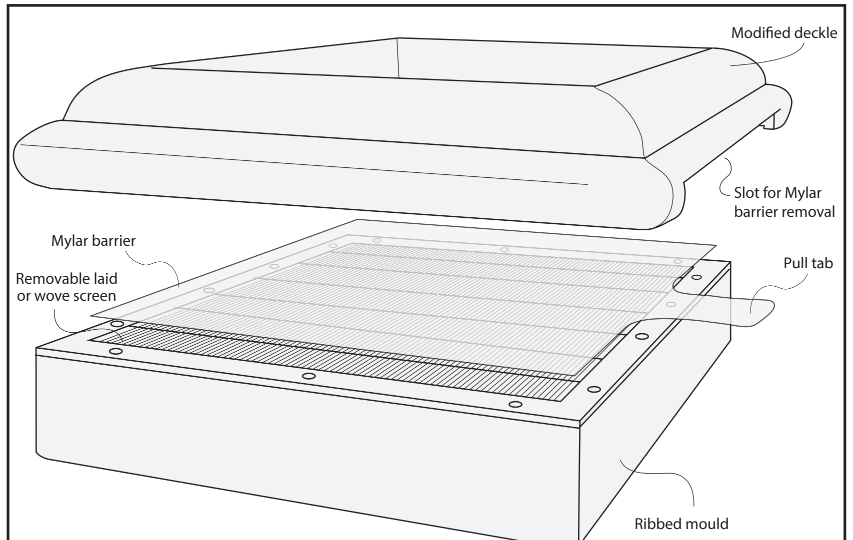
Determinate papermaking
with a traditional ribbed mould and deckle



Traditional vat sheet forming

Forming a sheet on a traditional Western mould involves dipping the mould into a vat of furnish, scooping an estimated quantity into the boundaries of the deckle, and forming a sheet. Experience increases the likelihood of making a sheet that hews to an intended weight. To make a determinate, known-gsm-weight paper on this type of mould requires a re-design of the deckle, per below: a traditional mould outfitted with a modified deckle.

3-D printed traditional mould and deckle



3D printed ribbed mould with a modified deckle,
slide-out Mylar barrier and removable laid or wove screen

Using a 3-D printer* we printed a 14.5 cm x 21.5 cm (5.75” x 8.5”) standard ribbed mould and a modified deckle. We increased the height of the inner wall of the deckle to create a confined area, enabling us to pour and trap a measured quantity of furnish for each sheet of paper. Additionally, a slot was created on the long side of the deckle’s bottom edge for a plastic furnish barrier.

*Our modifed mould, deckle and laid screen were printed on a Type A (PLA) printer. Our design is based on a 3-D model design generously provided to us by hand papermaking inventor Brian Queen. Brian modeled his mould using Geomagic. Magnolia Master Printer Nicholas Price imported Brian’s .stl file into Fusion 360 and made the necessary modifications.

A rectangle of mylar, cut to fit the inner frame of the deckle, includes a tab protruding from the long side. When the mylar is placed on the mould and covered by the deckle, the tab protrudes from under the deckle, through the slot, towards the far side of the mould.

With the mylar blocking the drainage of the mould, furnish with formation aid (AKA: tororo-aoi neri) to slow drainage* is poured into the deckle, filling the deckle area. Then, like the magic trick where a table setting remains in place when a tablecloth is pulled from the table, the mylar is quickly pulled (via the tab) from the mould, allowing the furnish to drain and the maker to form a sheet.

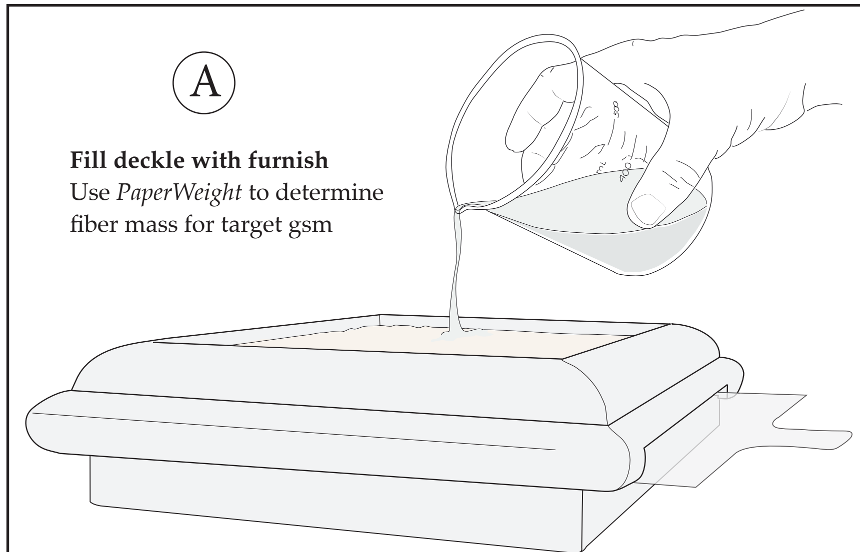
After draining, the deckle is removed and the paper is couched onto a felt, then pressed and dried as previously described.

*__Formation aid__ slows drainage, allowing more time to make a well-formed sheet. After blending half-stuff for 2 to 3 minutes, add 25 ml of formation aid and blend for another 1 second; with more blending, foam becomes a problem. Stirring, shaking or pouring from beaker to beaker helps agitate the furnish just prior to filling the deckle. It is easy to notice when too much formation aid is used: drainage seems to take forever.

Note: When using PNP (granular) formation aid, mix the solution at least one day in advance. Formation aid has a long shelf life in liquid and granular form.

A

Fill deckle with furnish
Use *PaperWeight* to determine fiber mass for target gsm



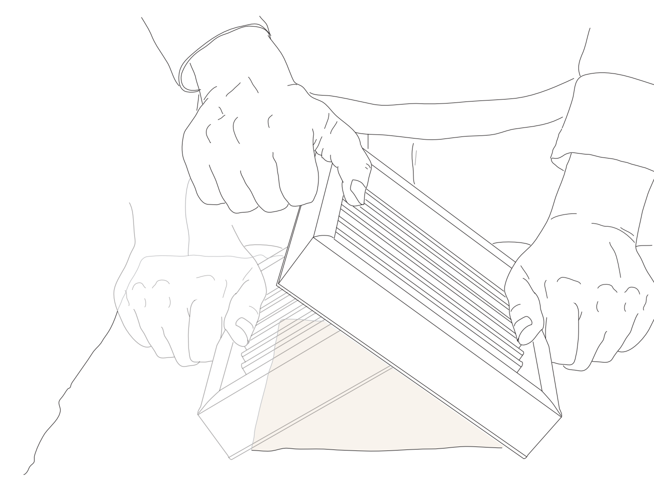
B

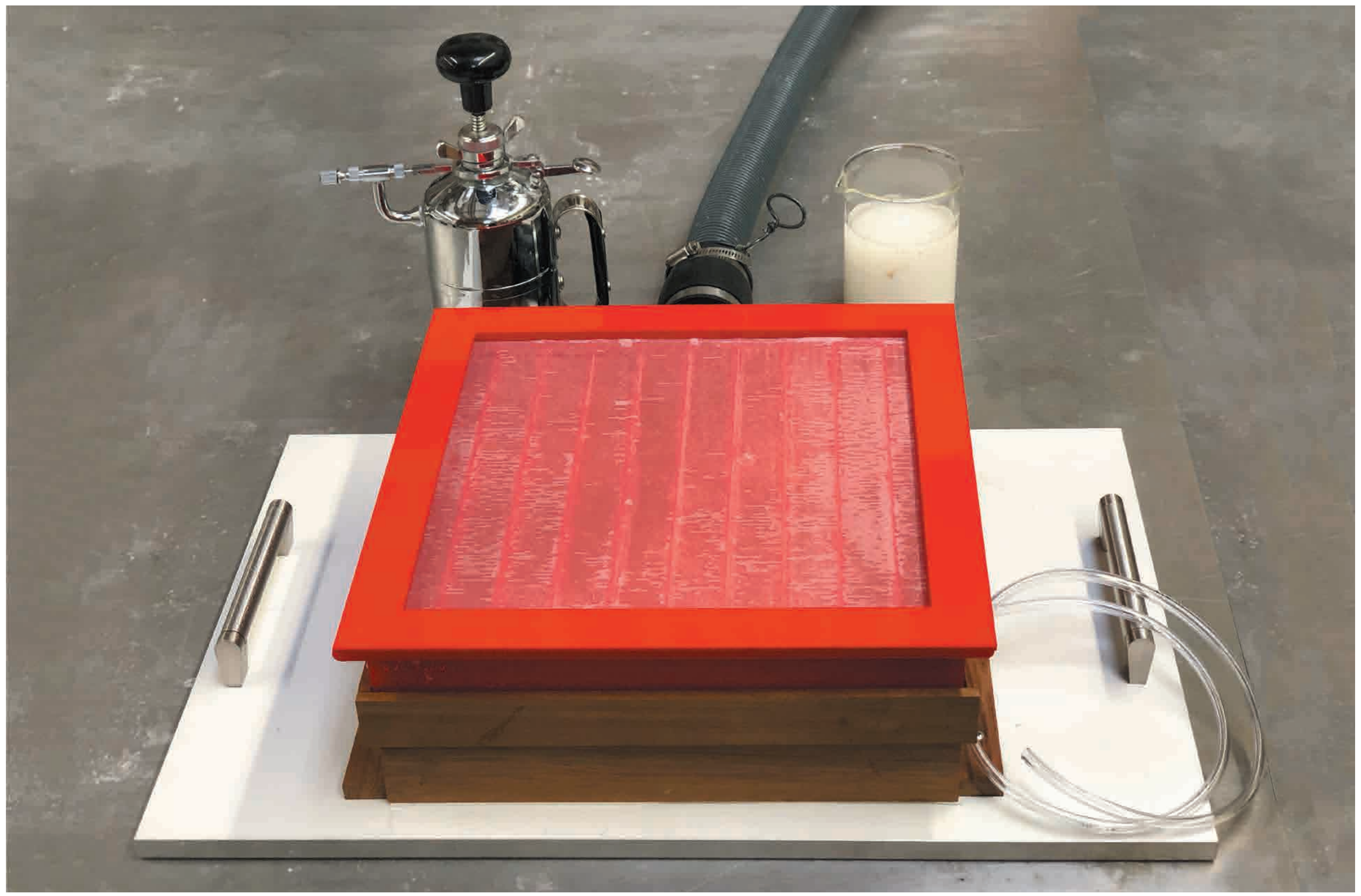
In one quick motion, **pull the protruding tab** to remove the mylar barrier. While holding the mould level, immediately shake forward, back, and from side to side to make a well-formed sheet.

Drain and remove deckle.

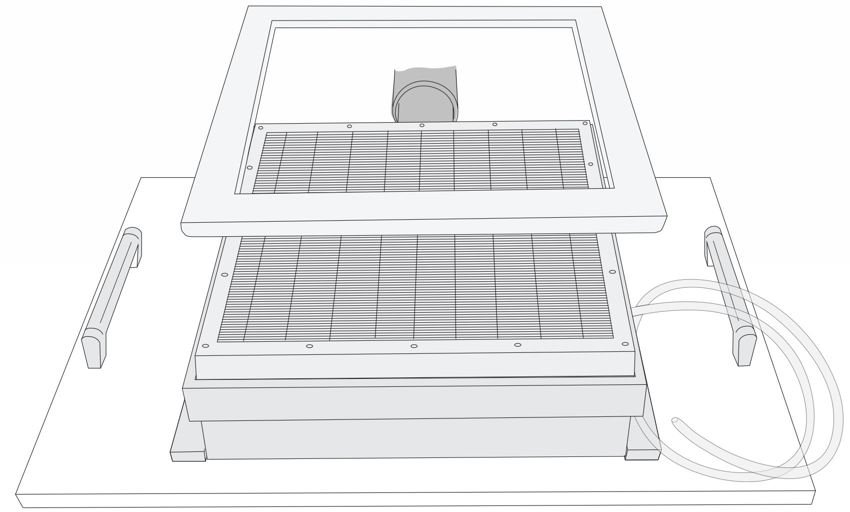
C

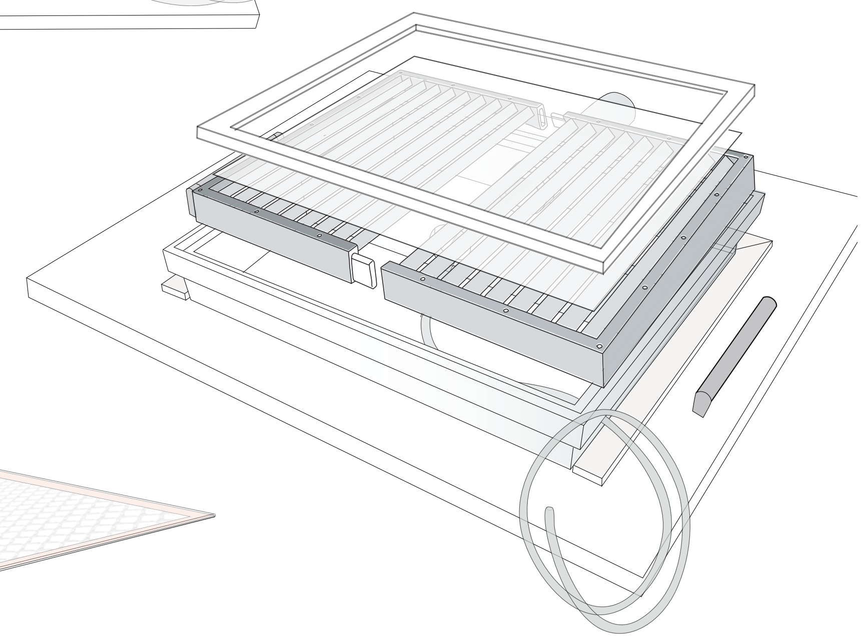
Couching onto felt with a ribbed mould
(per traditional Western method):
Place one long edge on a moist felt and roll through the couch as illustrated. With the first sheet of a post it is best to stop and press hard on the ribs while the mould is flat, then lift up the first edge that was planted. Italian papermakers in particular seem to prefer a curved surface for couching, though it is not usually necessary with smaller moulds.

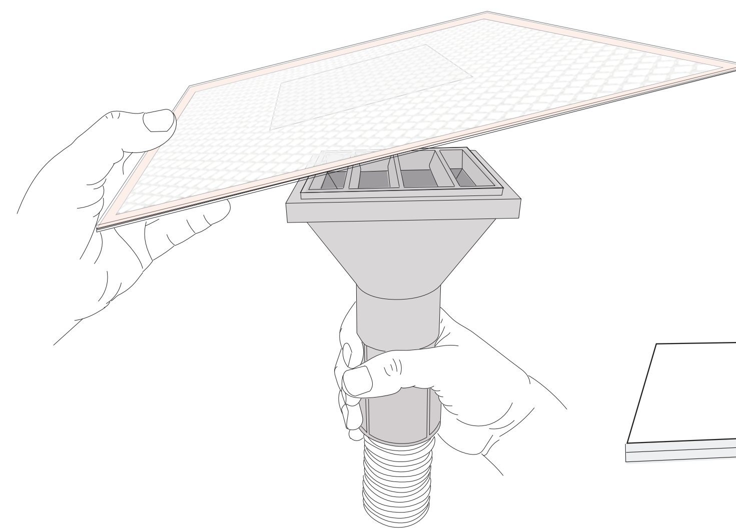


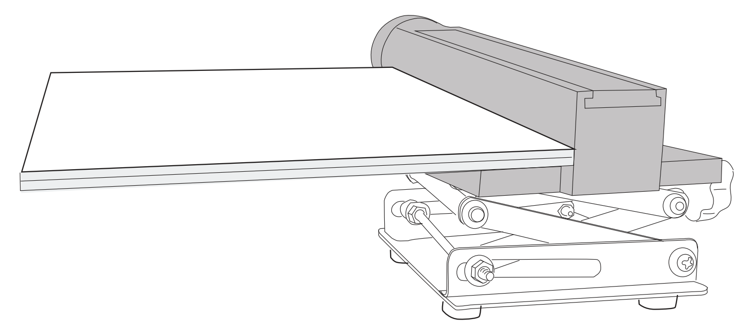


IX
Determinate Leaf Casting







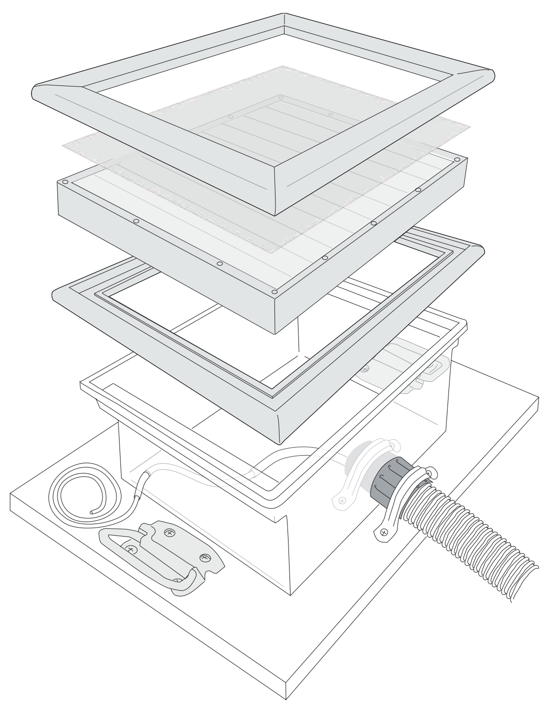


Leaf caster: design notes

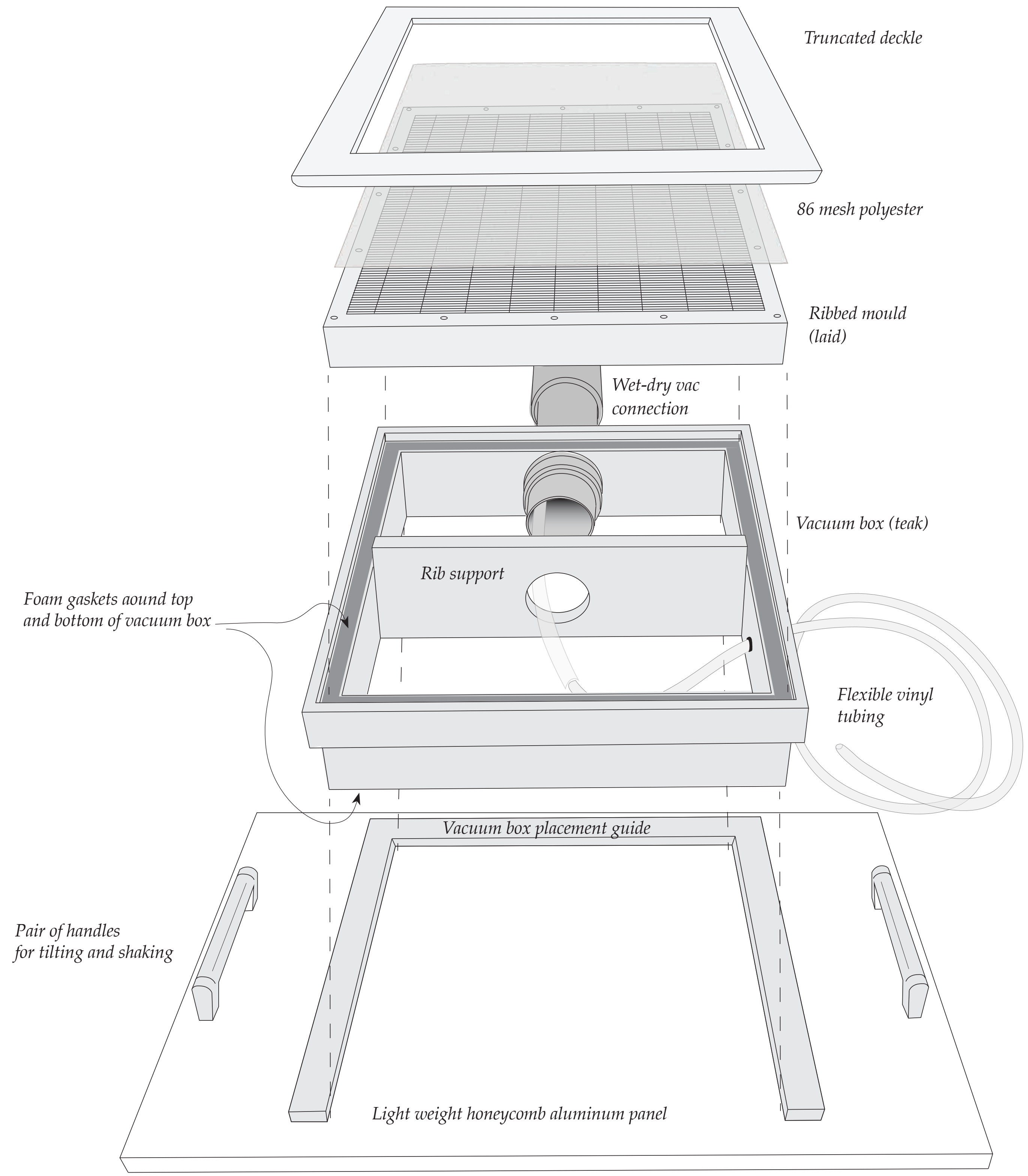
The designs herein combine a leaf caster's vacuum deckle box with a lightweight, 3-D printed ribbed mould and deckle. It enables the user to lift and shake the mould (as in traditional papermaking) under the vacuum. As diagrammed on the following pages, our leaf casters are comprised of a 3-D printed ribbed mould and deckle (laid or wove). When assembled, the handles on either side of the support tray allow the entire box and mould to be manually agitated during sheet forming, which – in conjunction with the use of formation aid – enhances fiber cohesion and ensures that the document is not simply covered with pulp. With a foam gasket around the bottom of the teak vacuum box where it meets the smooth aluminum tray and another where the mould sits at the top of the box, the whole structure sits firmly unified in place while under vacuum. When not under vacuum pressure, the mould may be lifted from the box and the box lifted from the tray, allowing for drainage of built-up white water.

The document is next protected with a polyester mesh and blotted while under vacuum. The mesh-document-mesh sandwich can be lifted and dried. This is the safer approach for delicate paper artifacts: forming on a 86 mesh polyester screen, then covering with another screen eliminates the need for direct handling of the moist document. Alternatively, mould and deckle can then be removed and the composite sheet couched in the traditional papermaking manner. The underlying mesh may be plain (wove), or printed with a laid-pattern and watermark.

3D printed leaf caster *(Early prototype)*
8.5 x 11 inches



Leaf caster
3-D printed mould and deckle
with removable vacuum box – 11.5 x 11.5 inches



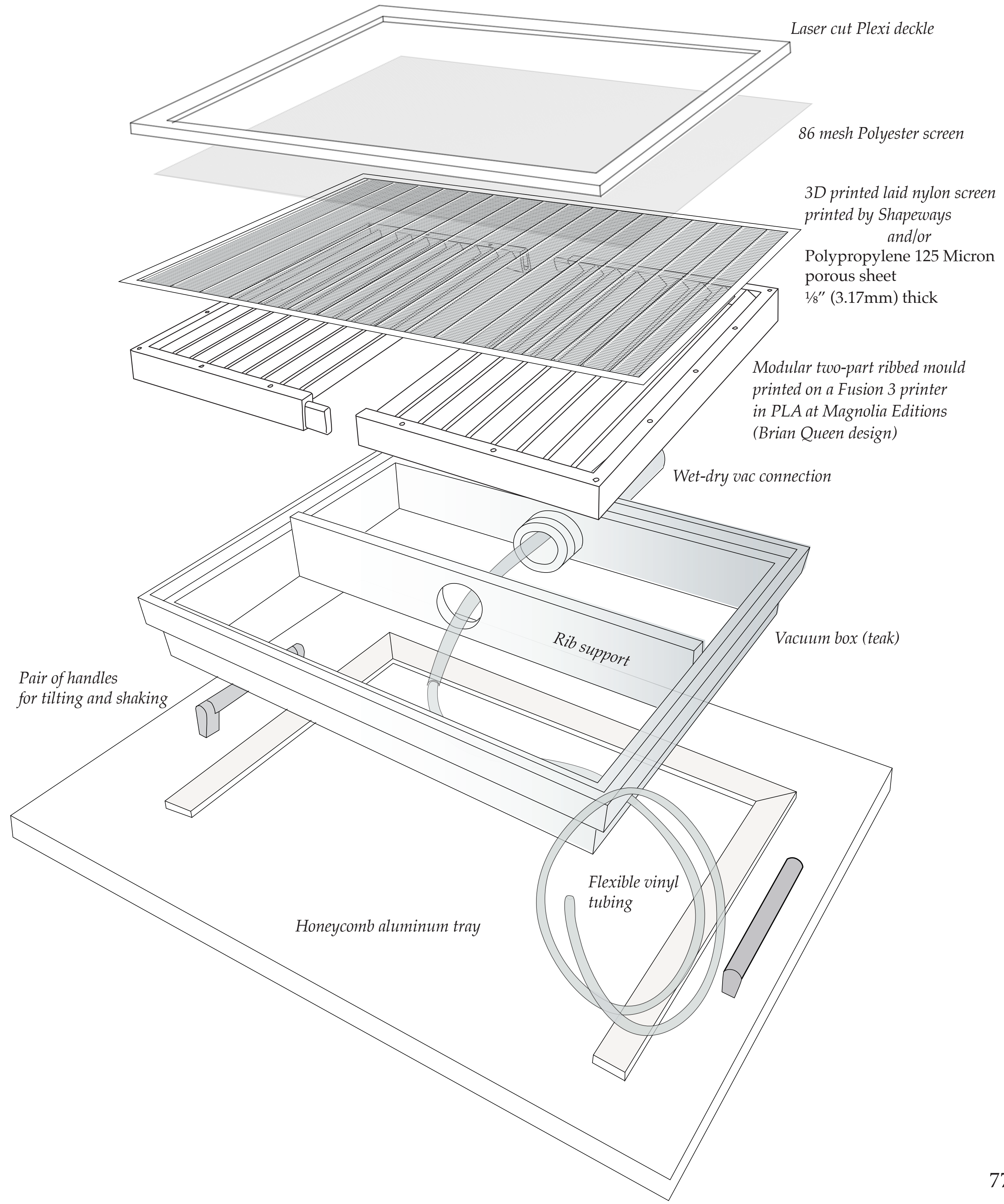
Modular leaf caster: design notes

A key component of a Magnolia Editions' leaf caster is a removable 3-D printed ribbed mould. Surprisingly – unbelievably, even – this lightweight ribbed mould, printed in-house entirely of plastic, looks and behaves like a traditional mahogany ribbed mould and deckle – so much so that it can be used in a traditional European handmade paper production line. The modeled (.stl) files for these plastic moulds and deckles were created and provided by Canadian papermaker Brian Queen – surely deserving of a ***Contributions to the Field of Hand Papermaking*** award (if such an award existed).

Although 3-D models can theoretically be printed at any scale, until January of 2019 our mould dimensions were limited by our largest 3-D printer, the *Fusion 3*, which has a build size of 14 x 14 x 12 inches (355 x 355 x 315mm). In two days of continuous printing, this printer can build only one mould and one deckle with maximum sheet dimensions of 11.5 x 11.5 inches – a bit small for most documents in need of infill.

Wishing to continue my research into employing this versatile leaf casting equipment design at a larger scale, I was excited to learn that Brian had developed, modeled and tested a modular paper mould: a ribbed mould that can be printed in parts and assembled to create a larger format ribbed mould. With Brian's help, I put his .stl files to the test, printing the two-part mould on our *Fusion 3*. The laid screen (not modular and too large for my printer) a 12.5 x 18 inch (nylon) was a file Brian had uploaded and ordered from the online 3-D printing company Shapeways specifically for my leaf caster design. Next, I made vector files to laser-cut a Plexi deckle with nesting, removable rect-angular masks. Cabinet maker Miguel Mendoza built the teak vacuum box and I used foam gaskets to form seals between the components.

Modular leaf caster
3-D printed two-part ribbed mould
3-D printed laid screen and laser cut plexi deckle
with removable teak vacuum box – 12.5 x 18 inches

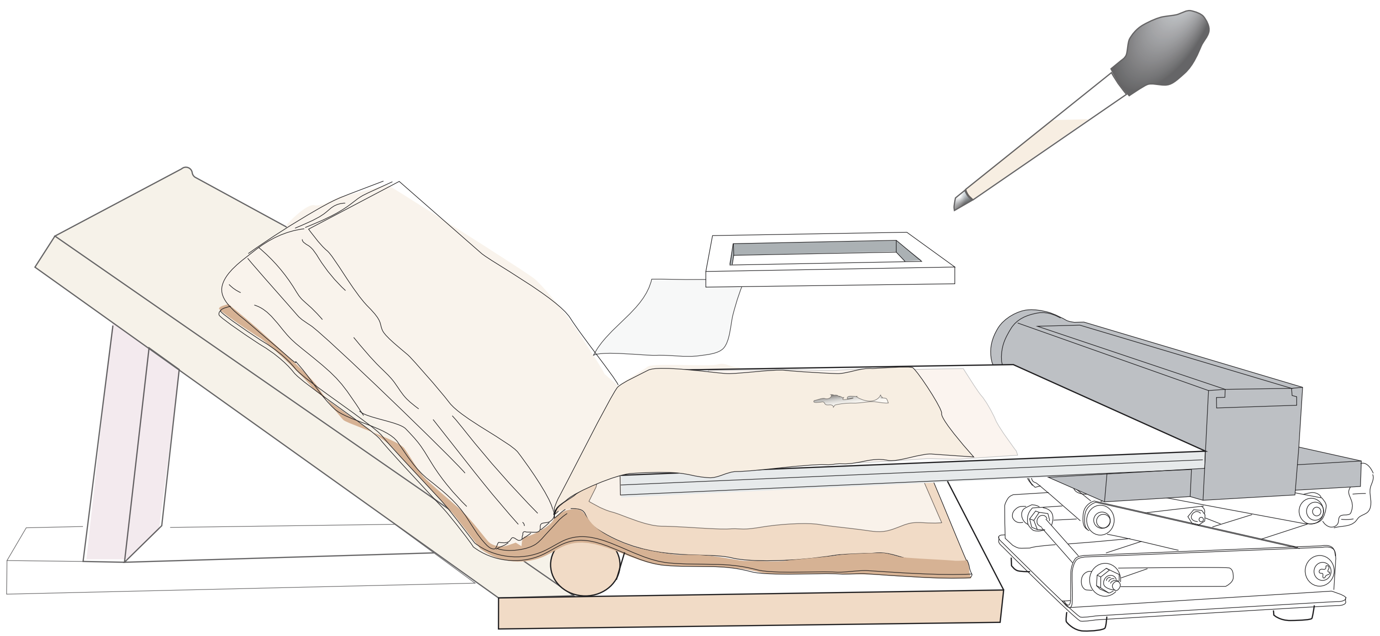


Slim profile leaf caster: design notes

Making cast paper repairs between the pages of a book requires a very thin leaf caster/vacuum table. An effective vacuum table a mere ¼ inch thick with an even distribution of suction can be made drawing from materials from diversrse diciplines. The simple constructon described below uses micro-porous polypropylene, breather mesh, plexi glass, foam gaskets and plastic edging.

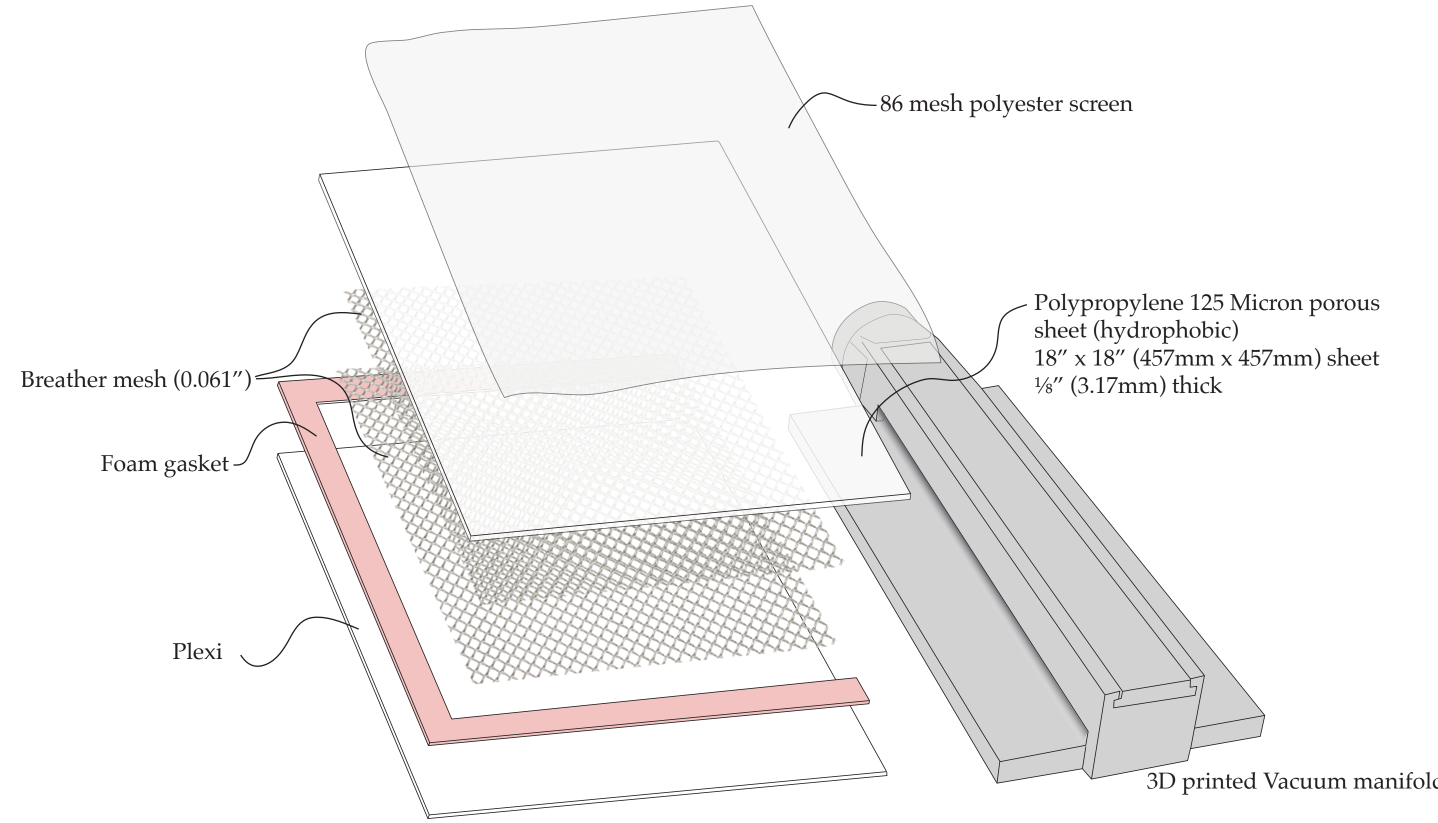
Micro-porous polypropylene: *⅛ thick, 90 to 125 micron sheets with a porosity of 35% to 40%. Made of high purity resins approved by the FDA and USDA. Can be heated safely to 230°F for a short period of time. Chemically resistant to most acids, alkalies and solvents. Sensitive to UV. Both hydrophilic and hydrophobic are available - hydrophobic used here. (Micro-porous polypropylene is often used for the liquefying of powders.)*

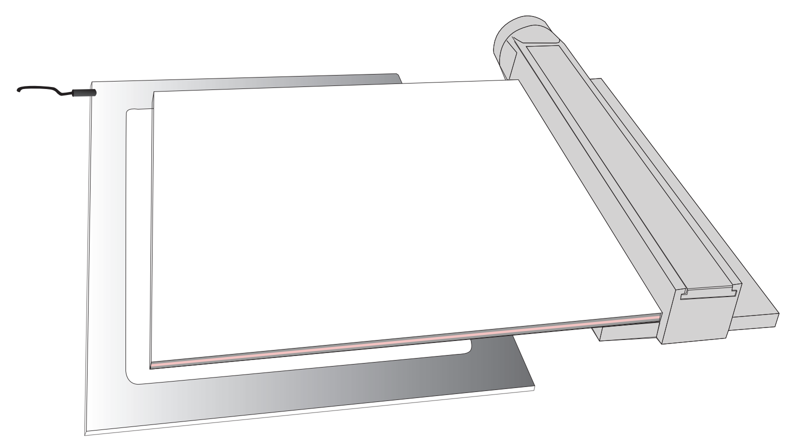
Breather mesh: *a plastic .046" fabric that is typically used in vacuum bag veneer gluing applications. It allows air to move toward the manifold and evenly build vacuum pressure across the table surface. Without the mesh, the vacuum of such thin dimensions would tend to self-seal. (Breather mesh is commonly used by cabinet makers in their suction bags - to glue veneer.)*



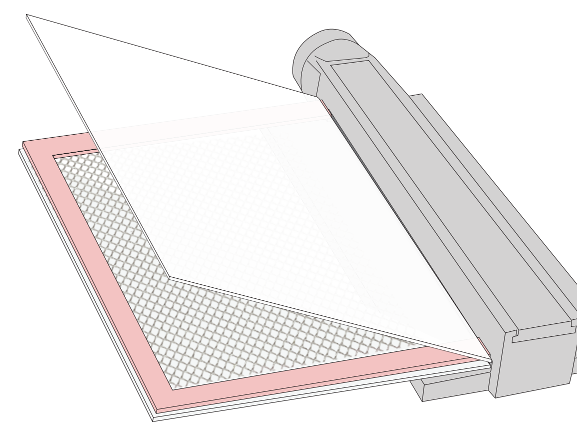
A slim profile leaf caster enables infill or repair of a leaf still bound within a book.

Slim Profile Leaf Caster
Diagram





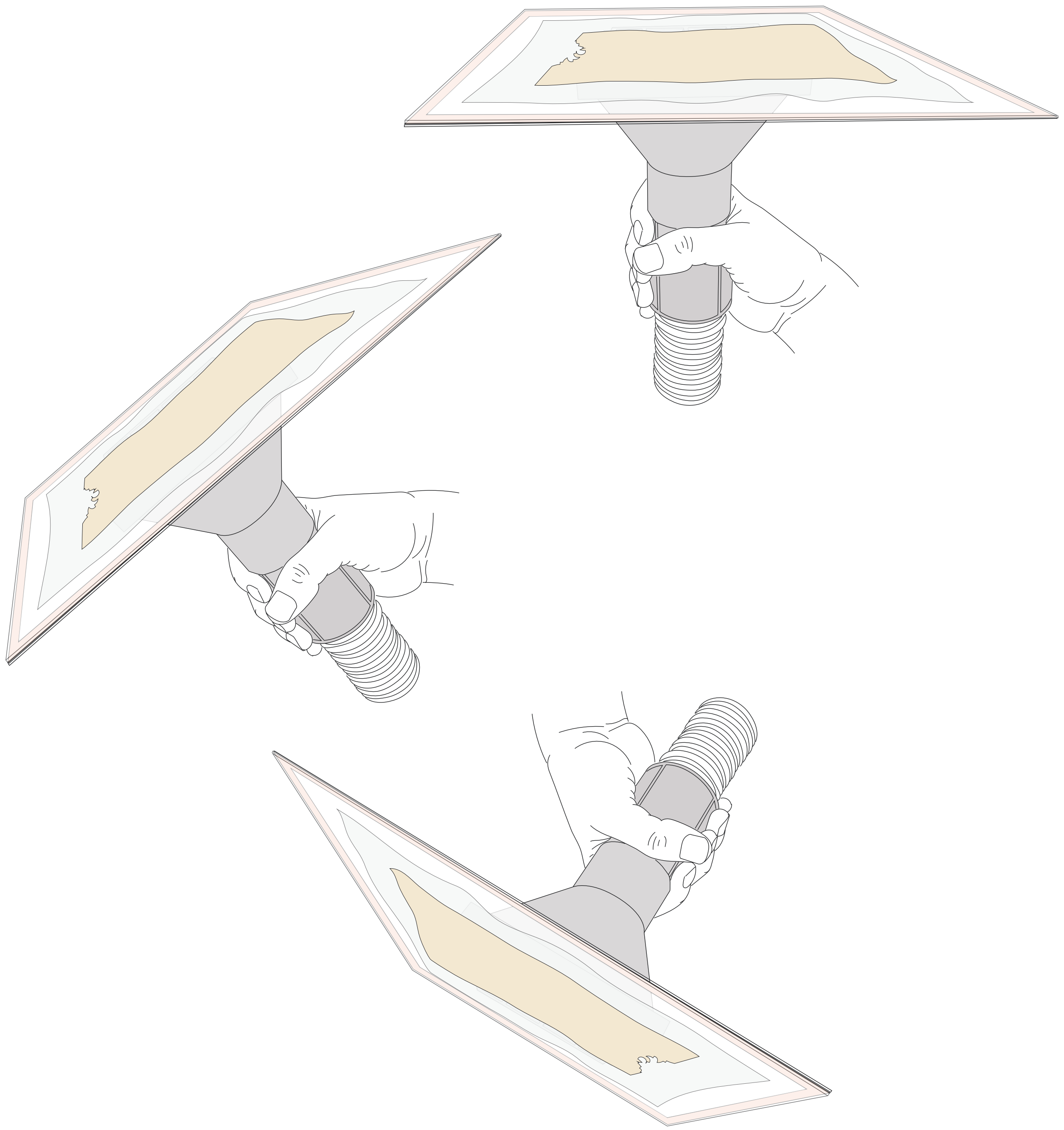
Closed and sealed to gaskets when under vacuum over a thin LED light tablet. Because the components of slim profile leaf caster are translucent a document may be inspected with backlight ilumination.



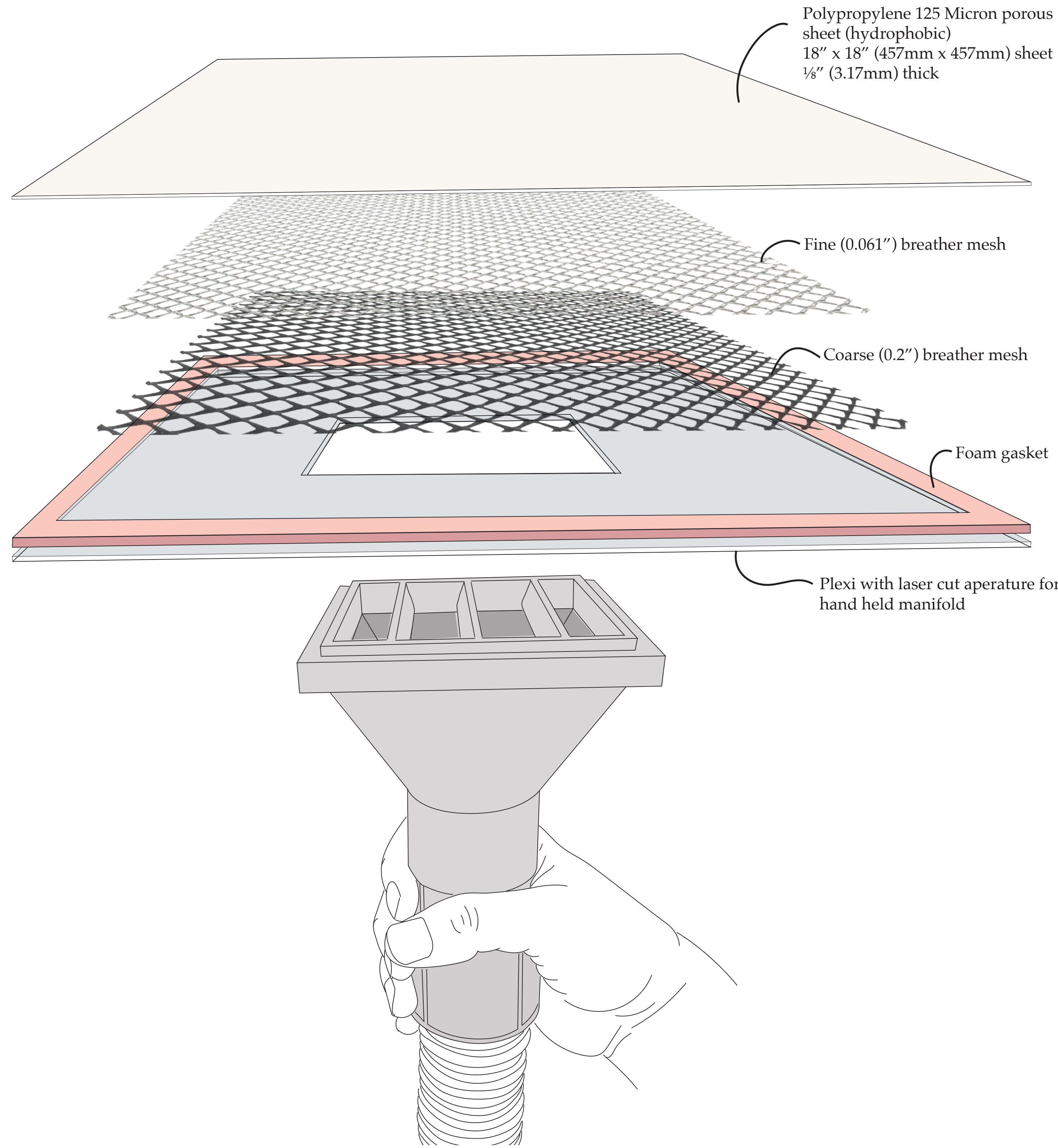
Open for cleaning

Hand held (caddy) Leaf Caster

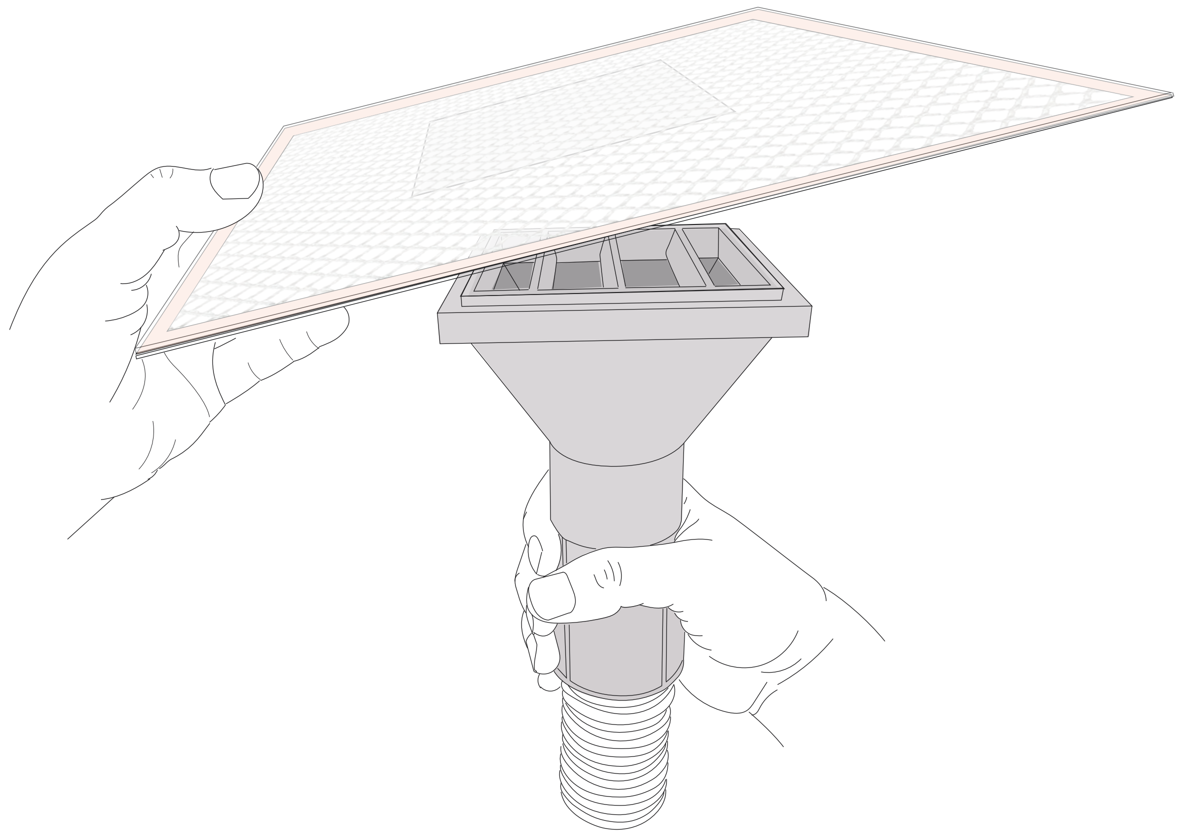
This thin vacuum/leaf caster design enables the handling of a hydrated, relaxed works on paper with minimal hand lifting or manipulation. A paper artifact can be placed and moistened on the caddy surface (with a 86 mesh polyester screen beneath as support). When vacuum applied, it remains in place at any angle.



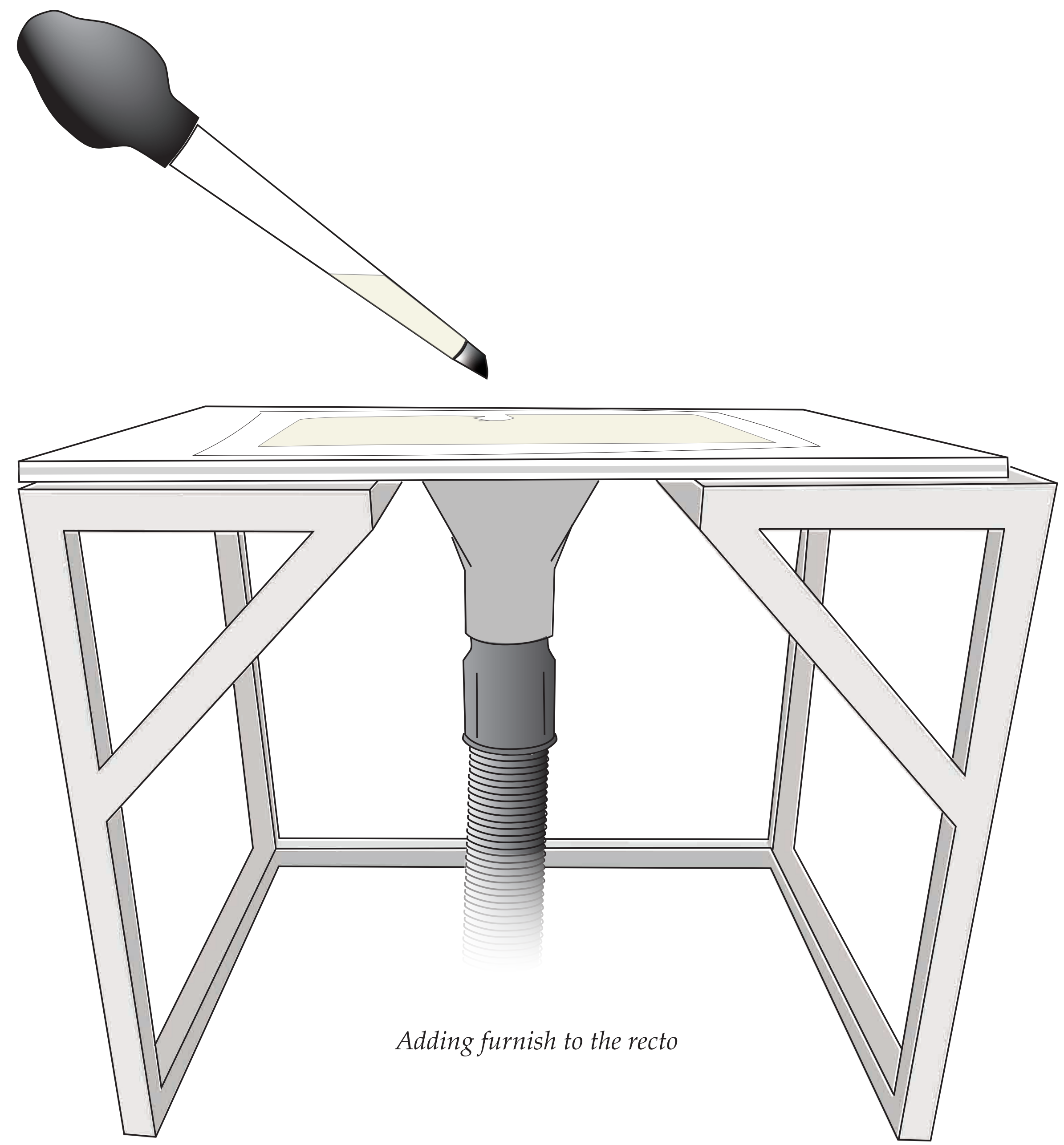
Hand held (caddy) Leaf Caster
Diagram



Inverting a hydrated document using a hand-held leaf caster



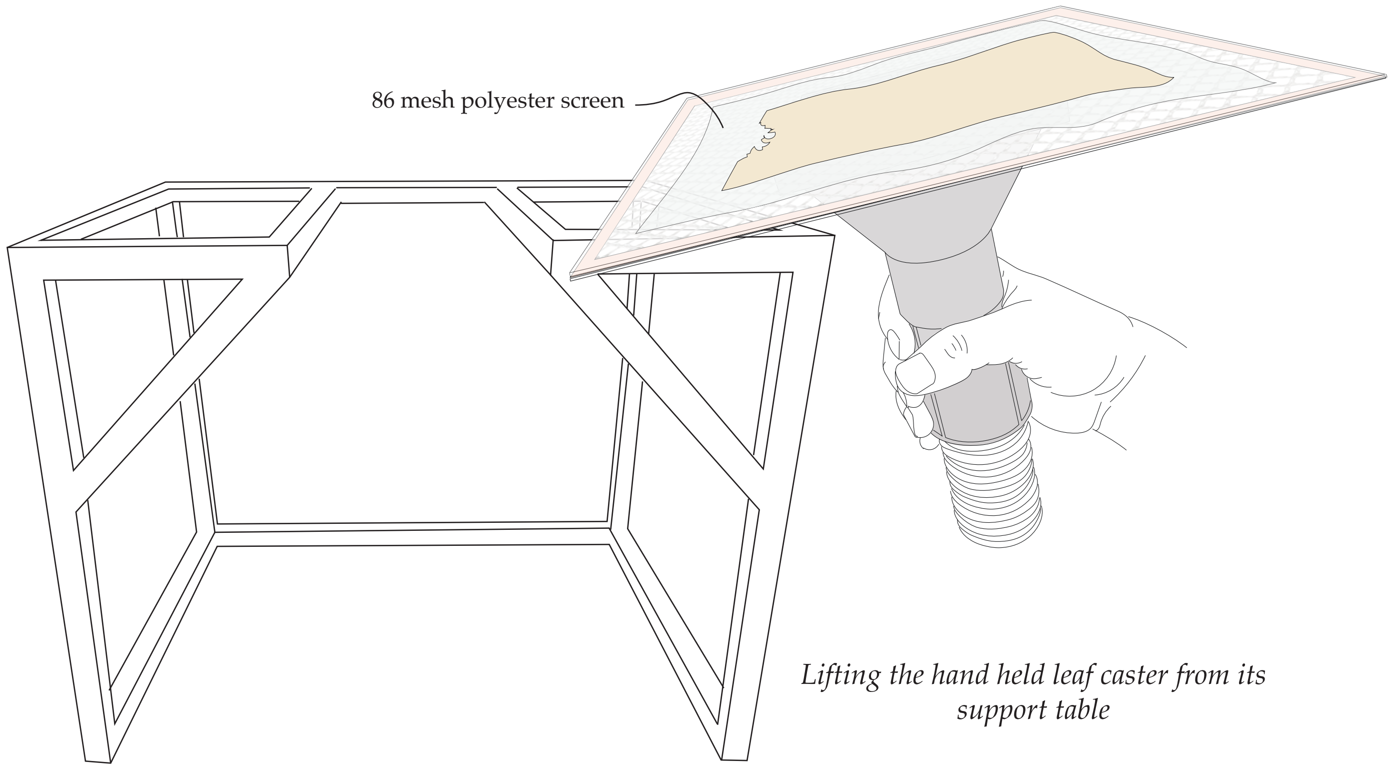
This very thin portable vacuum table (polyethylene micro porous sheet, gaskets, breather mesh and laser cut Plexi "sandwich") snaps together with the hand held (3D printed) manifold when vacuum is applied. It is important to place a moist 86 mesh polyester as additional protection for safety when handling a moist document. While under vacuum, the components of the leaf caster snap together creating a single unit as long as a vacuum is applied. Moisten and relax the document needing repair on the top surface safely resting on the polyester mesh.



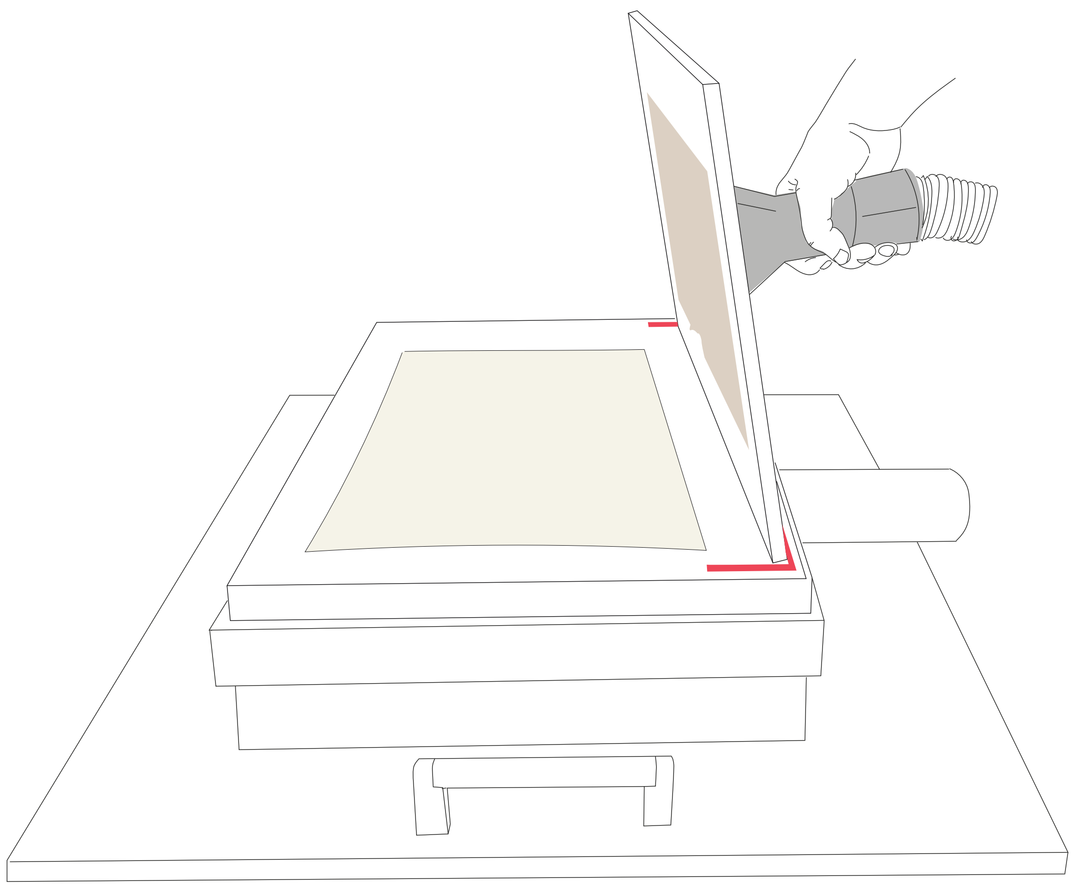
Adding furnish to the recto

This thin vacuum/leaf caster design enables the handling of a hydrated, relaxed works on paper with minimal hand lifting or manipulation. A paper artifact can be placed and moistened on the caddy surface (with a 86 mesh polyester screen beneath as support) . When vacuum applied, it remains in place at any angle.

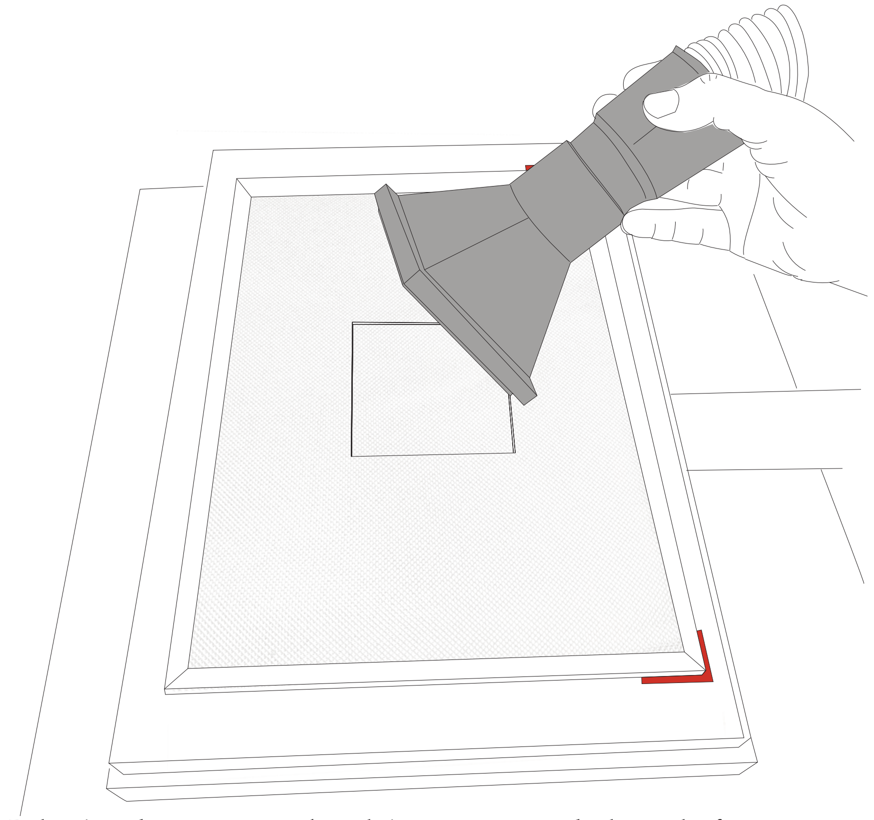
A thin wash of furnish can now be applied to the voids in the document. With sufficient formation aid and careful application, the furnish will slightly overlap the edges of the document in a gentle feather. This overlapping of the infill and document at this point is only on the recto. Because the document is under vacuum we can invert it and transfer it onto a second vacuum-aided leaf caster, and then apply furnish with feather to the verso, making for a strong, protective, two-sided mend.



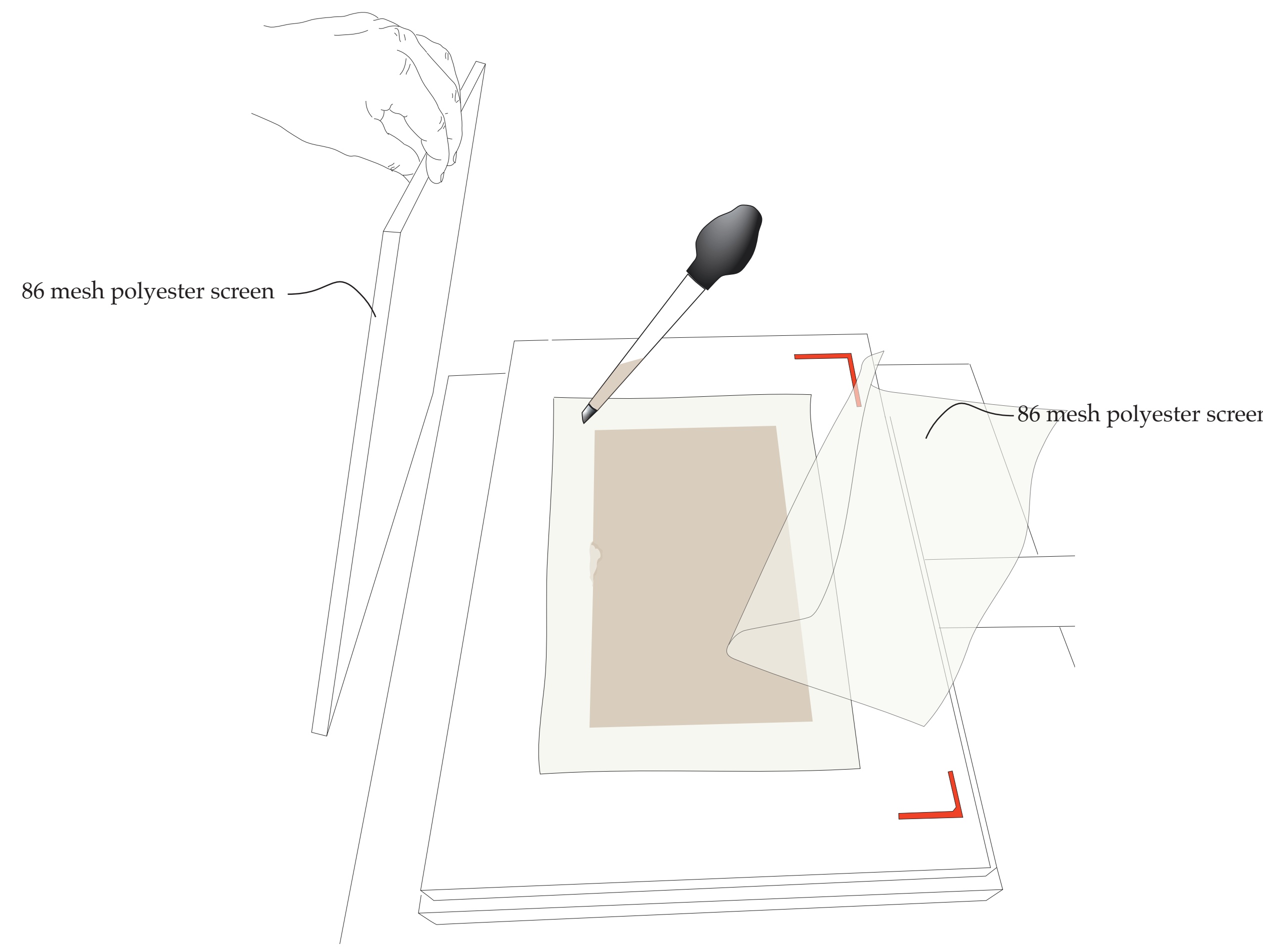
Lifting the hand held leaf caster from its support table



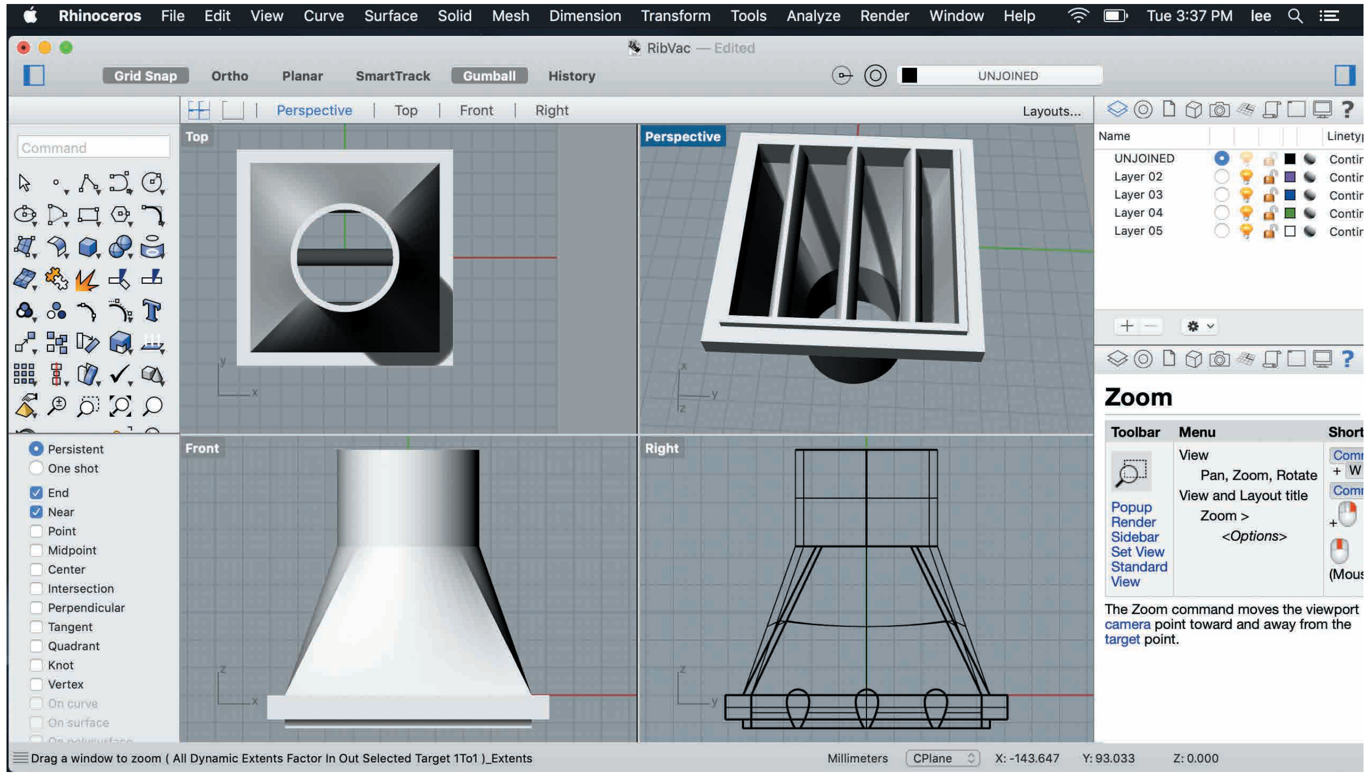
Transporting, then inverting moist document held by suction to leaf caster with moistened polyester mesh



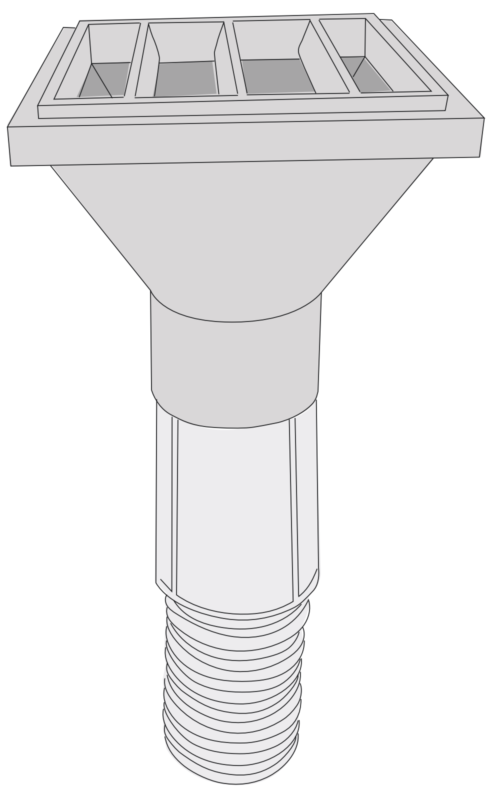
Releasing the vacuum and applying vacuum to the lower leaf caster, thereby transferring document from upper to lower leaf caster

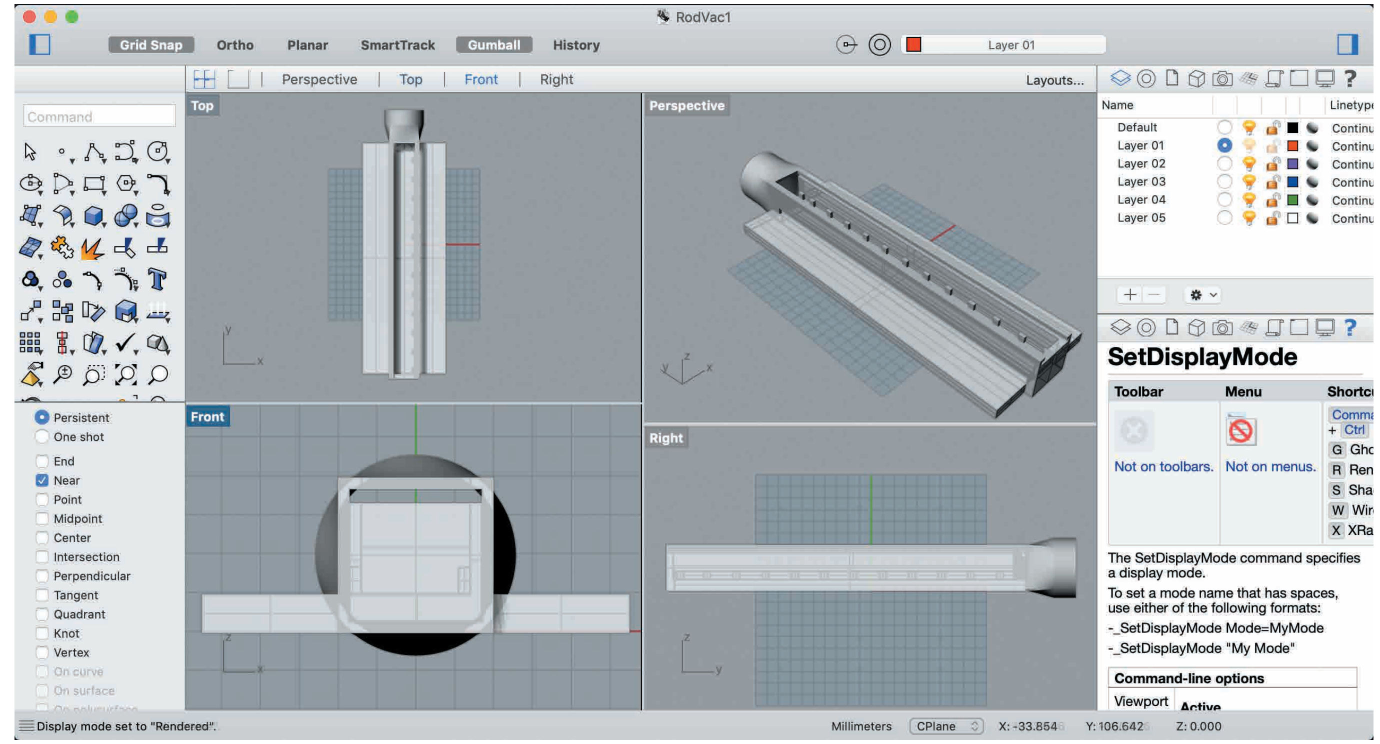


Removing the hand-held leaf caster (and polyester mesh from top surfance) and adding furnish to the verso



3D model created by Lee Bowen using Rhinoceros after design by Donald Farnsworth (G code created by Nicholas Price - Simplify 3D)





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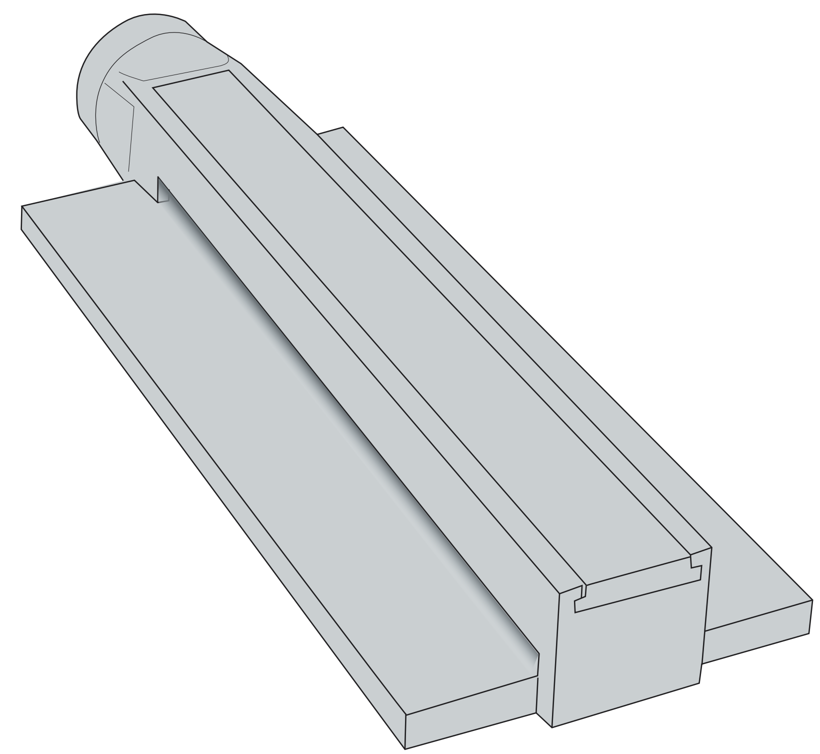


Leaf casting paper of a determinate color and weight

Using a ribbed mould

Leaf casting, a vacuum-equipped variation on the centuries-old deckle box technology, is used to strengthen and infill missing areas on damaged incunabula and other works on paper. The learning curve and meticulous effort required per leaf has caused some to shy away from this otherwise effective practice. My intent here is to make leaf casting more viable and flexible by integrating both modern and traditional papermaking techniques, enabling conservators to draw on the wealth of historical infill possibilities from both Eastern and Western papermaking traditions. My interest in employing handmade paper techniques in the service of conservation began in the early 1970s while attending art school, taking chemistry classes, and working in a conservation lab in Berkeley, California. Later that same decade, working in my first paper studio, conservator Keiko Keyes and I experimented with combining sheet formation, infill and document repair, culminating in a presentation at an AIC conference[17]. Some 40 years later and with my papermaking knowledge greatly fortified, I revisit my roots.

These designs combine a leaf caster's vacuum deckle box with a lightweight, 3-D printed ribbed mould and deckle, enabling the user to lift and shake the mould (as in traditional papermaking) while under the vacuum. Our leaf casters (as diagrammed on previous pages) is comprised of a 3-D printed ribbed mould (laid or wove). The mould dimensions can be scaled up according to the output capabilities of one's 3-D printer. When assembled, the handles on either side allow the entire box and mould to be manually agitated during sheet forming, which – in conjunction with the use of formation aid – enhances fiber cohesion and ensures that the document is not covered with pulp. The mould and deckle can then be removed and the composite sheet couched, or using a plain or laid-printed removable polyester mesh, blotted while on the surface of the caster under vacuum and transfered (much like the flexible *su* in Japanese papermaking) to blotters or simply allowed to dry on the mesh.

Not all damaged documents require leaf casting infills; one must choose from a variety of conservation techniques depending on the artifact in question. Leaf casting can be useful when recreating the integrity of the object's original dimensions is desired. One need not be intimidated by this leaf casting process, as the steps involved are quite similar to the familiar process of making a sheet of paper.

17 Keyes, Keiko Mizushima, and Donald S. Farnsworth: *A practical application of paper pulp in the conservation of works of art on paper*, 1976. In AIC Preprints, American Institute for Conservation 4th Annual Meeting, Dearborn, 76–86. Washington, D.C.: AIC.

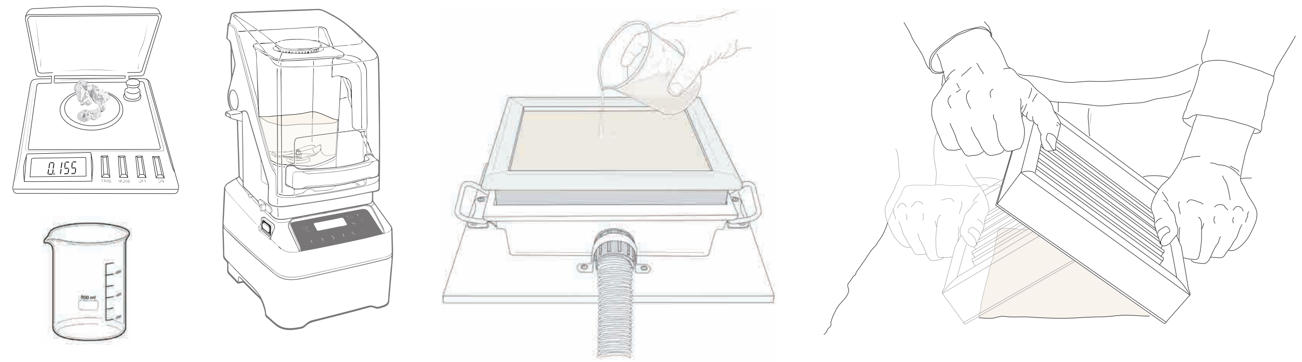
Avoid or minimize the use of cotton rag and cotton linter:
With the exception of leaf casting to match a contemporary paper, cotton should not be used. For older European papers, use linen (flax) and hemp half stuff; for Japanese papers, use kozo, mitsumata, gampi and abaca. These bast fibers contain hemicellulose, an important component in the European and Japanese methods; cotton, a seed hair fiber, has no hemicellulose. In leaf casting, **hemicellulose is important for edge adhesion (without using paste) and is compatible with formation aid,** a viscous mucilage additive that promotes even distribution of fiber.

Getting started: leaf casting an 81 g/m² (GSM) sheet

Using a 8.5 x 11 in. (22 cm x 28 cm) mould

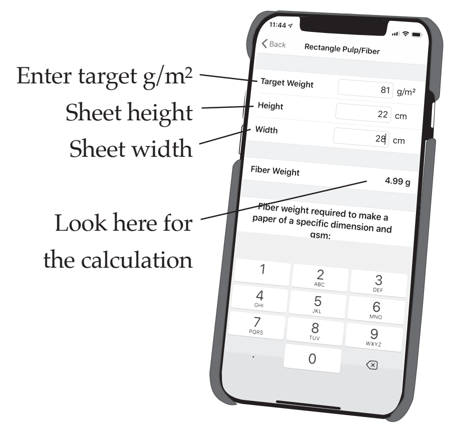
Terminology: (raw material –> half stuff –> pulp –> furnish –> paper)
- **Half stuff:** *partially processed paper fiber, usually dry (aka: first stuff, lap, wet lap)*
- **Pulp**: *aqueous processed fiber - retted, cooked, beaten; hydrated and fibrillated (aka: stuff, stock)*
- **Furnish:** *dilute pulp with additives (e.g. CaCO3, MgCO3, formation aid), ready for sheet formation (aka: charge)*

– Overview –



Calculate – Measure – Blend – Pour – Form – Vacuum – Couch – Press/Blot – Dry

To perform initial calculations such as determining the dry weight of fiber required for this size sheet, use the PaperWeight app:



Here we learn that **5g** dry weight of fiber will create an 81 g/m² sheet of paper 22 x 28 cm. If prepared (blended) in **400** ml H_2O with **100** ml of formation aid, we get **500** ml of furnish, which nicely works out to **1g** of fiber per **100** ml of furnish.

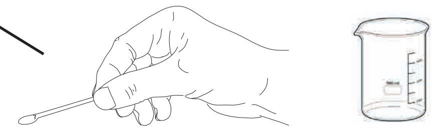
Note: blending 1 liter at the concentration **1g per 100ml** creates a very convenient suspension for formulating different weights of paper, as adding or subtracting 100ml of pulp solution will correspond to an addition or reduction of 1 gram of dry fiber.

In this example, the target g/m² of 81, height of 22 cm, and width of 28 cm in the PaperWeight app yield a result of 5 grams (4.99 g) of dry pulp. Blend in 400 ml of water; add 100 ml of formation aid at the last 5 seconds of blending.

As you might expect, there is some loss of fiber in the determinate papermaking process, e.g. fibers stuck to the blender blades, white water fines passing through the screen, etc. Therefore, it is wise to err on the plus side of any fiber weighing equation; in other words, too much is preferable to not enough.

Preparation

- Clean the surface of document chosen for infill
- Weigh the document (example document = 4.1 g)
- Test for aqueous solubility – gently roll a moistened cotton Q-tip on pigmented area and inspect for fugitive colorant
- Prepare formation aid (*neri*) in advance and let sit overnight



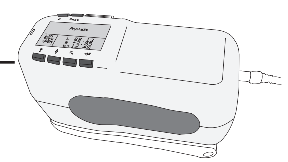
- Download and install *PaperWeight* app from the Apple App Store
- Determine document's square centimeters: scan document on a contrasting background alongside a 1 cm^2 white square and dividing pixel count per instructions on p. 22 (8,570,075 ÷ 17,283 = **496 cm^2**)

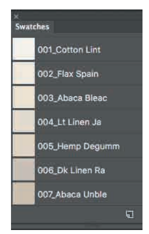
- Calculate document weight, g/m^2 (Grams per Square Meter) using PaperWeight's *Paper Calculations, Area* menu. (enter the data we have collected: mass: 4.1 g and square centimeters: 496 = **82.7 g/m^2**)

- Subtract sq cm of document from interior deckle dimensions to determine sq cm of the paper that will be made (22cm x 28cm = 616 cm^2 - 496 = **120cm^2** infill)

- Calculate dry weight of pulp required for matching the document's GSM and the surface area of infill using PaperWeight's *Pulp Calculations, Area menu* (in our example, 82.7 GSM and 120 cm^2 = **1g of pulp**)

- Calculate the percentages of pulp needed to match document color from your library of pulp colors (p. 36) and weigh and prepare in calculated proportions – 10 grams (Example doc Lab= 90, 0, 9)

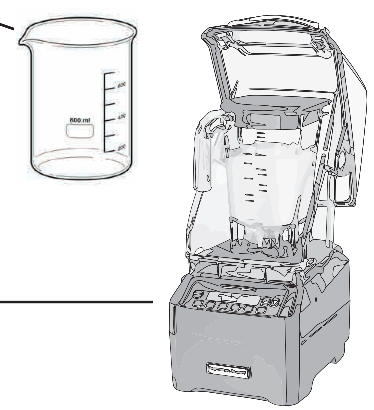




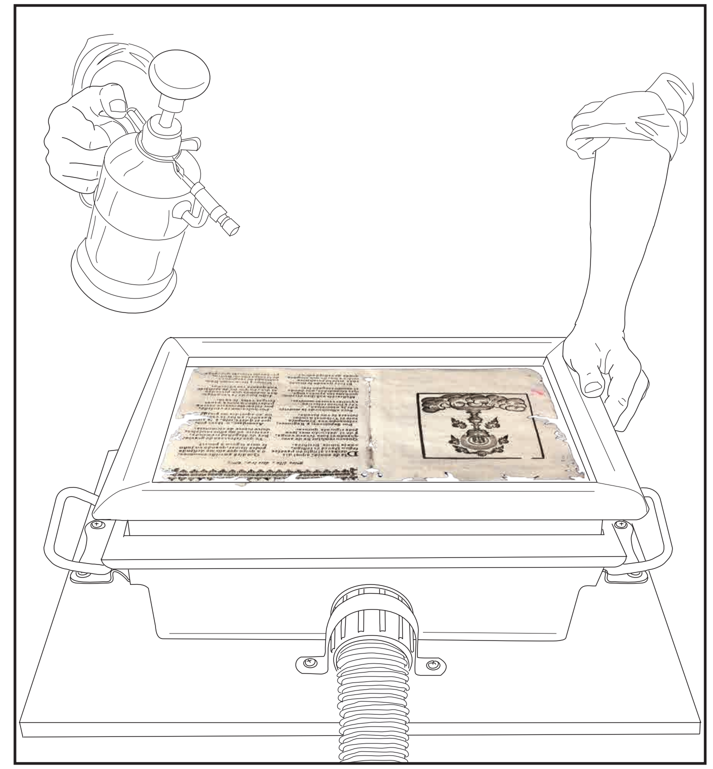
- Add 500ml of filtered water and allow to soak for 3 to 24 hours

Prepare Furnish:
- Blend the 500 ml and 10 grams of fiber for 1 to 3 minutes being sure there are no lumps
- Add 450 ml of additional water (total 950 ml)
- Add 50 ml of formation aid and blend for 5 more seconds

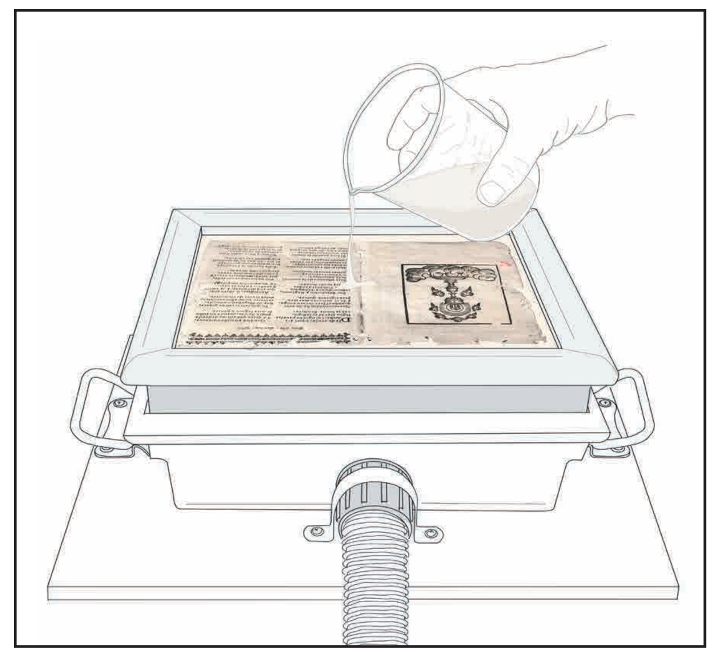
We now have 1 lt of furnish equal to 1 g of fiber per 100 ml of furnish. This makes the quantity needed in this example easy: 100ml
Let air bubbles subside, transfer to beaker, stir by hand prior to pour



Leaf casting with removable mould – step by step



Moistening document



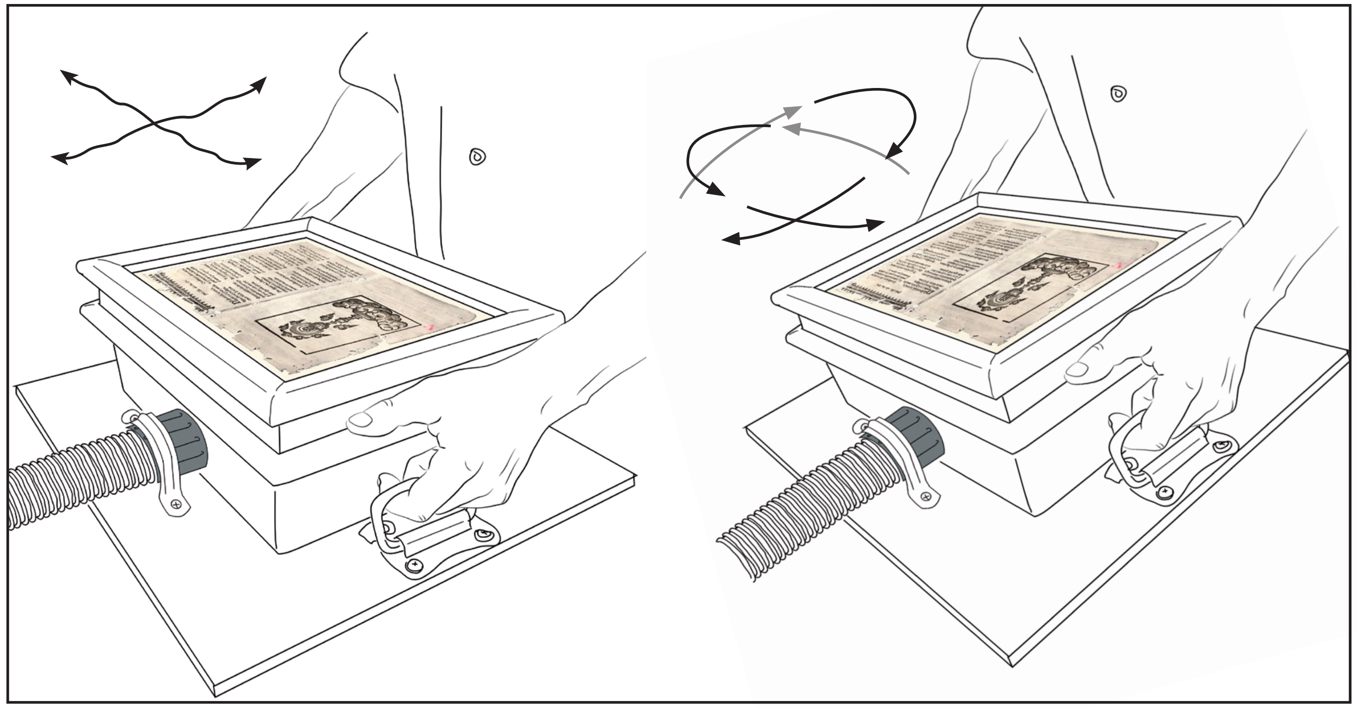
Pouring furnish

1. Moisten (prepped/cleaned) document and let relax until flat on the mould surface. Place the document verso up / recto down: consider that the end result will display a harder-edged definition conforming to the shape of the document apparent on the wire side (the face down side of the document that touches the screen) and softer edges are present on the felt side (the upward facing side). For example, given a document with a blank verso, it is best to place the document recto down on mould surface (verso up).

2. Try a test pour to ensure that the pulp solution quantity is sufficient to fill the deckle. If it is not, dilute the calculated GSM of pulp with water and formation aid (for example, 100 ml of furnish diluted to 800 ml total volume). Include formation aid when diluting furnish; with formation aid as a component in the furnish, more time is available for pouring, forming, shaking and couching. **Do not pour if the furnish is still foamy from the blender; transfer to a beaker, let stand and stir before pouring.**

3a. Turn on the vacuum and ensure it is drawing air through the mould surface and that the document is gently pulled flat to the mould surface.

3b. Pour the 800 ml of dilute furnish (with formation aid, the consistency should be as viscous as cream) onto the document while the vacuum is on, filling to near the capacity of the deckle (as tested earlier). Due to the formation aid in the furnish, this technique allows for direct pouring onto the document without damage.



The lightweight design of this 3D printed leaf caster gives the maker complete control of the pulp flow: start with initial shakes and vibrations, then tilt to slide furnish off document

4. Immediately after pouring the furnish (filling to the height of the deckle), use the handles to lift the leaf caster, first shaking using longer strokes front to back and side to side with slight up-tilt at the end of every shake so as to prevent wave from spilling. Then switch to more of a vibration shake, watching and assessing that your shakes are successfully aligning and smoothly setting the fibers.

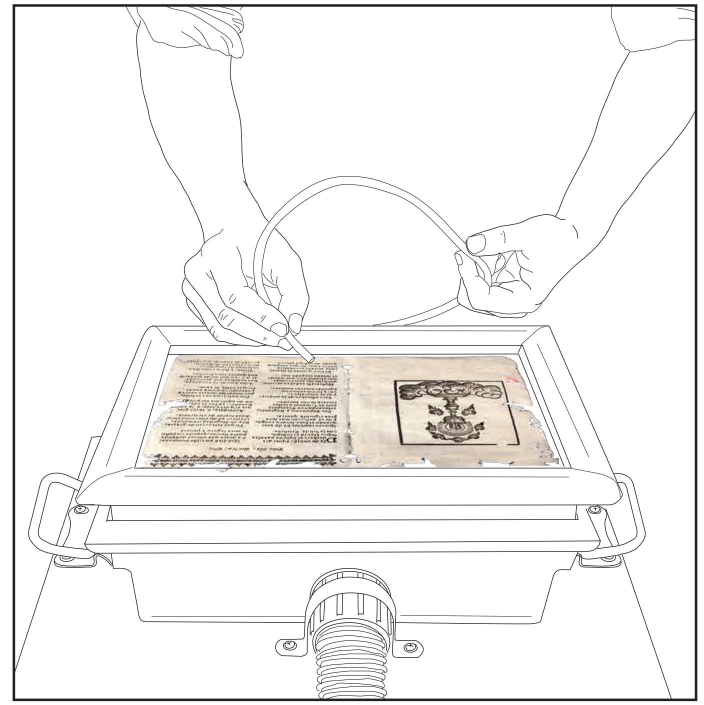
When the replacement areas have drained and while there is still liquid furnish on the document, slowly tilt in all directions and allow the furnish to slide off the document and into the document voids.

Japanese techniques may also be used; one can go as far as "throwing off" excess pulp during formation and employing multiple pours to build up a sheet.

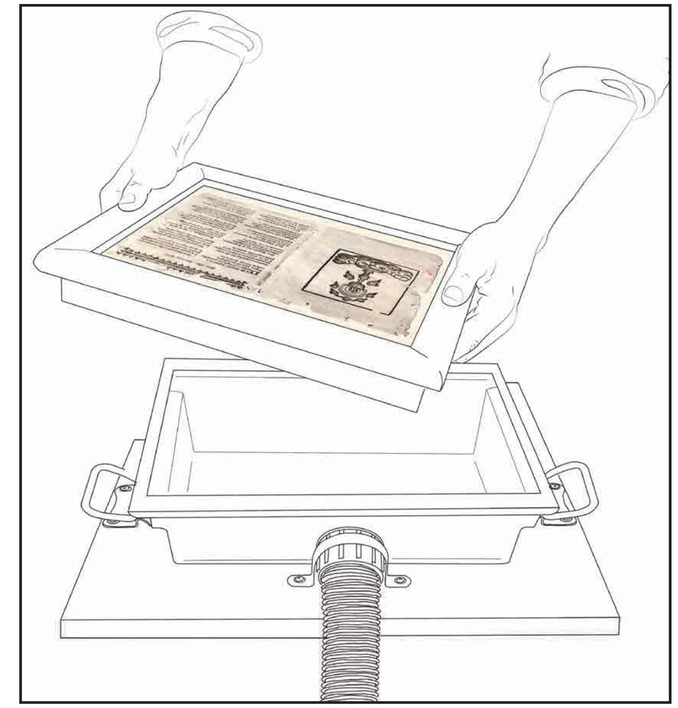
Why use formation aid?

Formation aid (*neri* in Japanese) solves many of leaf casting's potential problems and frustrations. With the proper amount of formation aid, one creates a slow-moving, slippery, viscous furnish that will not displace, lift or otherwise damage the document. Additionally, the thick viscosity of the suspension allows fiber to flow to the missing areas while tending to avoid settling on the document. If the furnish drains too quickly, try again with a higher percentage of formation aid and/or reduce the vacuum pressure.

Neri has been used in the manufacture of Japanese paper for hundreds of years. The solution itself is comprised of a very small percentage of solids (one teaspoon to a gallon) and does not size or have a lasting effect on the paper besides keeping the fibers from knotting and tangling during formation.



Use vinyl tubing inserted into the box and 6 inches down the vacuum connection tube to carefully remove excess furnish. Moisten with Dahlia sprayer to re-moisten and suck unwanted/drained fiber.



Remove moulds and deckle from vacuum box

5. Carefully remove any small areas of excess or unwanted furnish using a length of ¼ inch flexible vinyl tubing that passes through the box and into the vacuum tube. Per illustration on p. 61, maximum suction can be achieved by running the ¼ inch vinyl tube into successively larger gauges of tubing on its way to the vacuum.

6. Turn off the suction, lift the mould from the vacuum box, and remove the deckle in preparation for couching. I recommend an alternative couching method with removable polyester mesh screen:

Alternative to traditional couching:

My preferred method is to protect the document with a polyester mesh and blot while under vacuum. The mesh-document-mesh sandwich can be lifted and dried. This is the safer approach for delicate paper artifacts; forming on a 86 mesh polyester screen, then covering with another screen eliminates the need for direct handling of the moist document.

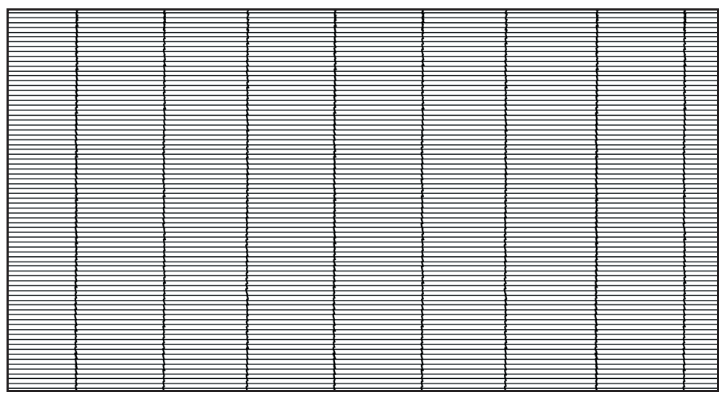
7. If performing a traditional couch, do not over vacuum-dry the sheet, as moisture is necessary for a good couch. Holding the center of the long sides of the mould, couch the cast sheet and document onto a layer of Evolon atop a felt. Rather than rolling the mould from left to right in the traditional single motion, stop when the mould is flat on the couching surface and press on the ribs. When you press on the ribs, moisture should be seen seeping up through the back side of the screen; this water, when pressure is released, will "wash" the fibers off the screen surface to make the couching transfer from mould to felt (Evolon). If no moisture appears, the sheet was overly vacuumed and may need re-wetting.

Note: Evolon AP (168 gsm) is a non-woven microfiber paper made from polyester and nylon. Evolon absorbs many times its weight in water and is tearproof and lint-free.

Watermarks & laid screen printed in acrylic on woven mesh

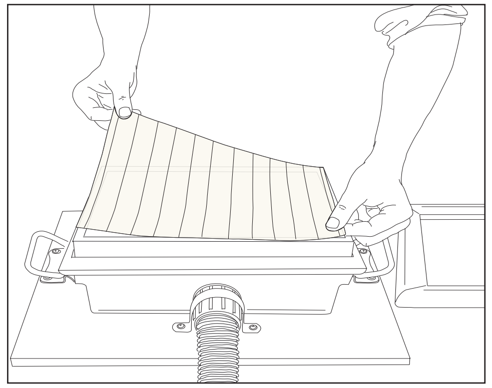
An entanglement problem often occurs when pouring furnish directly onto a laid screen when leaf casting (see *Laid mould "sealing dip,"* page 70). All western laid moulds are pulled through the vat perpendicular to the laid lines in order to align the wire side fibers across the gaps of the laid line surface (thereby forming a micro-screen on which a more random fibers of the felt side form). Pouring, on the other hand, creates a chaotic swirl of fibers on the wire side and are prone to tangle in the gaps of the laid wires, making couching difficult if not impossible.

One solution that can tolerate a random swirl of pulp on a laid screen is to print the laid pattern onto a woven screen (like a modern watermark). After designing the pattern in Photoshop, we printed it using a UV-cured acrylic inkjet printer onto **86 mesh polyester screen.** For improved results, we printed the laid pattern multiple times to build up ink thickness (see p. 43). We made the polyester screen correspond to the outer dimension of the mould so that the deckle, once in place, helps hold it down. Custom chain widths were chosen so we could more closely align the chain lines of the mould covering with the document's chain lines.

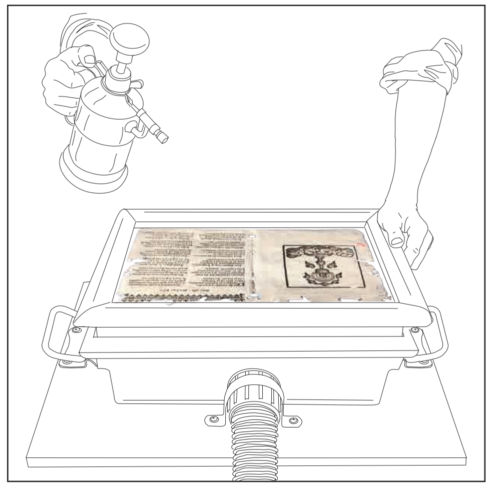


A laid pattern printed onto 86 mesh polyester screen can create a "modern laid" pattern in the look-through of the paper with no shadows along the chain lines

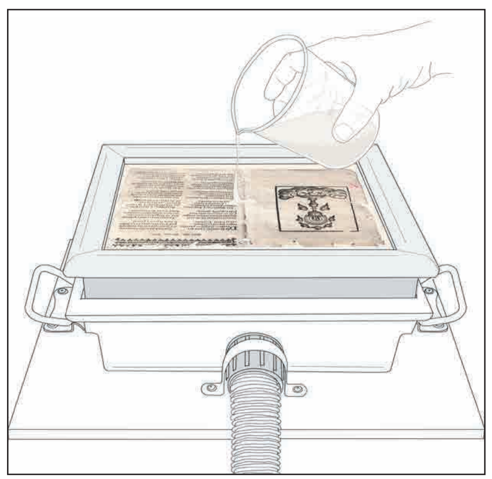
As we were not performing a traditional couch (see opposite page), we allowed the vacuum to pull for a longer duration, making the sheet easier to handle. Dewatering was augmented by laying dry Evolon sheets on our newly cast sheet (deckle removed), taking advantage of the suction to evenly pull the Evolon in contact with the work. As the laid pattern is printed on flexible mesh, the screen can simply be lifted off the mould to allow for further blotting and drying of the cast sheet.



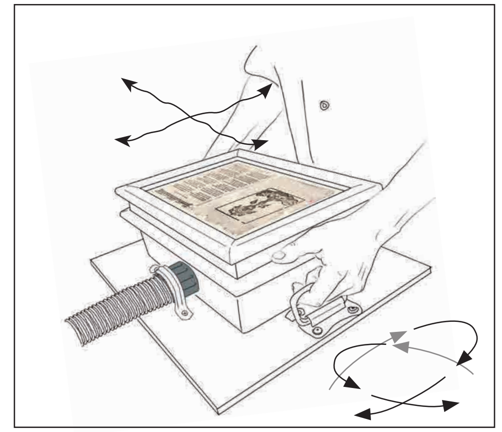
1. Place 86 mesh polyester (with or without laid-printed-pattern) on wove mould and moisten, smooth and remove air bubbles.



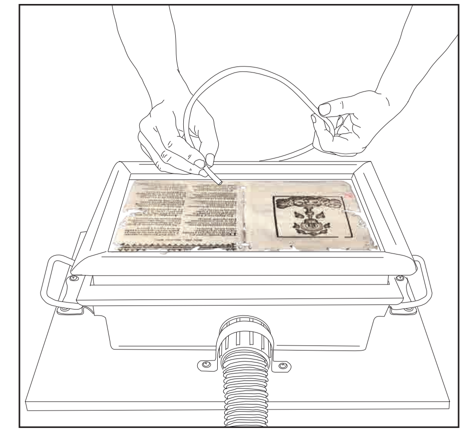
2. Place and moisten document.



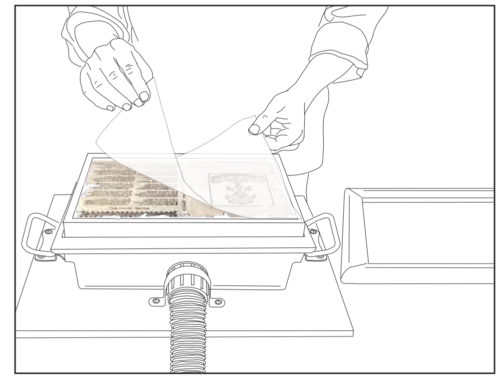
3. Start vacuum and pour furnish.
Note: Directly pouring furnish on a document while under vacuum requires the use of formation aid (see Additives p. 10) and works best with furnish made from bast fibers.



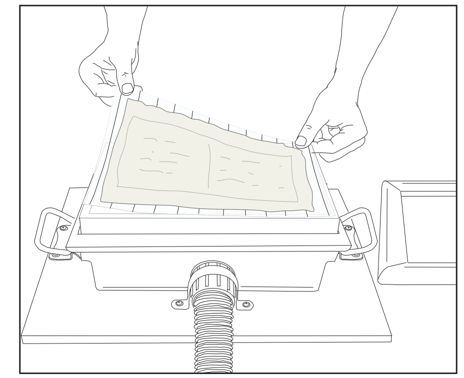
4. Shake and settle fibers while under suction – finishing shakes with short vibration. Stop shaking while furnish is still flowing.



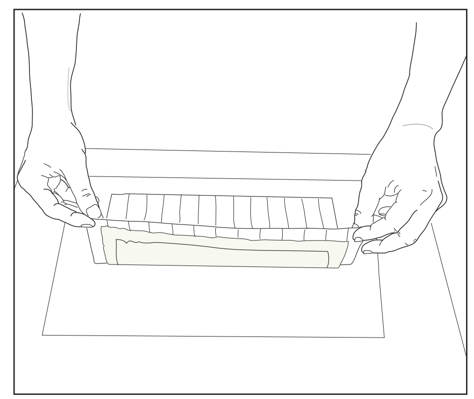
5. Use ¼ inch vinyl tube to carefully remove excess furnish. Moisten with Dahlia sprayer to re-moisten and suck unwanted/drained fiber.



6. Place 86 mesh polyester screen over document then blot with Evolon while under vacuum.

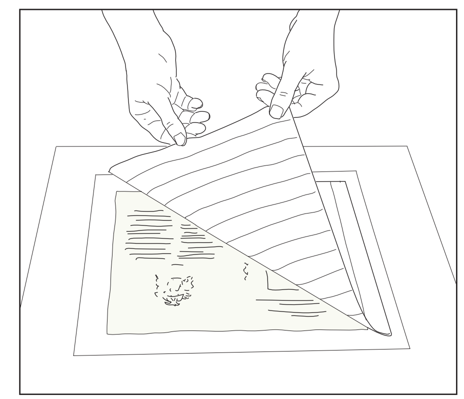


7. Turn vacuum off, lift mesh-enveloped-document from mould.



8a. Lay cast sheet, 86 mesh and document face down on Evolon atop a felt.

8b. Cover with a blotter and with moderate pressure, allow for absorption to continue the dewatering of the composite.



9. Carefully lift printed mesh from cast document; gently free one edge and pull away from that edge while lifting slowly and carefully. A tattered edge is usually of little concern, as edges will be trimmed. Transfer cast composite to Evolon for blotting and drying.

Note: *Keep cast paper areas from adhering to blotting material (e.g. Pellon, Evolon or Zorbix) when dry by placing a layer of 86 mesh polyester beneath the document when casting and on top when blotting and drying. This is especially relevant when using drying methods using heat. Test all methods before repairing any document of value.*

Laid mould "sealing dip" – pouring method

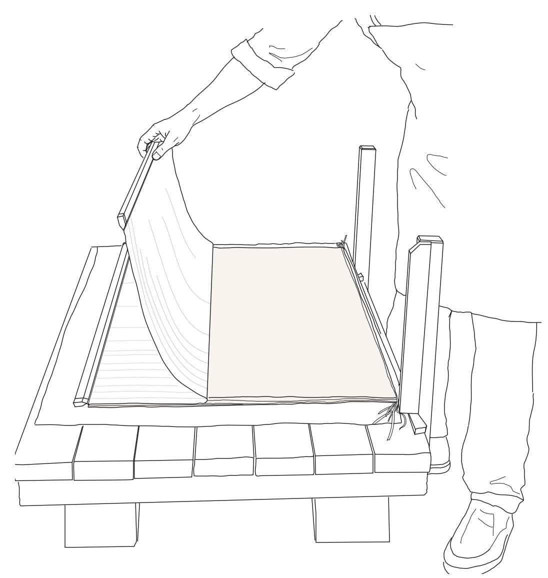
Controlling how fibers wash across the surface of a mould in the first half-second of sheet forming is very important, particularly when using a laid mould. In the case of our leaf casting technique where the pulp solution is poured onto the mould, the traditional western technique of pulling the mould through the vat is unavailable. Instead, we must take inspiration from the multiple dipping technique used in Japanese papermaking (using a *su* and *keta*) where the first few dips determine, to a large extent, whether the sheet will release easily during couching and therefore whether or not a successful sheet of paper will be made. In these sealing dips (*kumikomi*), the vatman scoops up a small quantity of pulp on the front edge of the mould, then tilts the mould quickly, making the furnish rush across and off the opposite side.

This technique deposits a thin layer of fibers aligned across the grain of the bamboo screen (not parallel and entangled).

Aligning the fibers on the screen side with a first pour, as in the Japanese *kumikomi* method, is possible with the addition of formation aid and by holding the mould at a steep angle. When executed properly, no matter what hydrodynamically chaotic swirl of fibers takes place in subsequent pours above this layer, the thin gossamer sealing mat protects the integrity of the paper, allowing for a perfect couch. With a thin consistency of pulp and plenty of formation aid, we can emulate *kumikomi* and align the fibers correctly for a perfect paper-to-felt transfer.

Japanese papermaking techniques we can adopt for use in leaf casting:

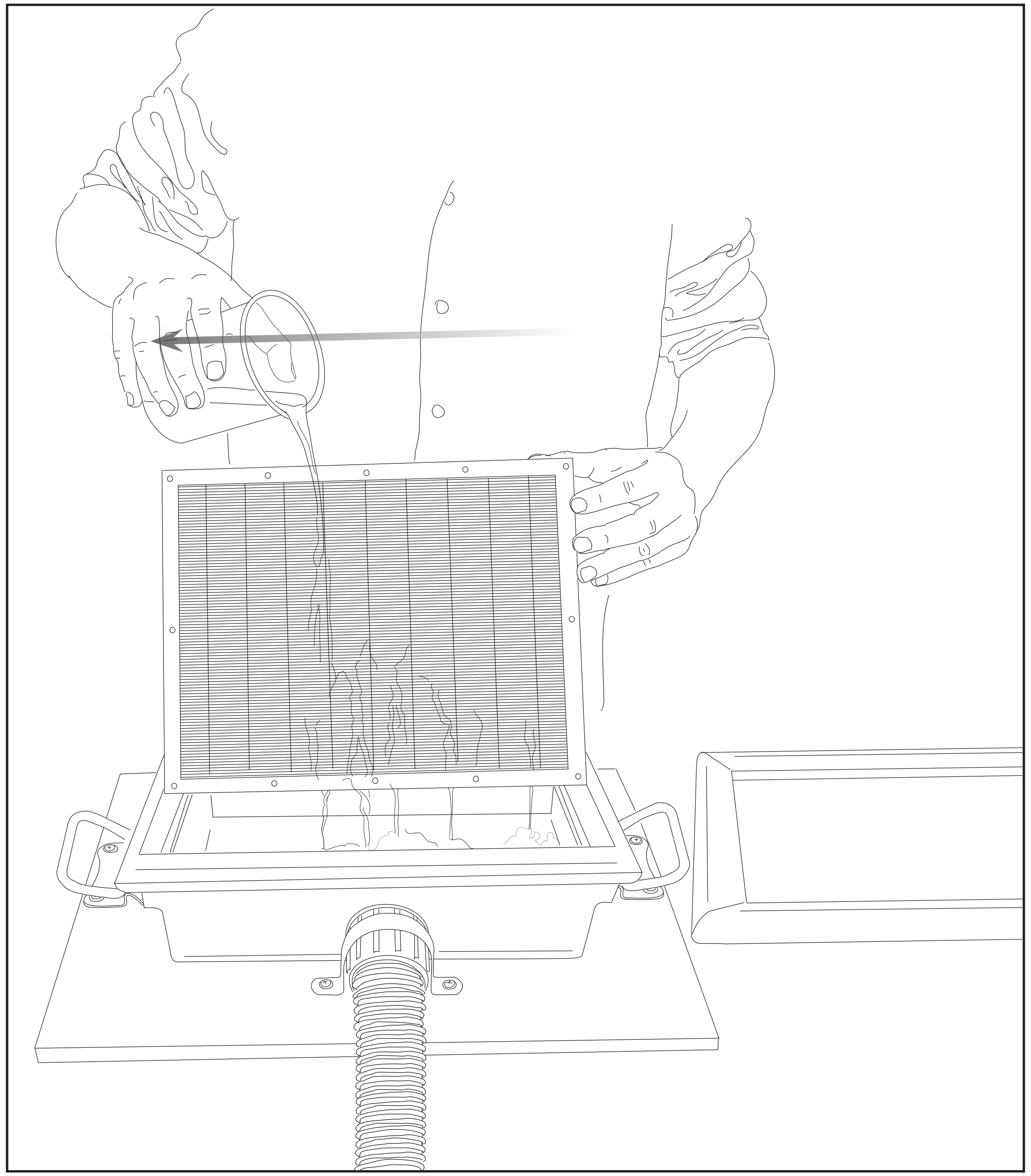
- ***Bast fiber cooking, rinsing and beating***
- ***Formation aid (neri) additive***
- ***Sealing dips for easier couching***
- ***Multiple dips "weaving" the fibers***
- ***Couching using a flexible screen***
- ***Drying on boards and hot surfaces***



For more information, download *A Guide to Japanese Papermaking* at www.magnoliapaper.com

Pouring a "sealing dip" on a laid mould

(prior to leaf casting – an alternate method to using printed laid pattern)



Mix a separate 500 ml of very dilute furnish; add formation aid until the solution reaches a consistency as thick as heavy cream. Tilt the mould without its deckle at a steep angle and pour across the high, upper edge, letting the furnish wash to the opposite side and into the vacuum box. Vacuum off at this point. (This step is not necessary for a wove mould unless a gossamer of fiber is desirable on the verso for added strength.)

Dies illa, dies iræ, &c.

Dia de enojò, aquel dia
deshará al ſiglo en paveſas
ſegun David es teſtigo,
con la Sibila Erithrea.

Quanto temblor ha de aver
quando el Iuez ſevero venga,
y de el deſcuido mas leve
pida riguroſa quenta.

Por Sepulcros, y Regiones,
reſonando vna Trompeta
ante el Tribunal à todos
juntarà ſu voz funeſta.

Sera aſſombro de la muerte;
y de la naturaleza,
vèr à Iuìzio reſuciten
aquellas cenizas muertas.

Moſtraràſe vn Libro eſcrito,
que haſta los apices tenga
mas eſcondidos, por donde
el mundo juzgado ſea.

El Iuez quando ſe ſiente,
toda maldad encubierta
ſaldrà à luz, ſin que ninguna
quede de caſtigo eſſenta.

Que dirè yo triſte entonces;
ò à quien que alli me defienda
podrè llamar, quando vn juſto
ſe mira ſeguro à penas?

Tu que ſalvas tan de gracia,
Rey de Mageſtad tremenda,
revierte en mi eſſos raudales,
dulce fuente de clemencia.

Acuerdate, ò Iesvs pio,
que el q̃ del Cielo, à la tierra
baxaſſes, yo ſoy la cau...
no en aquel dia me pierda...

Por buſcarme te canſaſte,
por ſalvarme muerte azerva
padeciſte: ò nunca vanas
fatigas tales ſe vean.

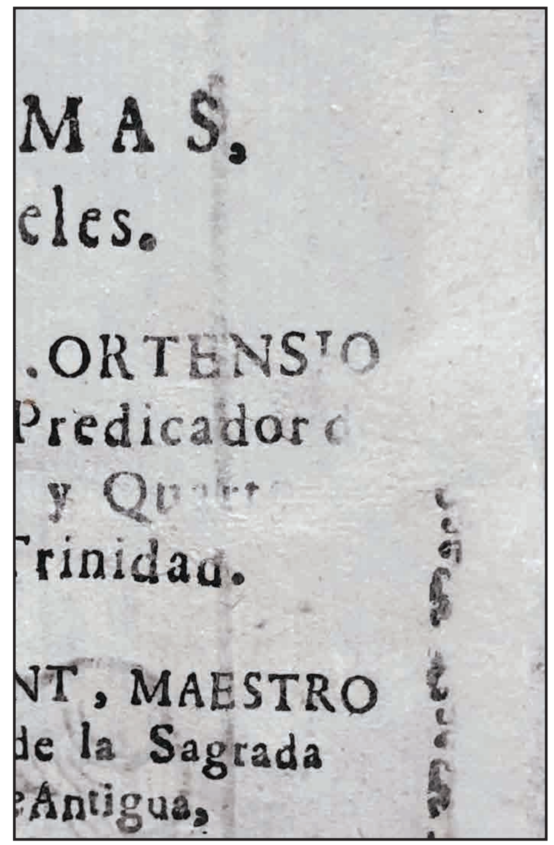
Iuſto Iuez de la vengança,
haz indultos que precedan
al dia, en que ha de ajuſtarſe
vna quenta tan eſtrecha.

Gimo, y lloro como Reo,
colorado de verguenza,
de la culpa eſta mi Roſtro,
perdon mi Dios, al que ruega.

A leaf from a 1694 publication – worm eaten with enlarged sewing/binding holes

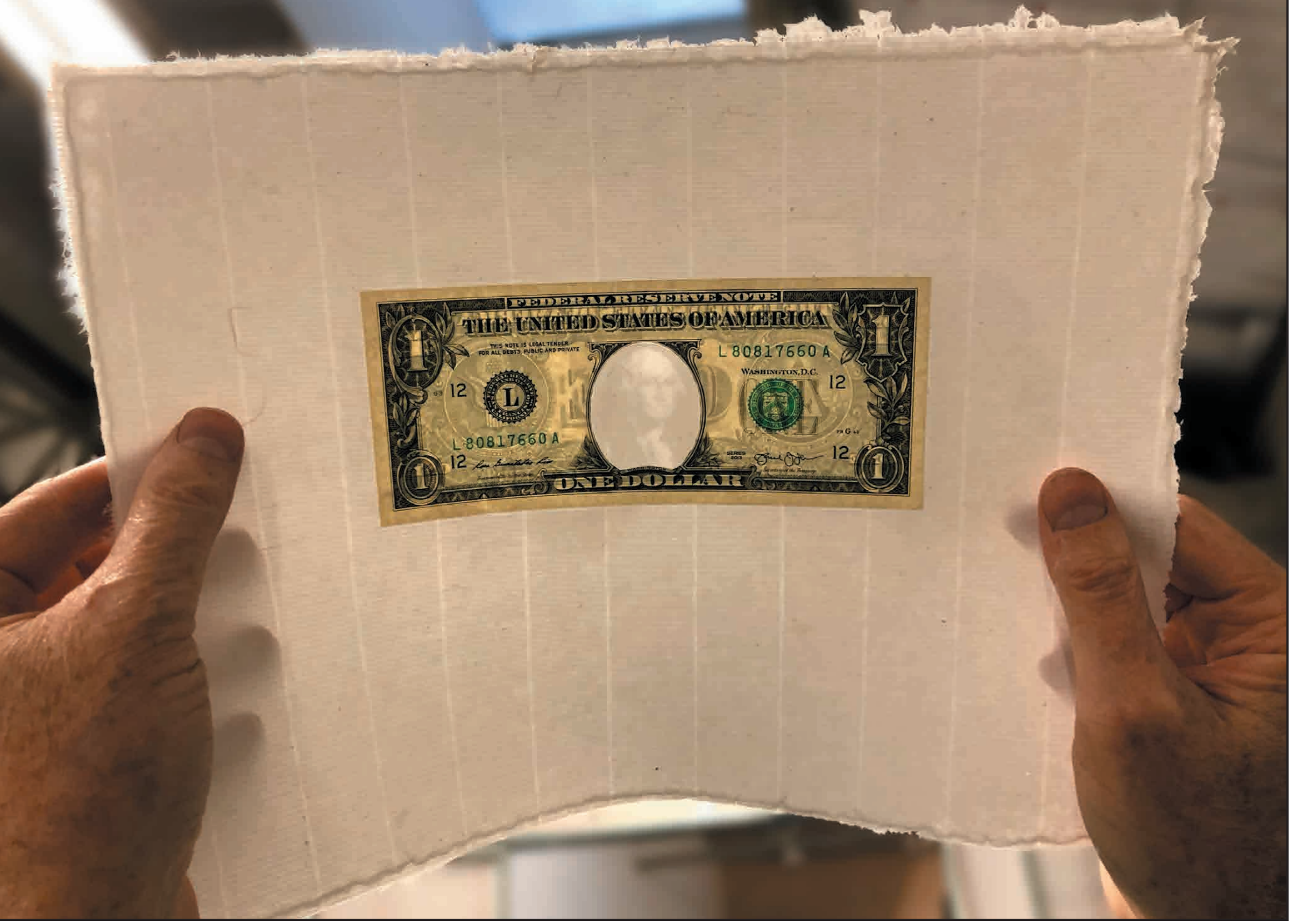
1694 publication leaf after pulp color matching, leaf casting, and trimming

1694 publication leaf, after casting and before trimming



1694 publication after leaf casting - detail: felt side

1694 publication after leaf casting - detail: wire side



Inspecting the look-through of a leaf cast dollar bill whose portrait has been removed and cast with a light-shade watermark; in the same casting, the area surrounding the dollar was cast with a laid pattern

As a studio-wide challenge, Magnolia Editions master printers Tallulah Terryll and Nicholas Price, artist Era Farnsworth and I attempted the leaf casting of a U.S. one dollar bill whose center vignette of George Washington had been excised with a scalpel.

After spending a day with artist Guy Diehl refining the gaskets of the leaf caster, it was time to repair the now damaged bill. The following day I created a short fiber pulp by beating very dilute Celesa flax half-stuff hard and fast in a Valley Iron Works beater for 20 minutes. The reason for extreme shortening of the fiber was our desire to insert a light-shade watermark of George Washington in the center egg-shaped area. On 137 polyester mesh (supplied that day by screen printer John Ream), Tallulah Terryll printed a dozen graphical interpretations of George with multiple layers of UV cured acrylic, upon which we leaf cast with the short fiber furnish until we determined which graphic would generate the most favorable light-shade watermark portrait.

We placed the laid printed polyester mesh on the leaf caster's wove paper mould surface. Next, we placed the printed image (negative) of Washington, registered to the missing 'egg' of the bill, the perimeter of which we trimmed smaller than the height and width of the dollar. With the suction on, we poured the short fiber furnish and settled the fibers. The laid-printed-mesh cast around the bill created a strong laid line show-through, and the mesh printed portrait (laid just under the dollar) produced what I consider a fairly decent light shade watermark, with no hint that just below it was the background laid screen.

Leaf cast dollar with central image replaced by light-shade watermark - detail

Leaf cast dollar with light-shade watermark

Leaf casting using a foam mask

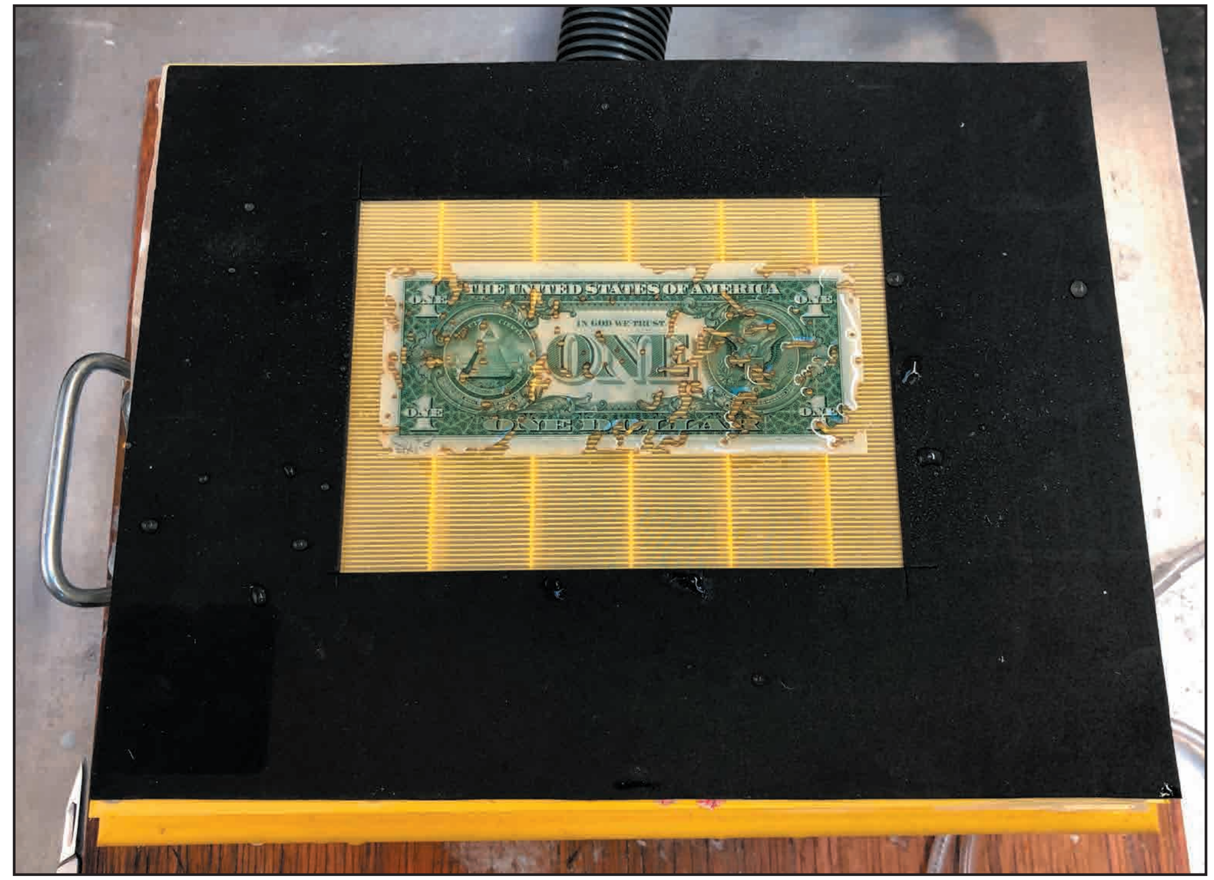
Worm-eaten dollar moistened and relaxed on 86 mesh polyester screen with cut foam mask – viewing side down

Ethylene vinyl acetate foam (AKA hobby foam or craft foam) can be cut to size and used to mask off documents on the leaf caster. Using an mat knife or scalpel, an aperture can be cut in the foam that fits the document's dimensions exactly (above) or exceeds them (opposite), allowing one to embed the document in a surrounding sheet of paper. In the example shown on this page, our casting was far more successful when the document is viewed from the front.

Using the ¼ inch vinyl tube connected to the suction of the leaf caster box to carefully remove excess furnish in the non-casting areas

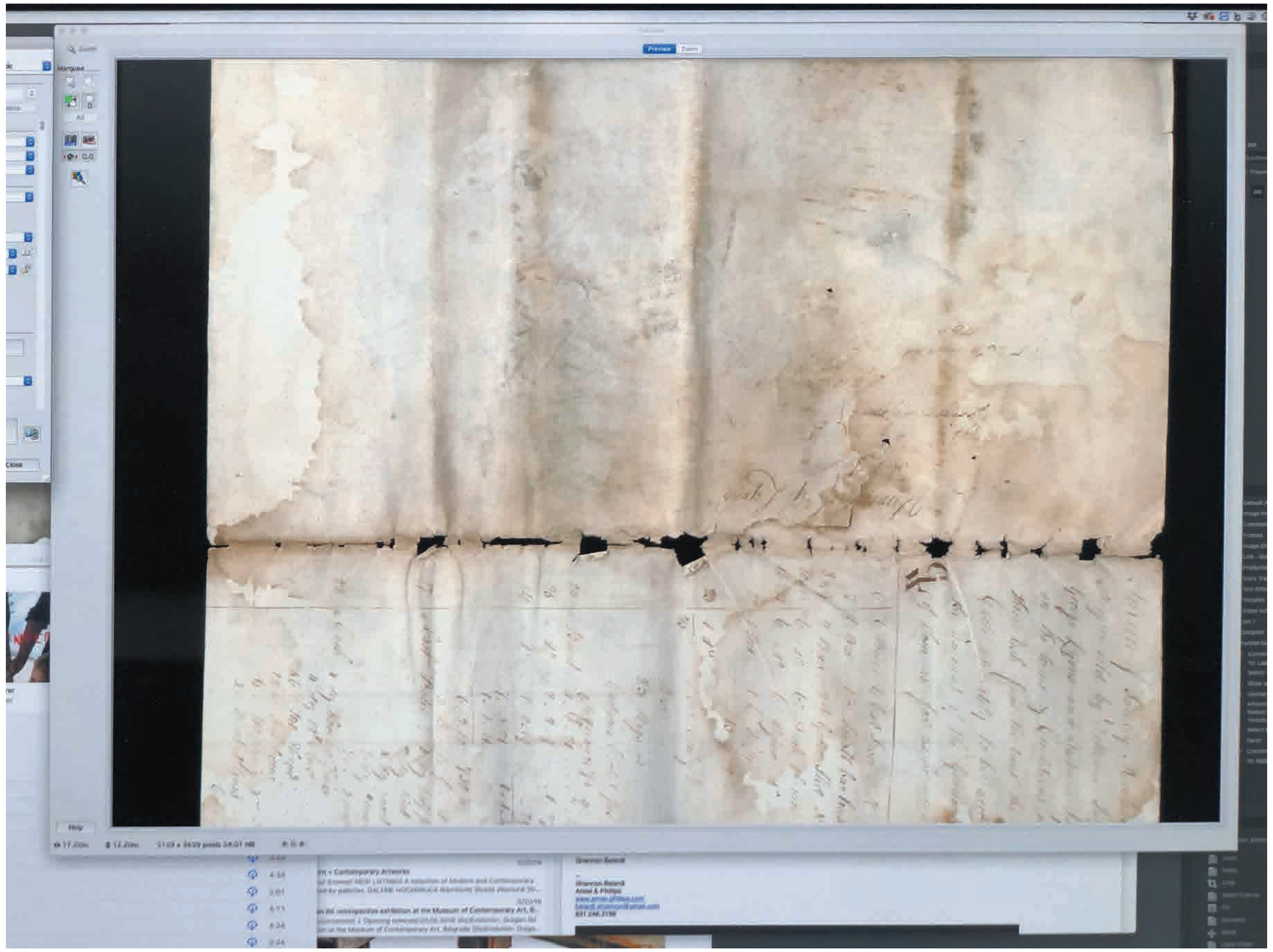
Leaf cast worm-eaten dollar - front side

Leaf cast worm-eaten dollar - less successful back side

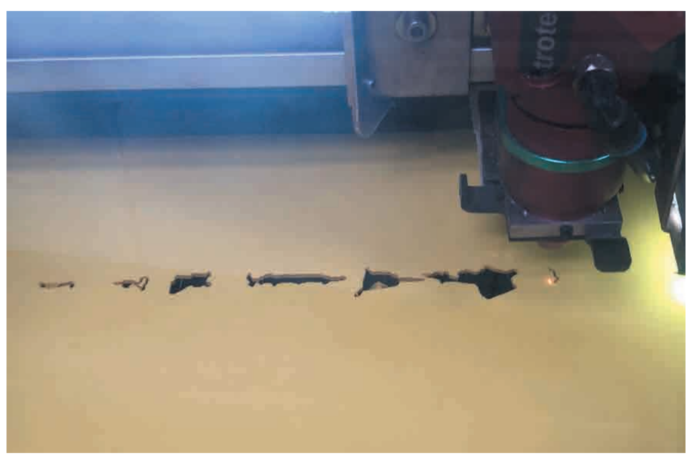


Using a larger aperture foam mask to cast a 5 x 7 inch sheet in and around the worm-eaten dollar

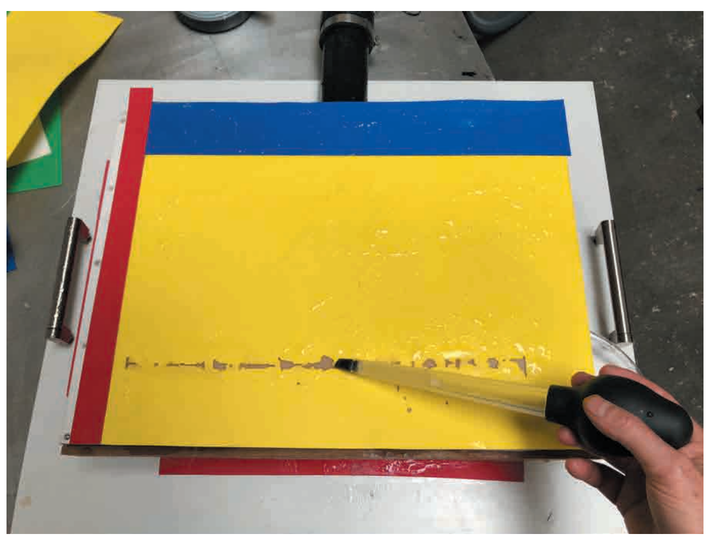
Worm-eaten dollar cast within a 5 x 7 inch sheet; shredded and processed foreign currency were used in the furnish



After scanning, the shapes needing infill were isolated and rendered into vector outlines



Laser cutting a foam mask to form the infill shapes



Case study: infill of irregular damage on water-fugitive document

This case study was conducted with the assistance of Max Thill at Karen Zukor's conservation studio, who provided many of the accompanying images as well as documentary notes upon which the following summary was based.

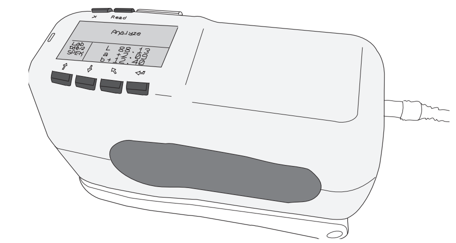
For this case study, a manuscript needed repairs in a complex series of missing areas found in the gutter fold of the folio leaf. As the document's inks were water-fugitive, the manuscript itself could not be placed in a leaf caster for direct infill. In this case, we create a foam replica of the document and use the mask to cast the missing areas, without involving the sensitive original in the process.

The document was scanned against a black background and the resulting black shapes rendered into vector outlines. Using a 200w CO2 laser, a foam mask was cut from ethylene vinyl acetate foam (AKA hobby foam or craft foam). This laser-cut mask was then used as a surrogate for the manuscript to form the infill shapes.

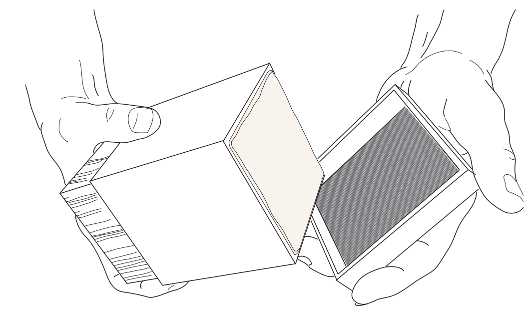
The manuscript was weighed and measured to find the weight of the folio leaf, which turned out to be very close to 90 GSM.

From each fiber type (linen, hemp, kozo and gampi) in a library of freeze dried pulp, a small (90GSM, 7.5cm x 7.5cm) sheet was formed using a 3D printed miniature deckle box. The color of each pulp in the library was measured (at D50/2) using a sphere spectrophotometer and expressed as Lab values, which were then compiled into a lookup (.aco) table in Photoshop. Likewise, Lab values were measured (again using a sphere spectrophotometer) from the document at hand to establish our target values.

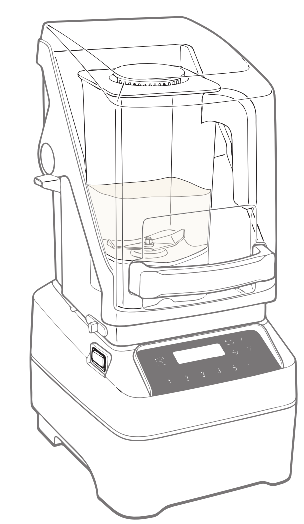
Indexing the document target values to the library of available freeze dried colors yielded a target pulp percentage calculated to match the various values of the document. Small 7.5cm square test sheets were fabricated for comparison to the document by weighing out 1g from the specified percentages of freeze-dried pulps. More 7.5cm sheets were made using a blender with 400ml of water and compared to the document. Because the pulp had been freeze-dried, there was no overnight soaking; re-hydration was quick and easy, taking less than a minute to blend.



X-Rite Sphere Spectrophotometer



Weighing small quantities of dry pulp



The piece was humidified and flattened overall before attempting to place any fills. Many of the fills needed some fibers teased out from the edges to create more contact with the piece, but this was easily achieved with a scalpel and fingernails. The largest fills were pasted only on the fringes. Two different shades were ultimately cast on a leaf caster using the foam mask.

In retrospect, the first set of fills [containing kozo and gampi] made with more of a fringe [feathered edge] may have been preferable. Since there was no layer of Japanese repair paper beneath these fills, the only points of adhesion are those fringes. Removing excess is easier than teasing out fibers to create a new fringe, especially on a small fill. Using water would make for a better edge, but since the fills are small to begin with, a scalpel is more precise and has less risk of removing too much material. However, the small lip contained a suitable repository of fibers to create fringe where none was present. Applying water with a fine brush and then using a scalpel would perhaps have worked the best, but when working with waterleaf, experimenting with any uneven wetting would have been unwise.

A few of the larger fills needed slight reshaping because folded-over areas made the losses appear larger than they actually were. This could have been avoided if the piece had been flattened before scanning. Still, the adjustments were easy to make. Despite initial concern that the fills would be too thick, and that they had a bit of a lip from the edge of the foam, feathering with a scalpel and burnishing through Hollytex (polyester sheets) seemed to resolve both issues.

Making a second set of fills while still in the foam provided a significant advantage: if the shapes had been smaller and less distinct, placement might have been a problem. Leaving the fills in the foam until pasting them in avoided any guesswork about placement or orientation.

Additional mends were also necessary in areas where the paper was cracked but had no loss.

As anticipated, the extensive and uneven staining along the fold precluded a perfect color match.

Conservator Max Thill writes:

On the hand-cut fill, I first decided which swatch was the best color match. I chose the darkest. Then I made a rough tracing and cut the shape out with a scalpel, leaving room to cut the edges once the fill was already in place. Further refinements in shape were made while comparing the fill directly with the space to be filled.

Since there was already a piece of lightweight kozo repair tissue over the corner to which the fill could adhere, a fringe is not necessary. Instead, I shaved the edge of the fill down to a bevel, the idea being that the fill can just barely overlap without adding noticeable dimension. If the loss were more of a clean cut, a butted-up fill would be more suitable. Since this is a worn down edge, a very slight overlap looks cleaner.

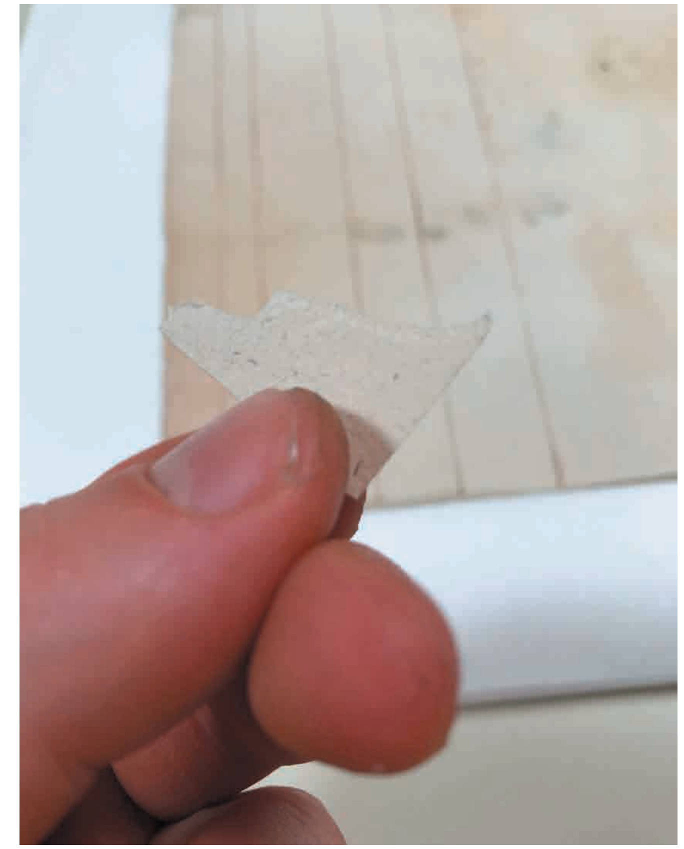
I then pasted up the fill overall with wheat starch page, strained twice and then thinned with water to be about the consistency of honey. The fill was put in place, and then burnished with a Teflon bone folder through a sheet of Hollytex (non-woven polyester). Next a clean sheet of Hollytex was placed over the adhered area, followed by a blotter, a piece of 8 ply mat board, and weight. The Hollytex keeps any wayward paste from sticking the blotter, and the mat board distributes the weight evenly. It was then left to dry for at least an hour. The excess left on the edges could then be trimmed to match the border of the piece.

Texture detail of leaf-casted fill

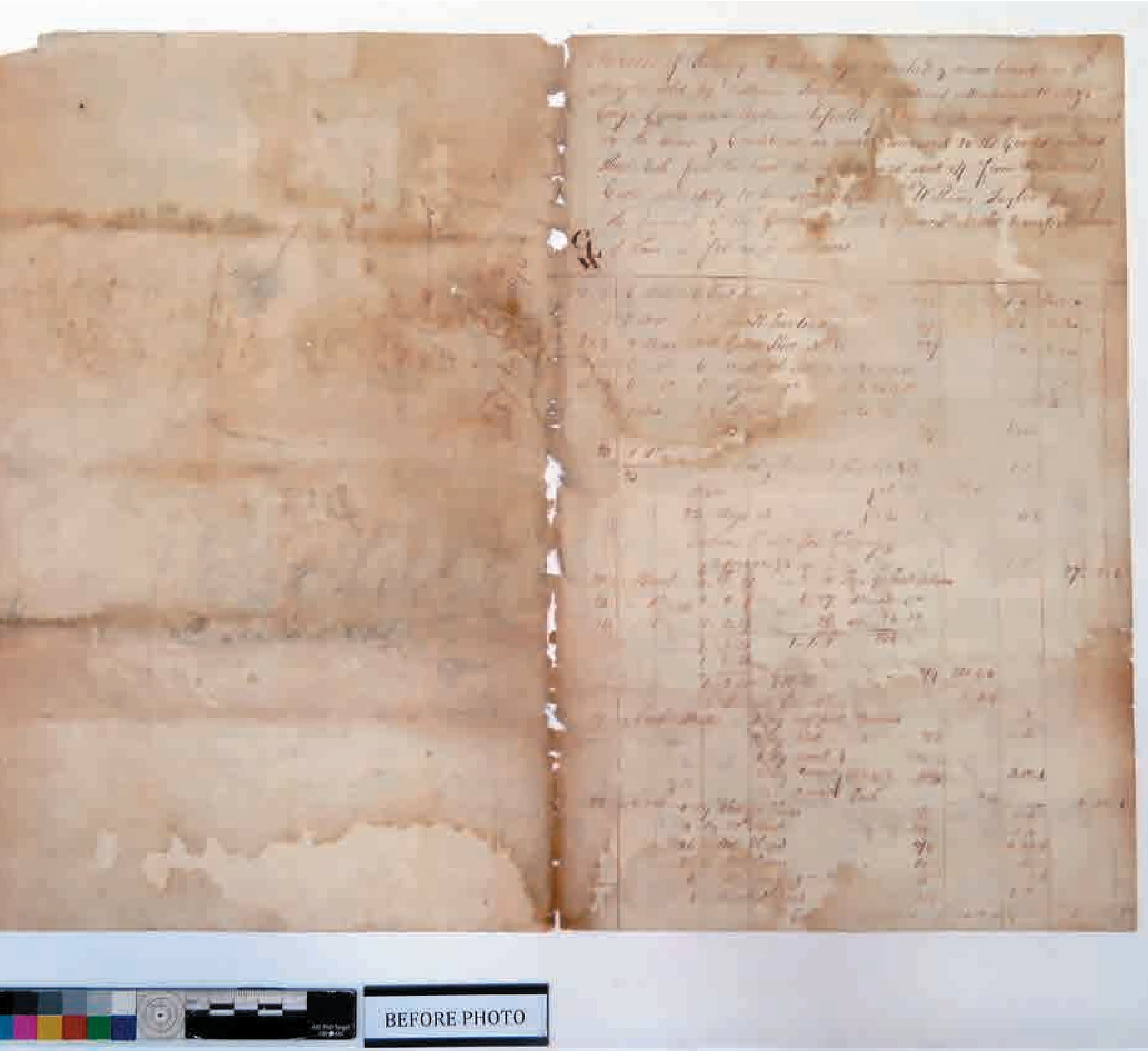
The texture of the leaf-casted fills did not stand out to me as noticeably different. The fill made by hand from predetermined swatches seems a bit smoother. Much more attention-grabbing was the color difference/relative cleanliness, and the absence of laid lines — especially on the larger corner fill.

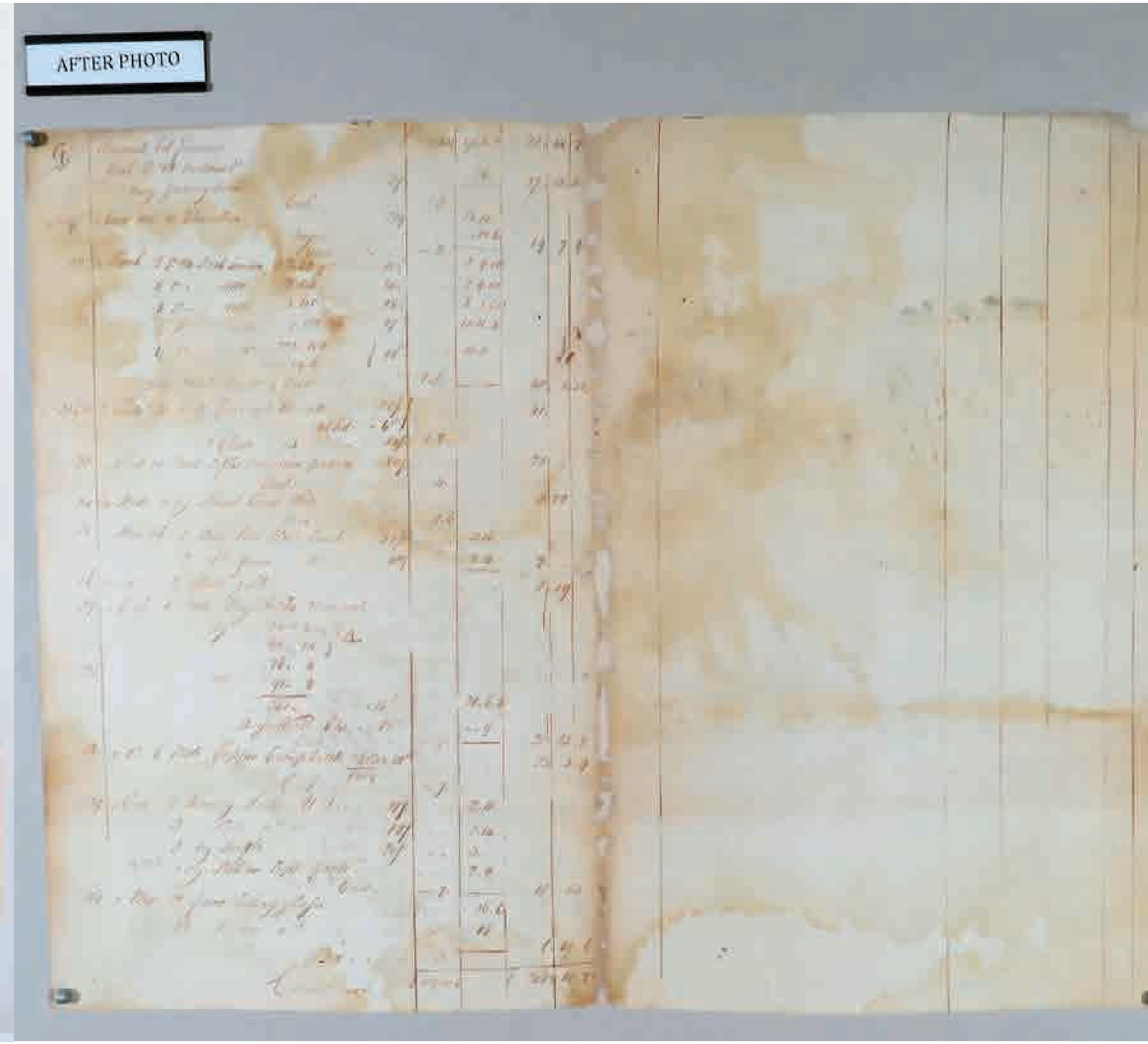
Overall, the fills produced were eminently usable. Doing the same by hand would have taken hours.

Max Thill at Karen Zukor's conservation studio



Beveled fill edge


BEFORE PHOTO

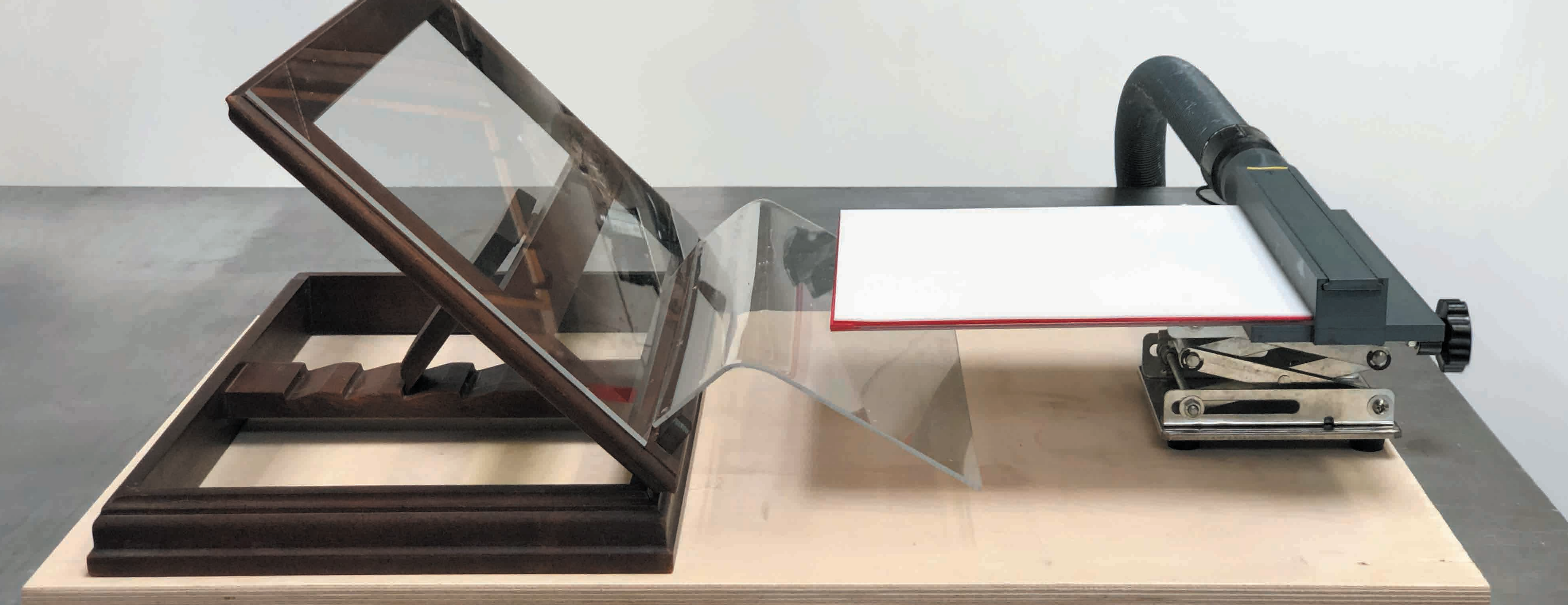

AFTER PHOTO

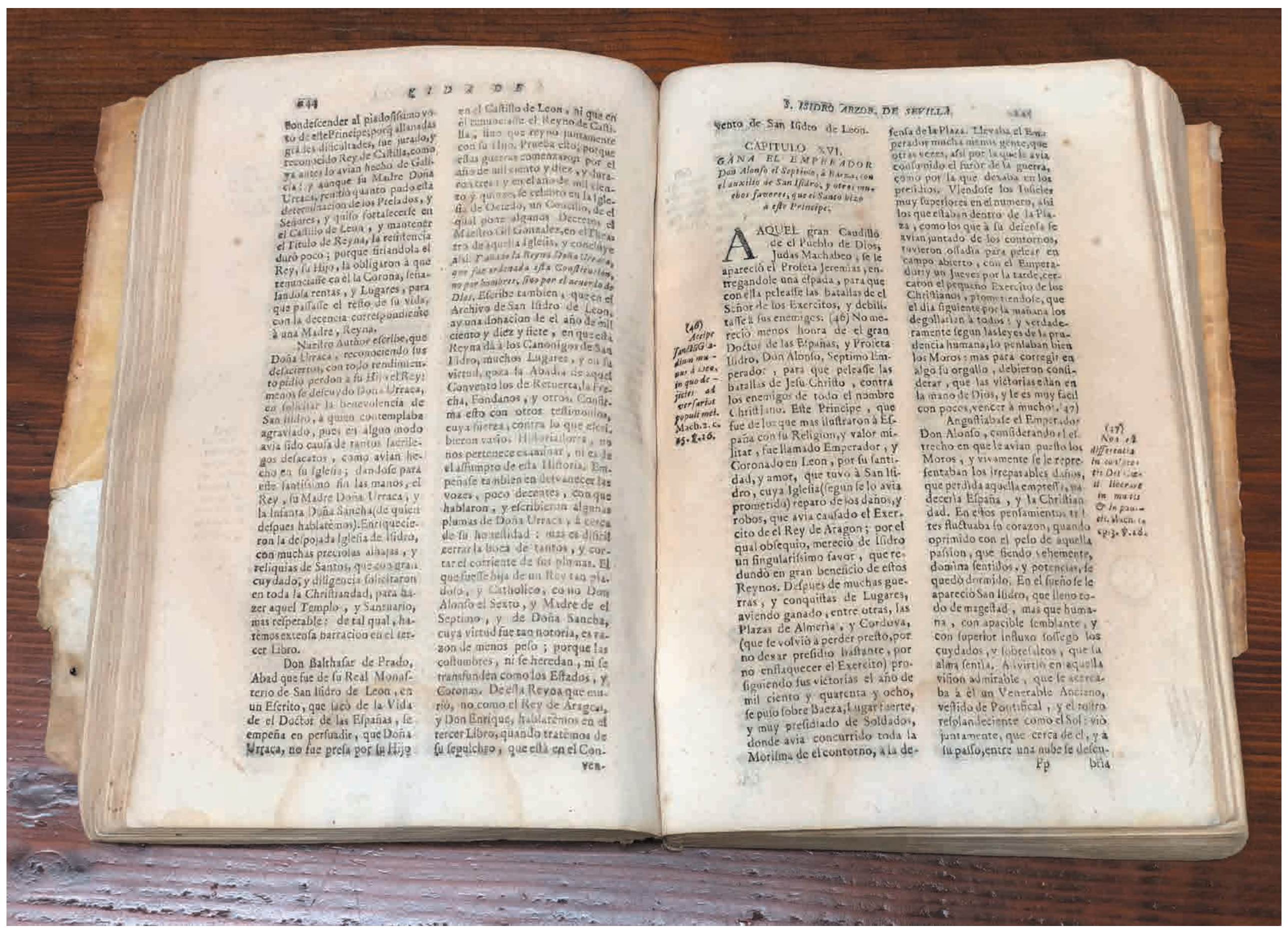
Case study: leaf casting between the pages of a bound book

Successful edge repair and infill of a leaf in a bound book can be achieved using a thin profile leaf caster such as the one described on the following pages. With careful preparation and safeguards, torn edges or missing areas of a leaf can be cast in a fairly fast and efficient manner that does not disturb the book's binding. In conjuction with the use of freeze-dried furnish, the methods herein make this approach to book conservation more efficient, color accurate and durable.

In the following case study, a damaged leaf from a bound folio dating to the 1730s was color matched and leaf cast without needing to be removed from the book.

Below: thin-profile book leaf caster and book stand/support





Folio dating to the 1730s from the library of Don and Era Farnsworth

Overview: step-by-step

- Surface cleaning
- Spectrometer reading of book paper color (Lab)
- Measure the dimensions and mass of the book; count the number of leaves, divide mass by leaves and use PaperWeight to approximately calculate the g/m² per leaf
- Index book leaf color into a library of freeze-dried colors
- Use Photoshop and *PaperWeight* to calculate repair area and dry fiber weight required to make fill
- Blend percentages of freeze-dried fiber colors together in water - add formation aid (2g per lt)
- Cast area while under vacuum within a mask
- Avoid tide marks by moistening the repair area and the surrounding area with alcohol and formation aid (AKA tororo, neri)
- Blot and dry with warm air under vacuum or isolated in book between blotters and moisture barrier

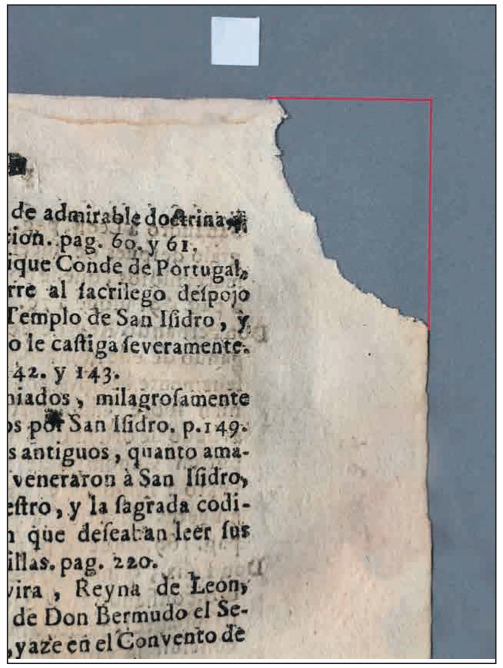
Calculating repair area and GSM

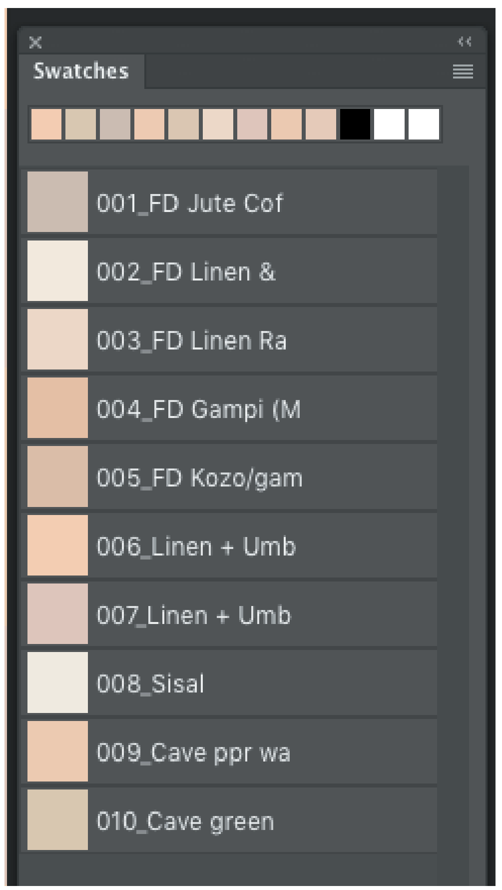
After weighing the book and dividing by the number of leaves (compensating for the cover weight), the GSM of the book paper was determined using the *Magnoia PaperWeight* app.

Using the technique for determining the area (sq. cm) of an irregular sheet, photographing the missing area with a 1cm square and dividing 1cm pixel count by the missing area pixel count, the repair area was also calculated.

Knowing the GSM of the book paper and missing area, we then calculated the amount of dry fiber needed to make the fill using *PaperWeight.*

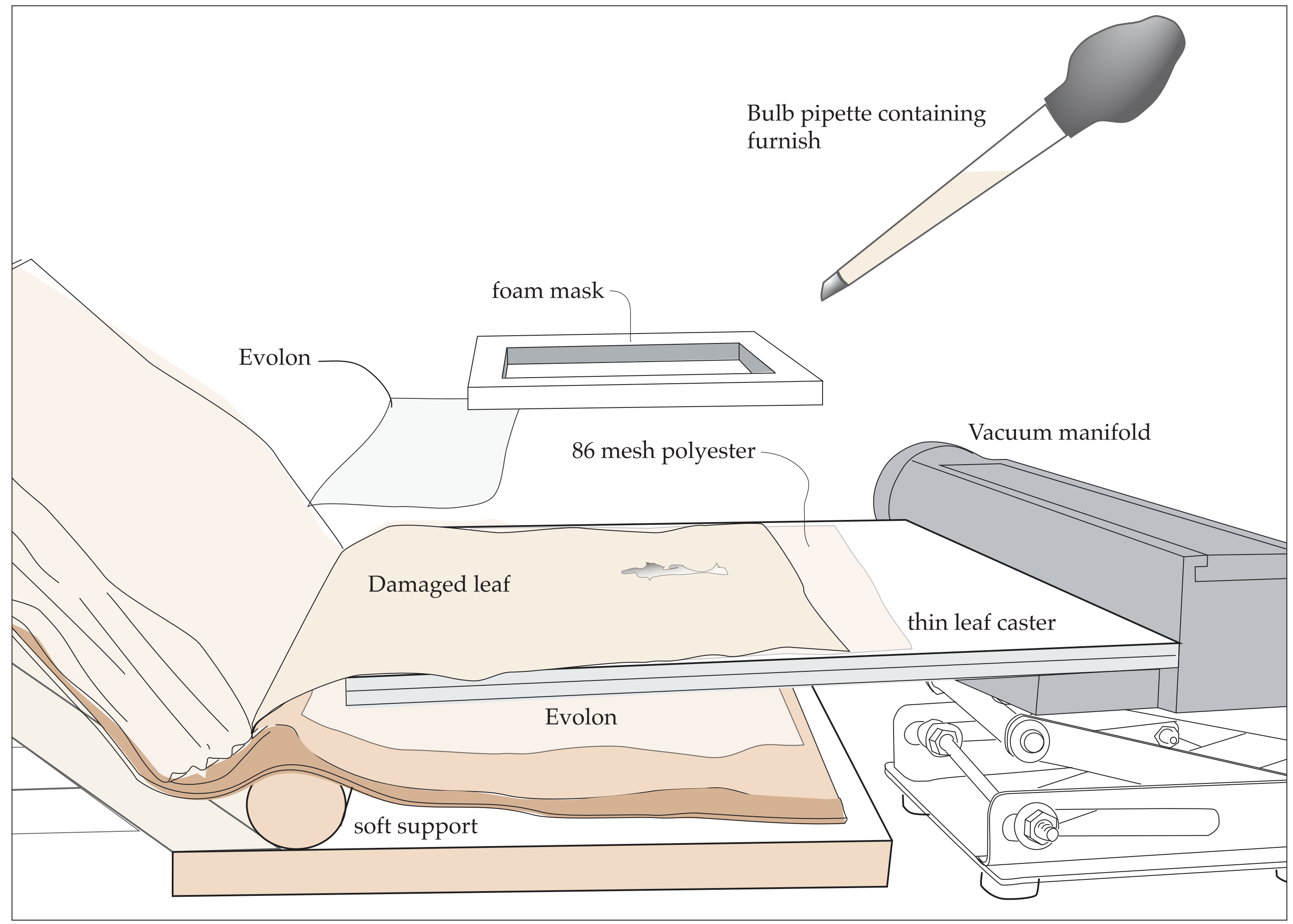
After surface cleaning of the leaf to be repaired, sphere spectrometer readings were taken to find the paper's average Lab color value (our target value) and the target value of the book paper was digitally indexed (100% dithered) using Photoshop to arrive at a ratio of freeze-dried pulp that would match the target color (see p. 58 for step-by-step explanation of this process).





Casting with vacuum and mask

As illustrated below and on the following page, the book was placed open on a soft support and Evolon placed beneath the leaf to be cast. The page was laid on the ¼-inch thick leaf caster with vacuum attached and a layer of 86 mesh polyester, and then covered by a foam mask; Evolon was also placed along the right-hand edge to isolate the corner and protect the rest of the book.

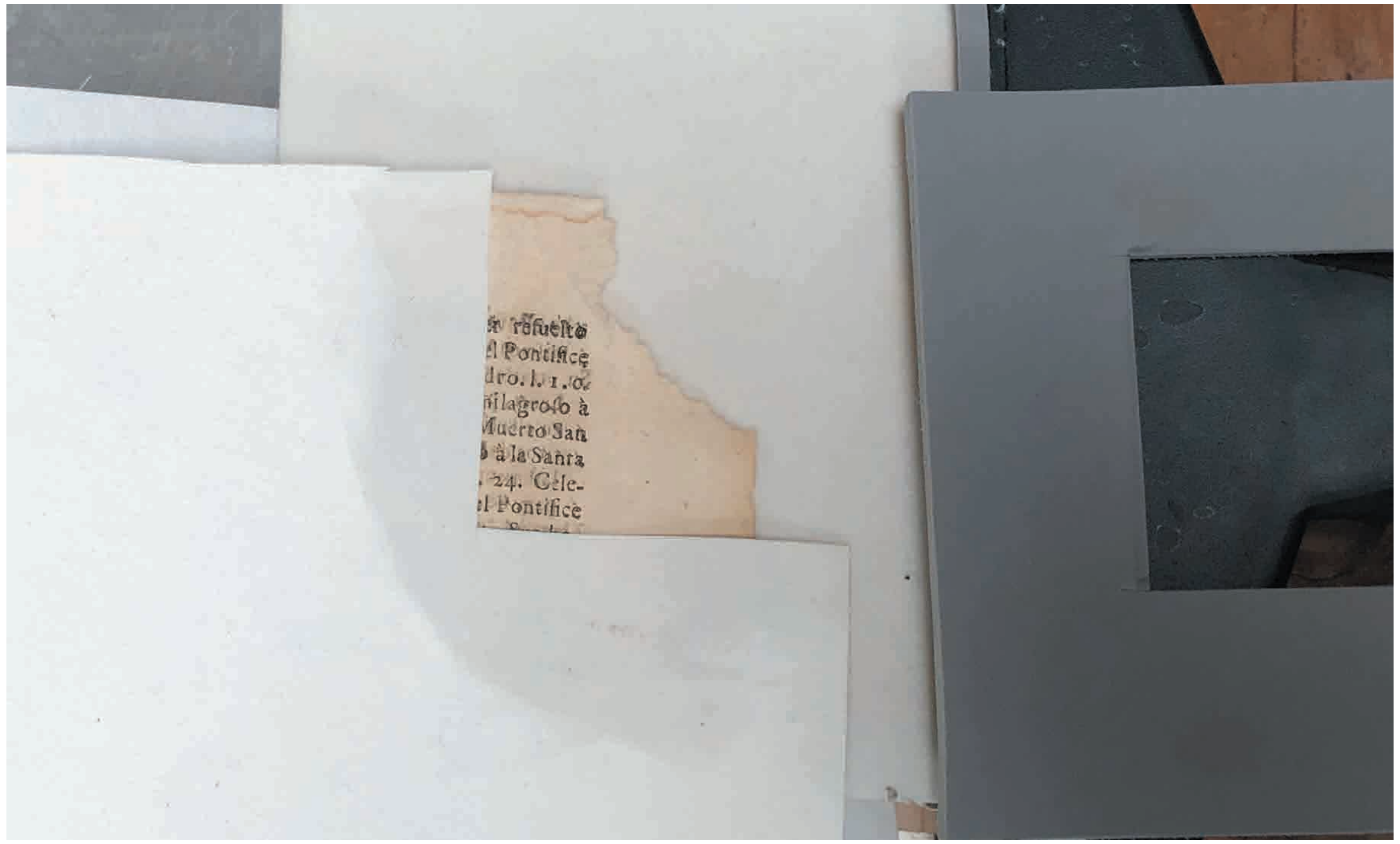


Cross-section of caster in use on the page of an open book; under vacuum, a seal is formed between plexi, gasket and porous polypropylene with breather mesh allowing for even airflow.

Casting, blotting, and drying

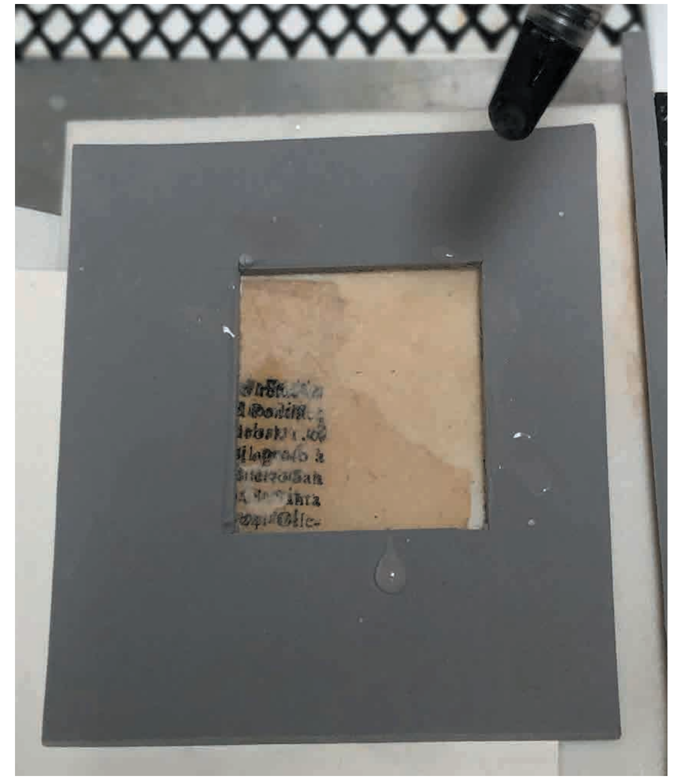
Repairing a leaf within a bound book

By using a large plastic pipette to flood the masked area with furnish while under vacuum pressure, layers of pulp were built up within the perimeter of the mask. The edges of the surrounding Evolon were moistened with formation aid to prevent the migration of water from the furnish. The vacuum helped remove any excess water prior to mask removal. The mask was then removed and the freshly cast corner was carefully blotted and warm-air dried while still subject to the vacuum. To produce a blended transition from infill to book leaf on the verso, a layer of furnish can be flooded under the leaf at the start of the infill.



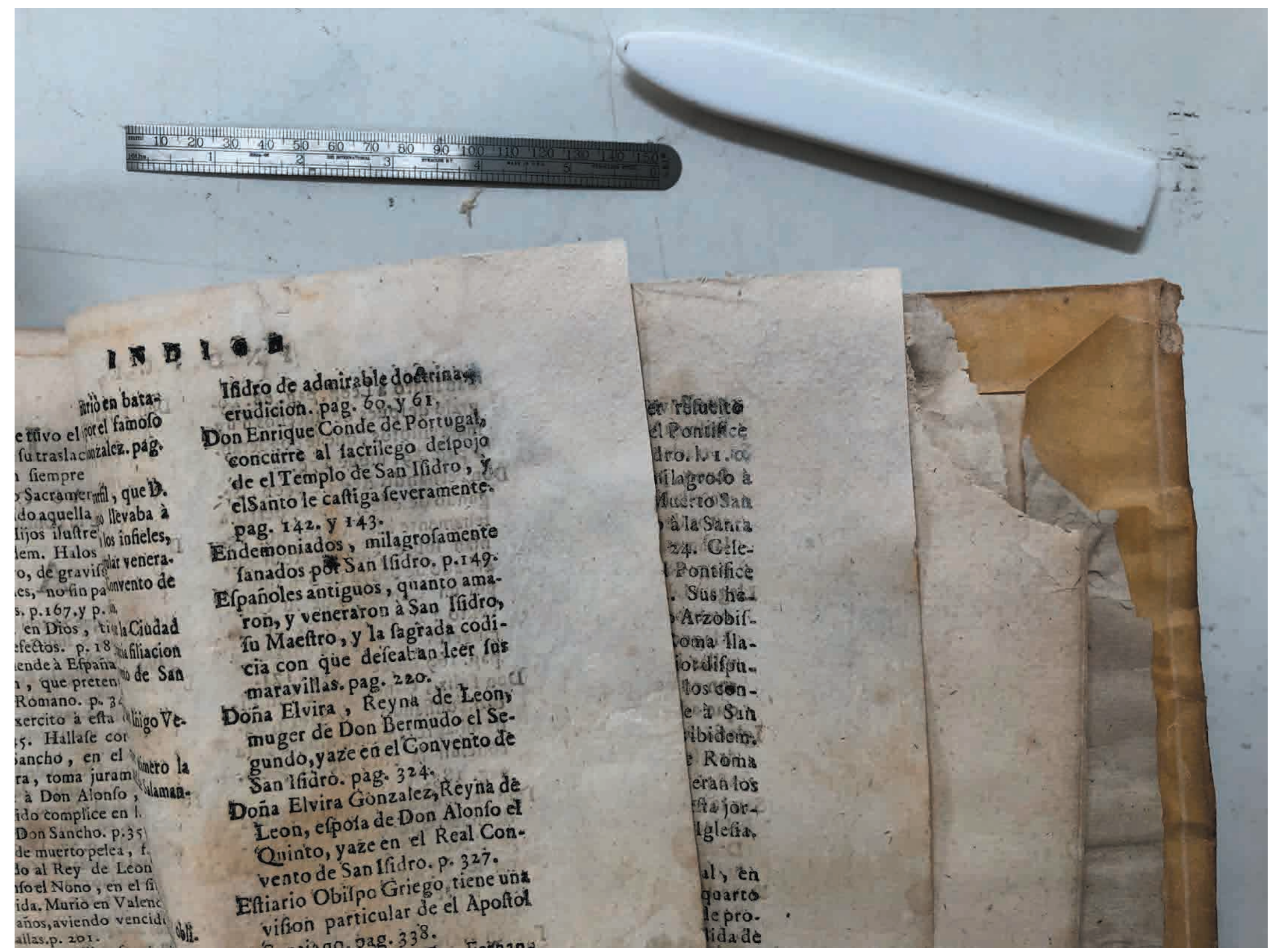
Corner isolated with Evolon; the edges of the Evolon and document are moistened with formation aid to slow migration of water from furnish. Later in the process the outer parimeter of the work area was sprayed with alcohol to prohibit tide mark formation - a sort of solvent exchange.

Isolated corner mask in place

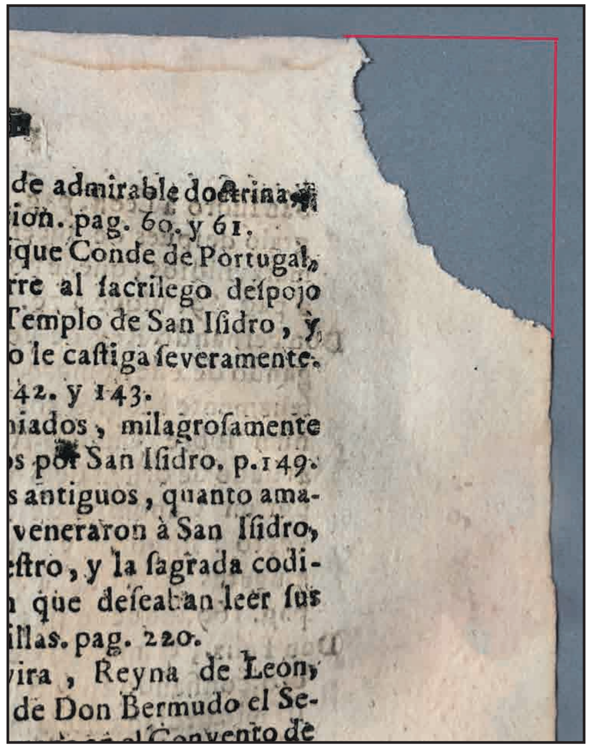


Building up layers of furnish while under vacuum

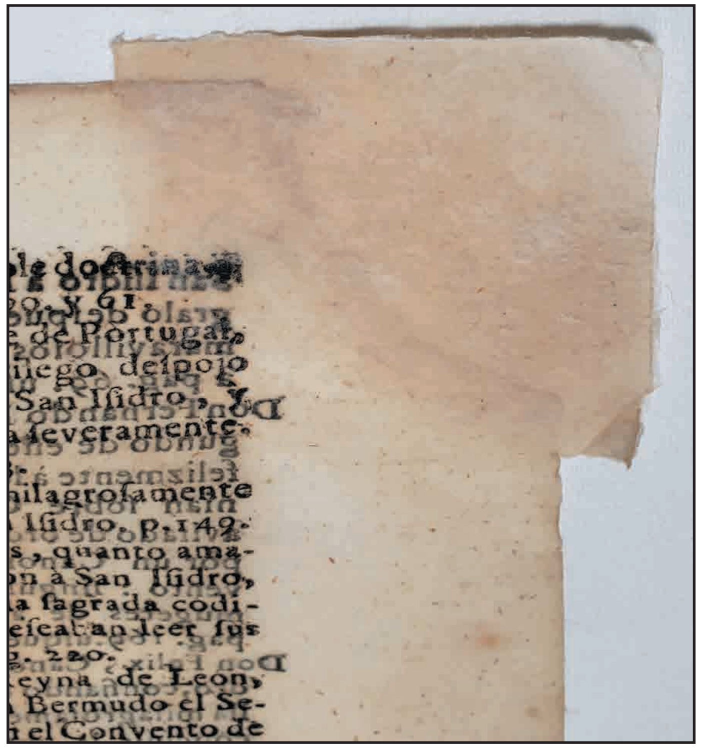
Mask removed; slow drying while under vacuum



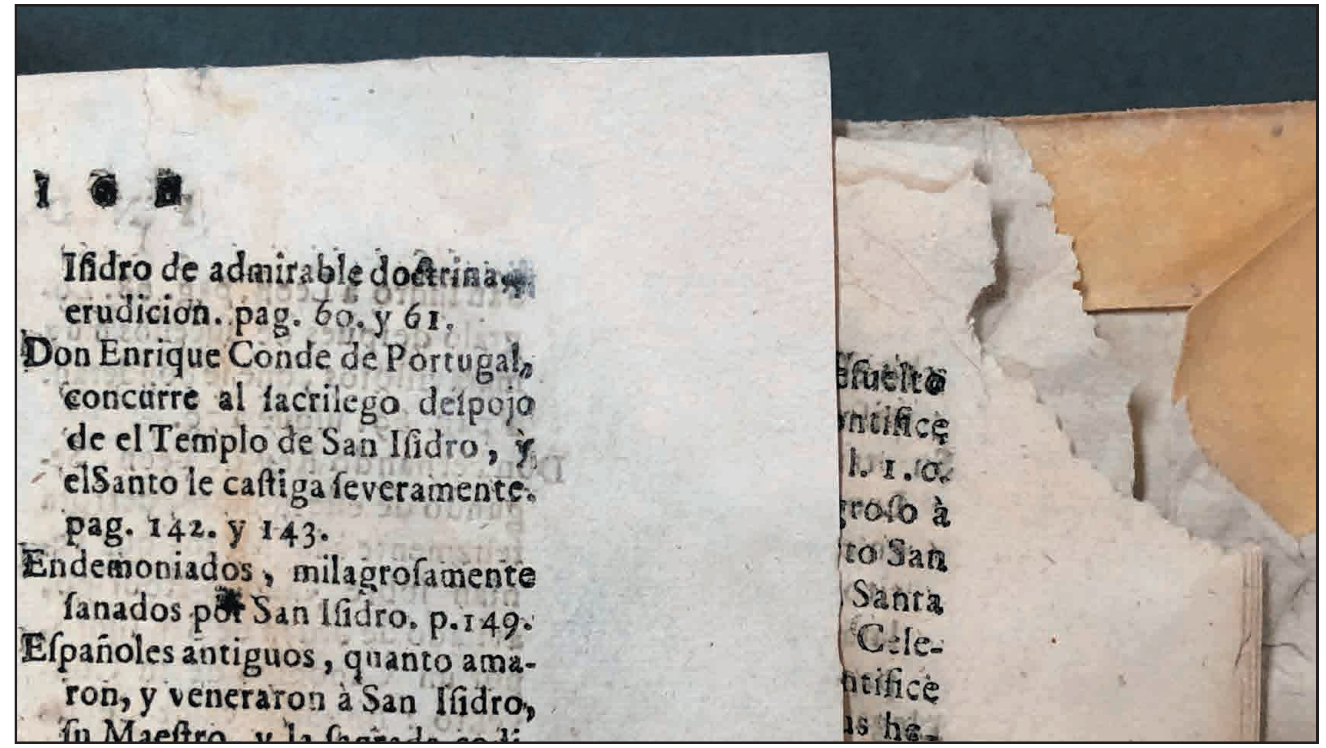
Trimming the cast corner to match the dimensions of the book



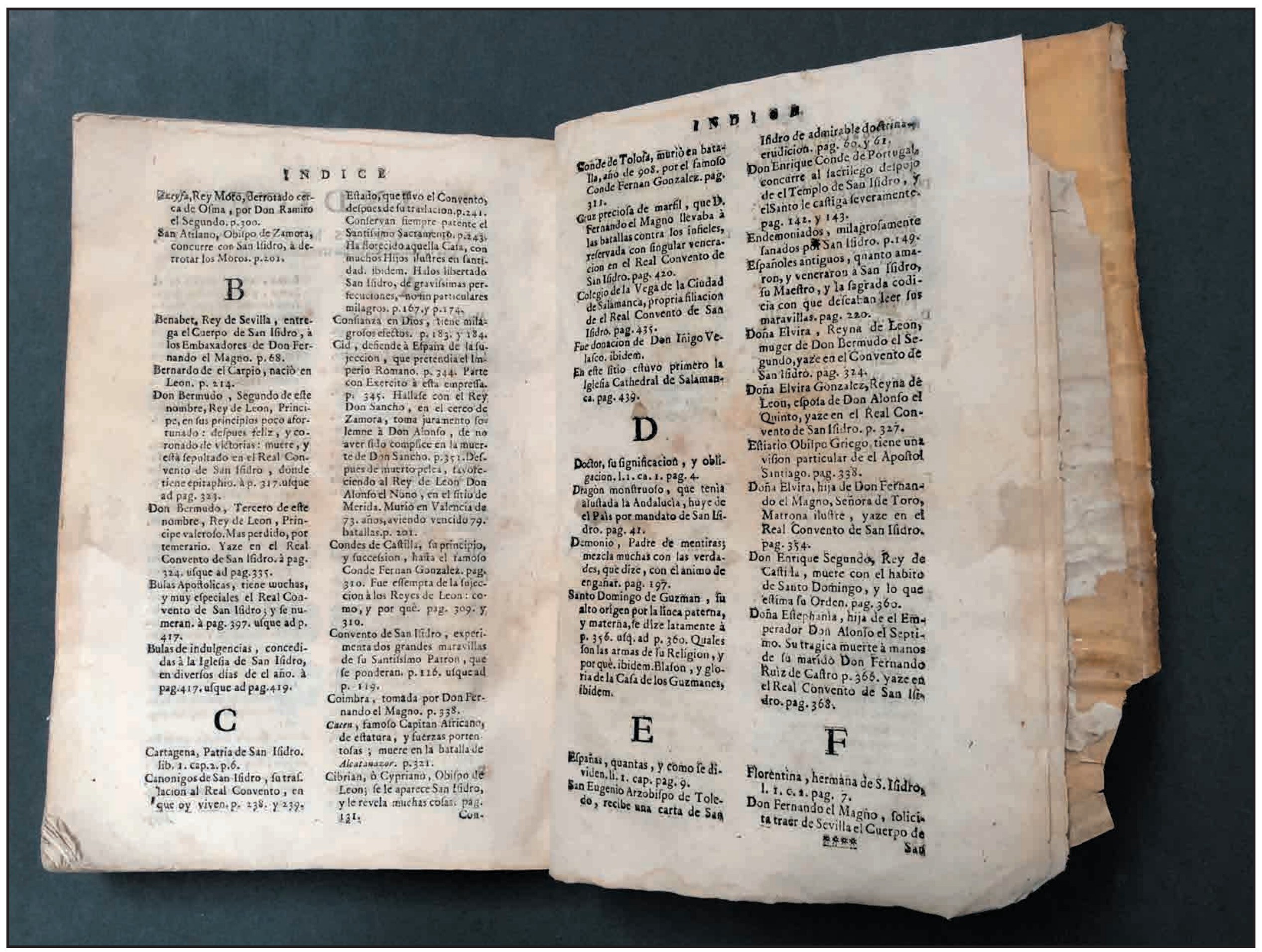
Before repair



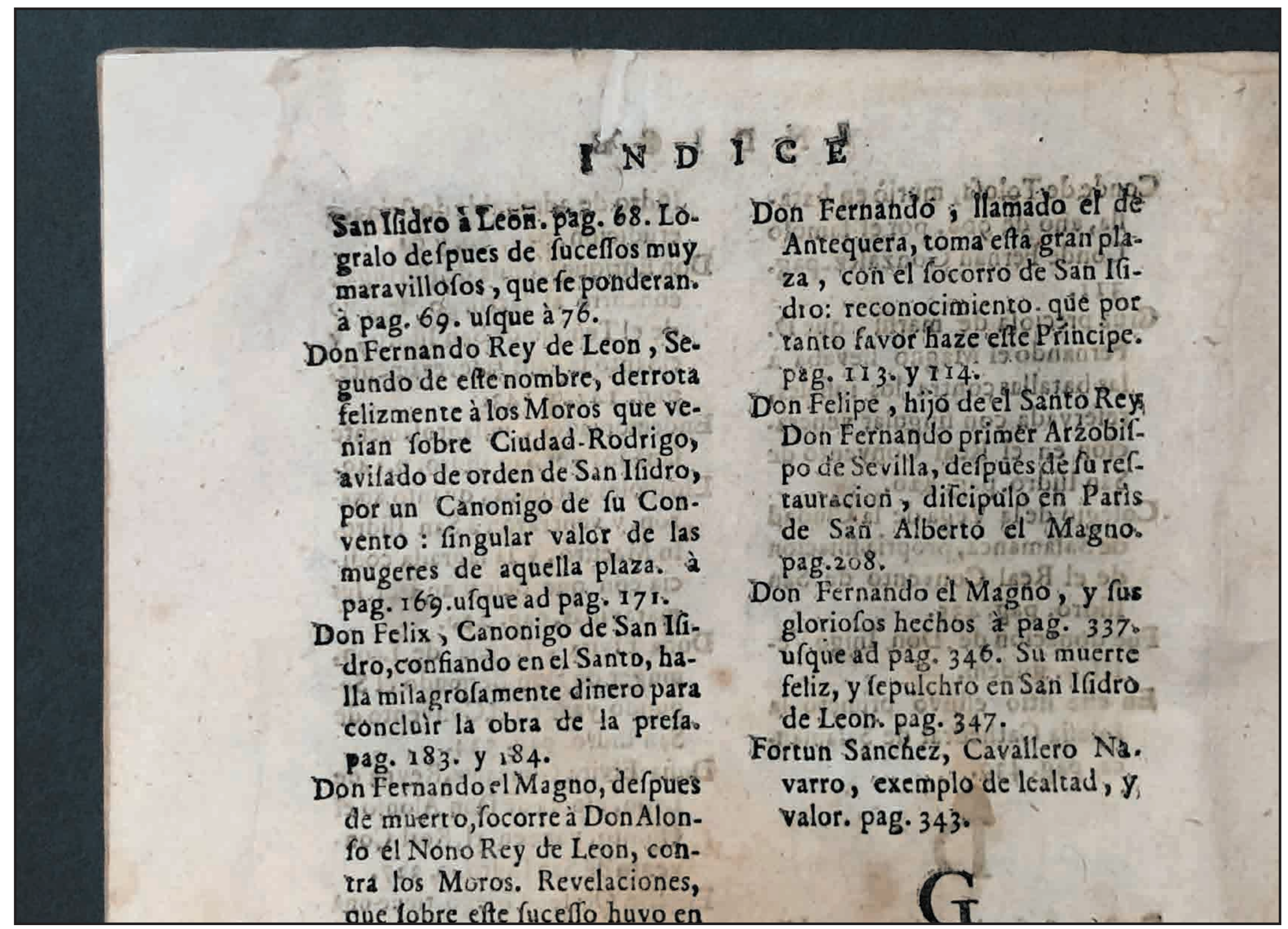
Infill still moist



Recto side of leaf-cast page; the leaf-cast section is virtually indistinguishable from the original document



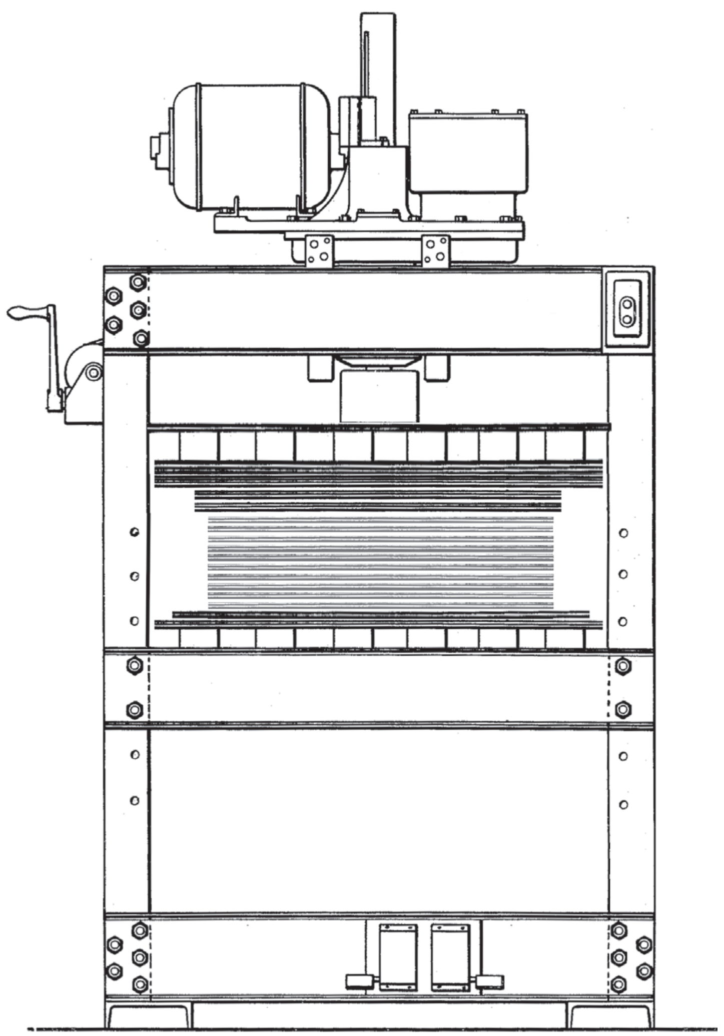
Folio leaf after repair (leaf casting top right-hand corner of right-hand page)



Verso of leaf-cast page corner

X

Dewatering

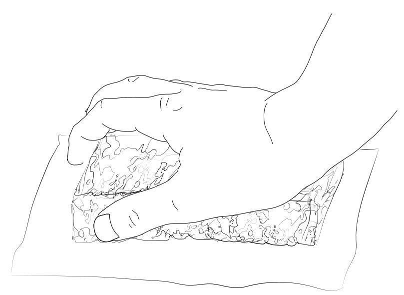


Dewatering technology's transition from wood screw presses to wood and steel and finally, to hydraulic presses

As engineering and steel work in Europe advanced in the late 17th century and throughout the 18th century, the efficiency and capabilities of presses built for dewatering paper improved. Paper mills could now apply significantly greater pressure to press a post (500 sheets) with. This increased pressure enabled 18th-century papermakers to switch from felts made from the highly coarse and hydrophobic outer coat of the sheep to felt blankets made from the finer, inner fleece, yielding the smoother and less fiber-marked paper desired by their clientele.

Dewatering newly couched paper by hand:

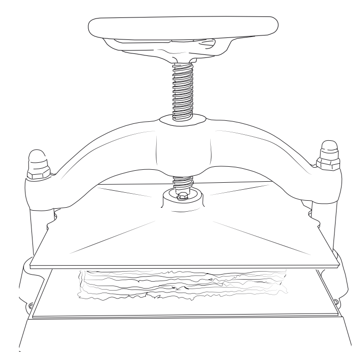
Individually couched sheets can be pressed and water removed using a sponge. With paper safely between felts or polyester interfacing, gently sponge water from the moist sheet. Once the paper is more compressed and solidified, switch to using as much pressure as you can muster. This takes a few minutes and requires wringing out the sponge at regular intervals.



The sponging process can be helped along by switching from the sponge to pressing on dry blotters.

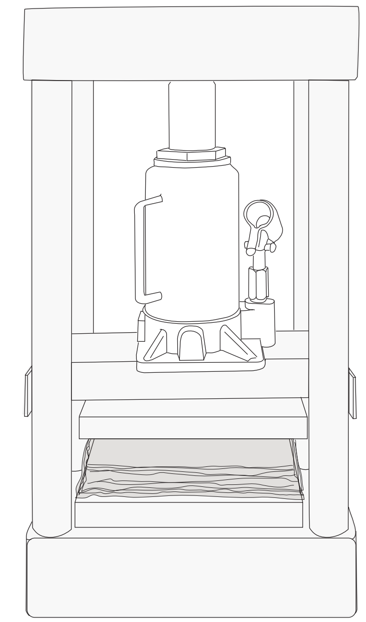
Dewatering with a book press:

It is possible to press paper in a book press; the pressure generated will not be ideal, but it will get the job started. Coarser (outer wool) felts will help. Augment the dewatering by inserting dry blotters top and bottom after the initial pressing and then repressing with fresh blotters several more times.



Efficient dewatering using hydraulics:

Although a stack of formed paper and felts (a post) can be pressed in a book press, better results are gained by using a hydraulic platen press. Many years ago, desperate for more pressure, I inserted a long pole into the crank of an arched frame, standing book press for more leverage; while I did achieve more pressure, I also managed to crack the cast iron arch, rendering it useless and unrepairable.



Hydraulic presses come in all sizes since the size of the press must scale both in size and strength according to sheet and felt dimensions.

The sheets in a post are traditionally pressed multiple times before being dried. The paper's first ***post*** pressing, between felts, removed the bulk of the water and required the most pressure, (50 psi or so). In the second pressing, called ***pack pressing***, the damp sheets are separated (*parted*) from the felts and are gently pressed while stacked and in contact with one another (at about 5.5 psi). For more delicate, less textured paper, the sheets are separated while still moist from the second pressing, shuffled, and re-pressed. With each new shuffle and re-pressing, the paper becomes incrementally smoother.

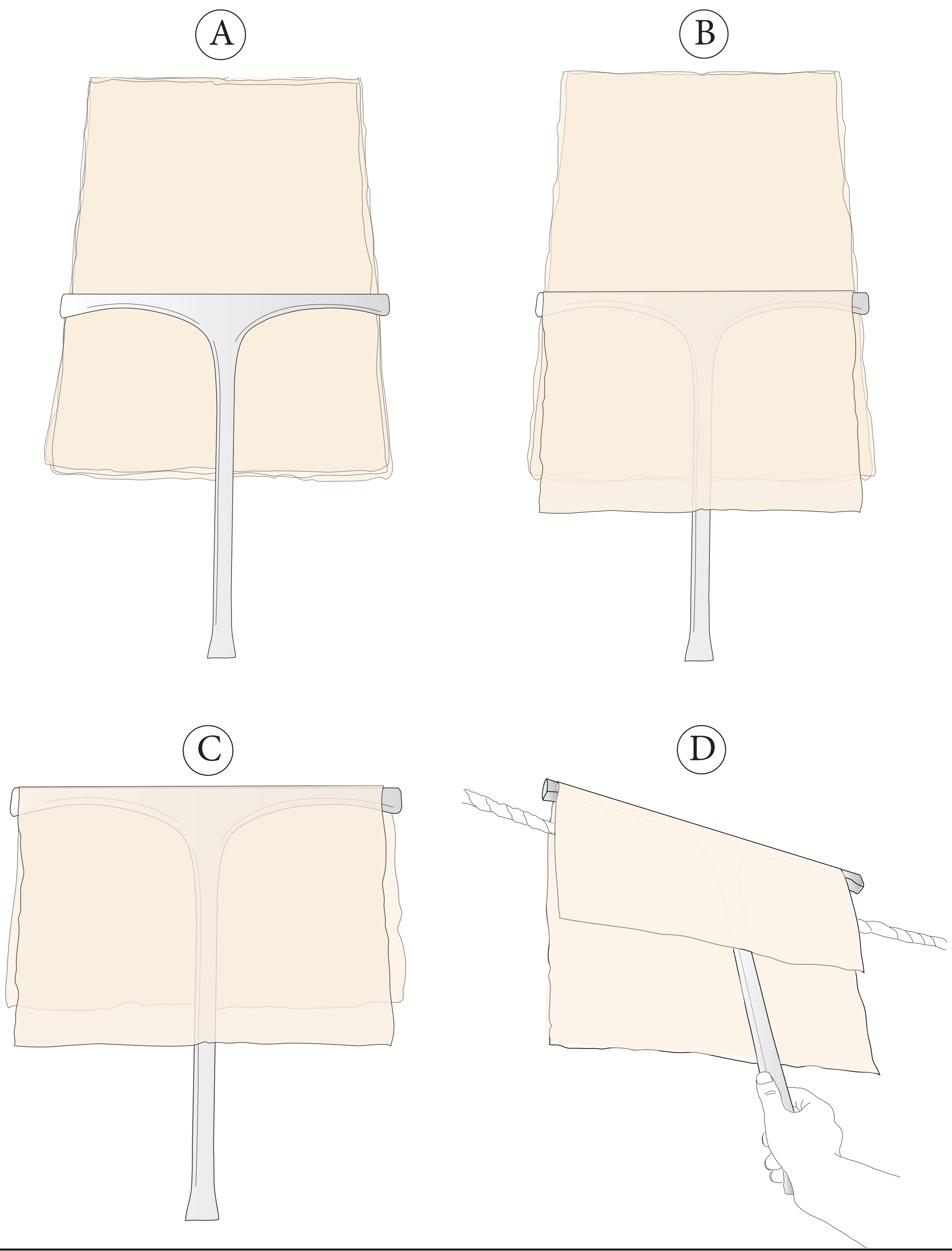
With numerous felts cut slightly larger than the paper dimensions and two boards a bit larger than the felts, but able to slide into the opening of the hydraulic press, couching may begin. Couching builds up a layered, carefully aligned stack of alternating felt and paper. As the post builds, it soon develops a natural curve, and couching becomes more natural, allowing for a quick, arcing transfer of paper from mould to felt. When your supply of felts is exhausted, insert the post and center it in the hydraulic press. Bring the press up to pressure slowly to allow water to drain at a slow even rate. As the pressure builds, less water will squeeze out. It is best to use the full (maximum) force of whatever device you choose to use. I have never over pressed a post of paper; our current press is regularly taken to 50 tons pressure. Let the post set for approximately 5 to 15 minutes after the full force has been reached.

Parting: Release the pressure and remove the pressed post from the hydraulic press. Peel off the top felts, exposing the top sheet on the interleaved post. Lift the sheet from two corners of one end. With about ¼ of the sheet lifted, slide a slice (wooden stick) under the lifted sheet and lower the sheet onto the slice; lifting the slice lifts the sheet. Have a board with a single nearby. The board should be inclined 45° or more waiting for the pressed sheet dangling from the slice. With a flick of the slice, the sheet is laid onto the felt. Another felt is removed from the post exposing the following sheet; this sheet is lifted on the slice and becomes the second sheet of the pack. With a flapping motion, it too is "thrown" and lands with a slight cushion of air, making it somewhat easy to align accurately on top of the previous sheet.

Pack pressing: Where the felt-interspersed post was pressed to maximum pressure, press the pack to only 10% of the maximum pressure. Once pressed, counting to six to eight sheets lifting slighly at one corner of the pressed pack. Peel the group from the pack to make a spur. (Use more sheets for thinner paper, fewer for thicker paper.) For paper with a maximum degree of coarse texture, skip the pack pressing and dry the sheets individually and unconstrained.

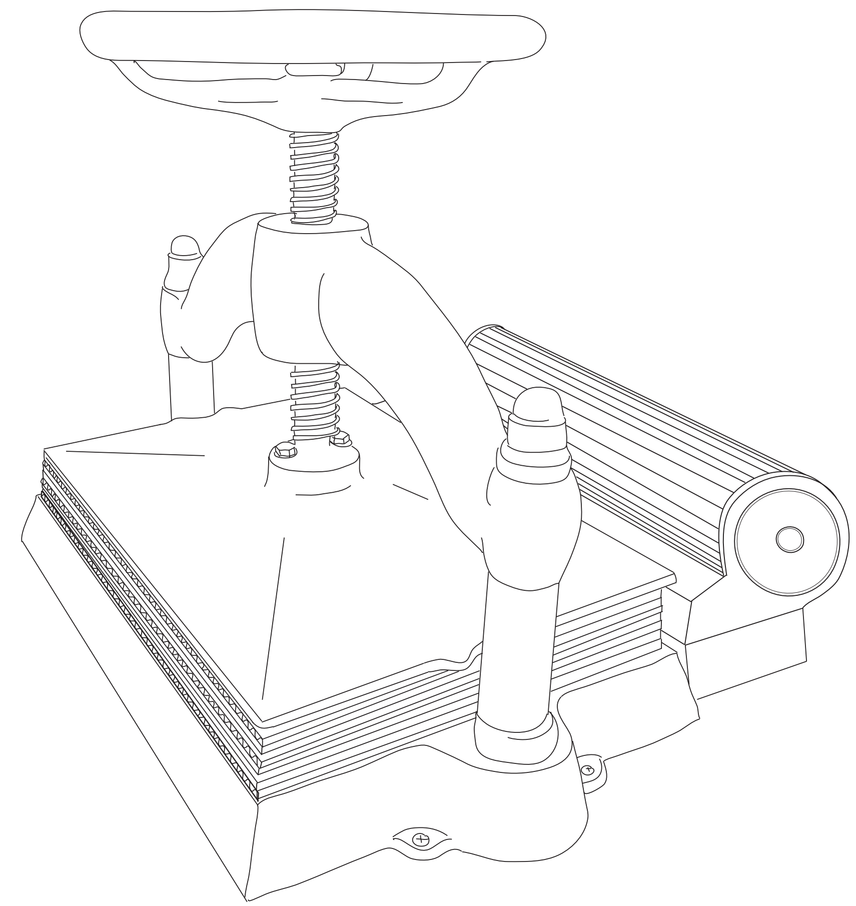
Hanging sheets after pack pressing:

A. Place T off-center on spur
B. Fold one or more of the top sheets over T
C. Lift a single sheet or a spur (3 to 8 sheets)
D. Hang sheet(s) on horse hair rope or pole

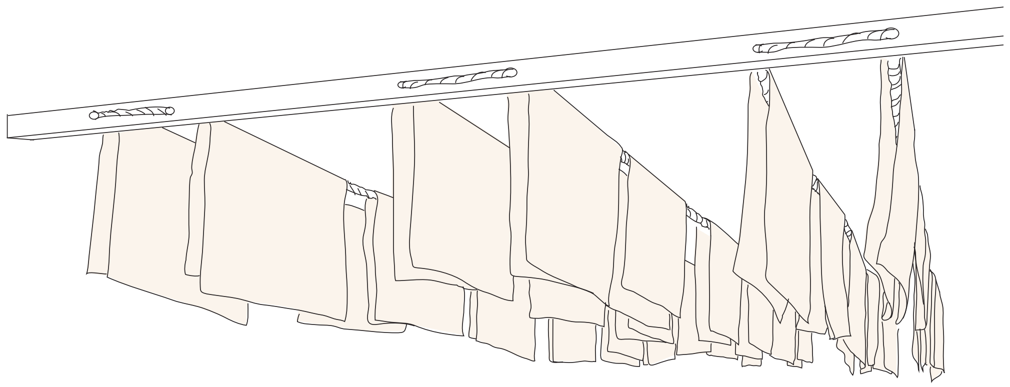


X

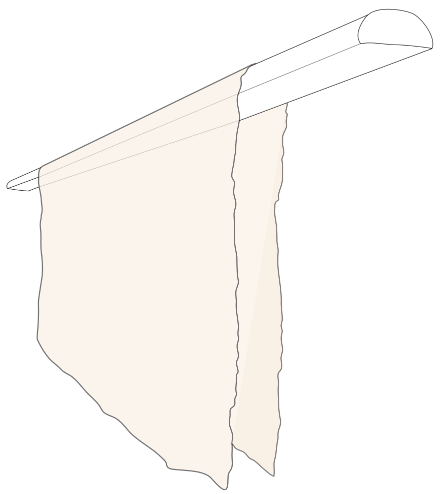
Drying Handmade Paper



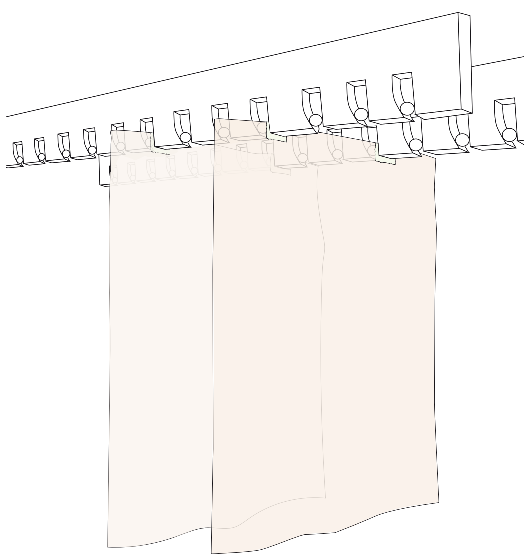
Air drying



Waterleaf sheets pressed and hung in spurs or individual sized sheets may be hung on stretched horsehair rope to dry



Individual sheets or spurs can also be hung on rounded pole to dry



Gravity-assisted marble paper drying rack

Whether hand-sponged, hydraulically pressed or having had moisture removed with a vacuum, paper must be dried further, to about 2 to 10% moisture depending on the relative humidity in your environment.

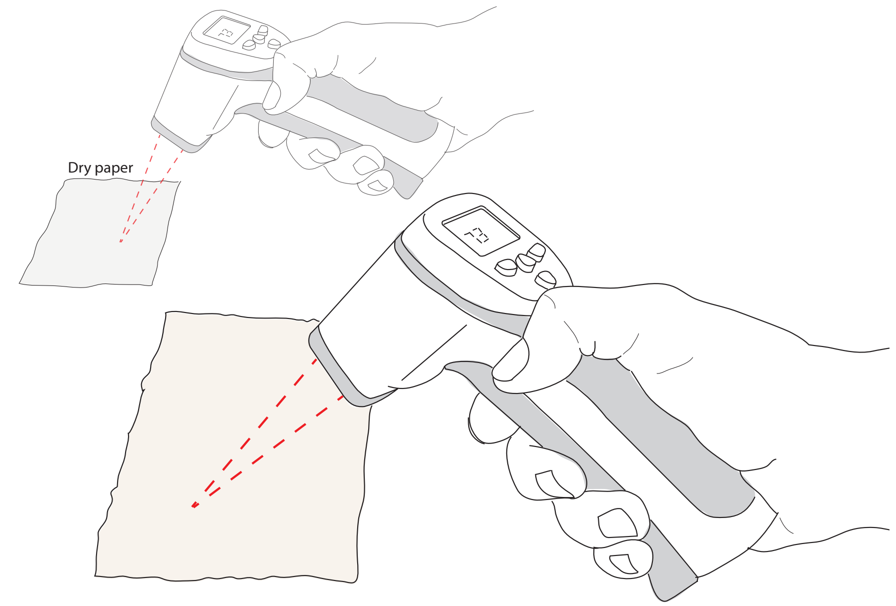
There are many paths you can follow to dry paper. The easiest is just to let sheets **air dry**: simply lay the paper down on a clean surface, or hang it to dry and wait for nature to take its course and the moisture in the sheet reach an equilibrium with the relative humidity of your environment. (see facing page)

The speed of evaporation depends on the temperature of the wet paper; the air temperature; air humidity; and air velocity above the paper's surface. Raising the air temperature and velocity will speed drying time but, if unconstrained, will make for a cockled sheet, curled unevenly due to the differential in shrinkage between the damp and dry areas of the paper and the differential surface grain of the wire and felt sides created when the sheet was formed. On the other hand, high humidity and slower drying will help minimize the cockling. Air drying unconstrained sheets will likely produce a pronounced surface texture and a cockled sheet. This cockle can be flattened over time, first by lightly re-moistening with an atomizer, coaxed flat then placed (one or more sheets) under a felt to dry slowly. The sheets will retain the surface texture, but will dry flatter. Then, pressing or weighting groups of (twice dried) sheets with increasing pressure rotating the sheets regularly, will result in beautifully textured, flat sheets. This method of single sheet, unconstrained drying or loft drying produces the maximum degree of surface texture. (see *Sizing and Finishing*, p. 146 - 151)

Spur drying the paper in groups (pack pressing and separating 4 to 8 sheets at a time) constrains the sheets in the spur, producing less cockling and less texture. A variation of this traditional approach is to couch and press the paper onto a felt or polyester blotter and let the sheet and interfacing felt air dry together; the polyester interfacing will constrain the paper to some extent smoothing the texture and keeping the sheet more or less flat. Simply peel paper from felt when dry.

Determining the dryness of paper

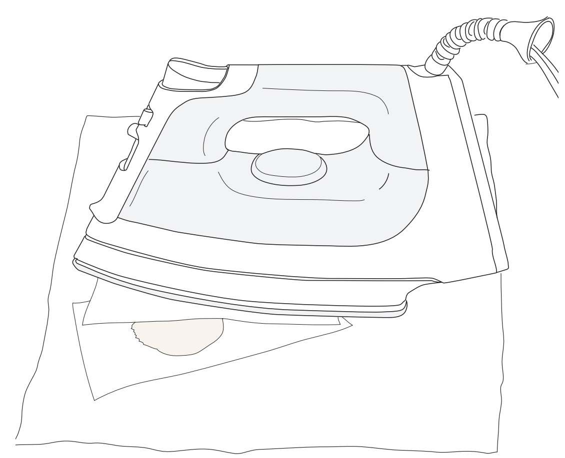
Using an Infrared Digital Temperature Gun Thermometer with laser point, take the temperature of drying paper and compare its temperature to a dry sheet to determine if the sheet is completely dry. If the temperature reading of the air drying paper is cooler than a dry sheet's temperature reading, the paper is still damp.



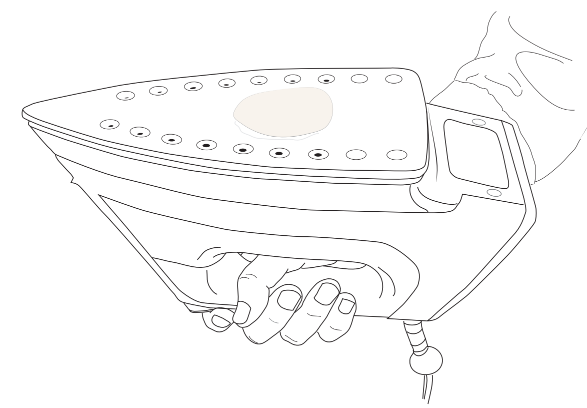
When water goes from a liquid to a gas (evaporation), it absorbs latent heat. So a wet sheet whose water is in the process of evaporation is cooler than a sheet that is completely dry. This same principal is effective when using a stack dryer (p. 134) with a dual digital remote probe thermometer: one measuring the room temperature and one measuring the exiting air temperature.

In the example at right, both temperatures read 73°, therefore the foreground sheet (the sheet in question) is dry.

A hot iron works for a quick test for small sheets, like an AeroPress 5.7 cm circle. After sheet forming, pressing and blotting, iron sample between blotters. Next, carefully invert the iron, using it as a hot plate; allow the disk to slide around, flipping it regularly as if toasting flatbread or a tortilla. As the sheet dries and starts to cockle, resume ironing between dry blotters.



The iron is perfect for quickly drying small test samples; Japanese papermakers also dry large sheets on hot surfaces.



Above: tortilla/flatbread style. Slide sample around on the surface of a hot iron, flipping frequently, alternated with ironing between blotters (right). Be careful with this process.

Interestingly, paper swelling properties are diminished via additional drying processes: repeated wet and dry cycles make for a more dimensionally stable paper. This is why older papers that have been through multiple humidity changes over time tend to expand, contract and cockle less than a newly-dried sheet. Multiple wet and dry processing cycles can make your sheet more closely match the minimal swelling of an antique sheet.

All air drying techniques benefit from a less hydrated stock, measured as freeness (see p. 9). A freer pulp makes for a more dimensionally stable paper that is less likely to cockle and less likely, for example, to pop off a drying surface before completely dry. In general, more freeness produces a less cockled sheet.

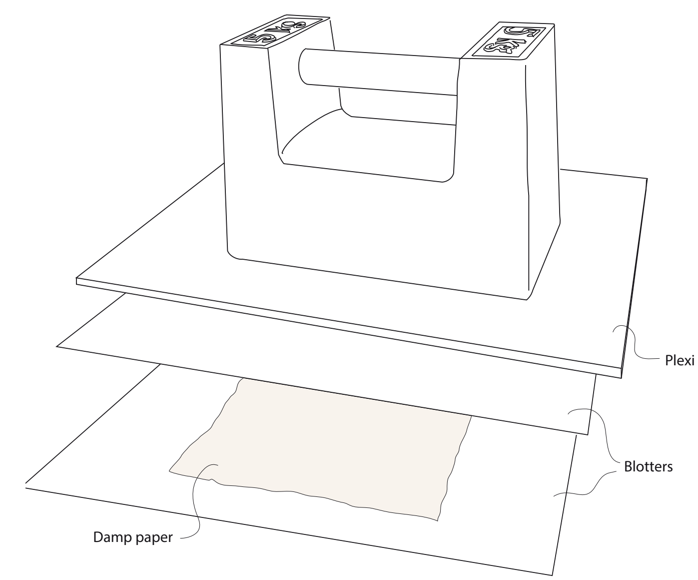
Drying under pressure (constrained drying)

Drying paper under pressure, so it is constrained as it dries, maintains flatness as the humidity equalizes during the migration and evaporation of the moisture from a newly formed sheet. Constrained drying helps maintain a distance between the fiber as they dry making for a more dimensionally stable paper.

One common technique for drying paper under pressure is to place the damp paper between alternating layers of blotters (cotton, polyester or another absorbent material) under weight. The blotter is changed 3 or 4 times at increasingly longer intervals until the paper is dry.

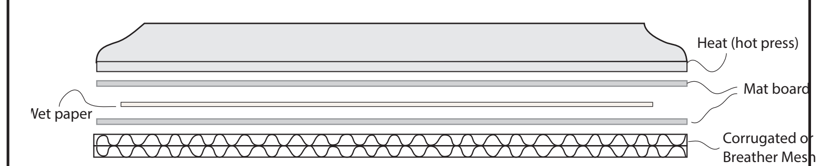
Drum dryers and hot presses can dry a paper flat but can also be hard on the paper if allowed to over-dry, as the prolonged application of heat during drying drives the moisture out of the inter-fiber spaces, capillaries, and lumens of cell wall in each fiber. This lost moisture is important to paper's flexibility and tenacity. Normal, dry paper has a moisture content of between 2 and 10% depending on the paper and the relative humidity of its environment. Avoid over drying your paper. Forced drying of paper via hot press has its place, but is no panacea.

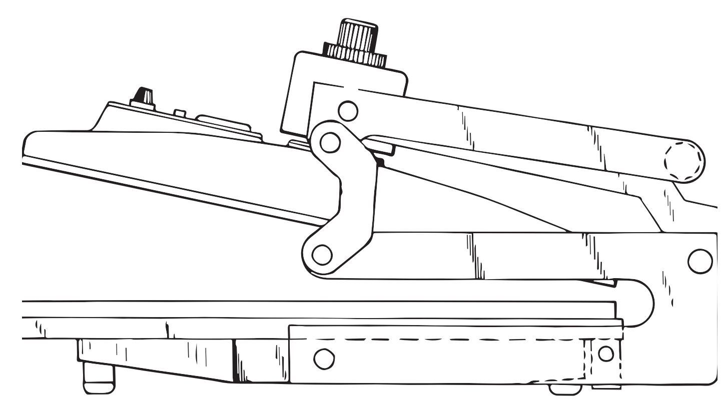
Dry under weight between blotters for medium texture.



Force dry under weight with heat in a dry mount hot press

Heat forces moisture down to air passage where blown air removes moisture. Note: This "Hot Press" method, although smooth, fast and forceful, can over-dry paper.





Stack dryer

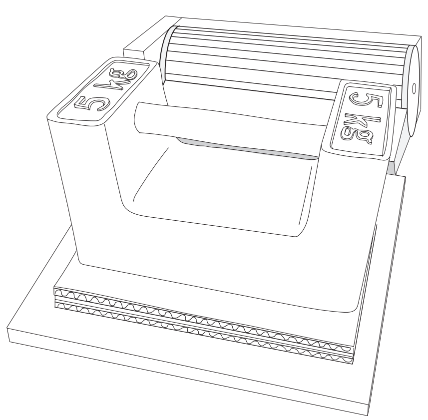
First introduced to me by Crown Point Press in 1973, the stack dryer has my vote for ease, efficiency, and effectiveness when a flat, smoother surface texture is desired. It is based on the principles of evaporation, and equilibrium. Wet sheets are constrained under pressure, trapped between alternating layers of blotters, mat board and cardboard – moisture migrates from the wet paper through neutral pH blotters and mat board to fluted air passages in cardboard or breather mesh and evaporates until a stack and the wet paper is dry, reaching equilibrium with the relative humidity of the local environment.

Stack drying for small dimension paper has the added advantages of being compact, efficient, and easy to implement. Additionally, the paper surface will depend on the texture of the material in contact with the sheet in the stack dryer, as paper dried under pressure conforms to the surfaces between which it is dried.

2b. Place the damp paper between alternating layers of blotters, 4-ply acid-free mat board, and corrugated cardboard.

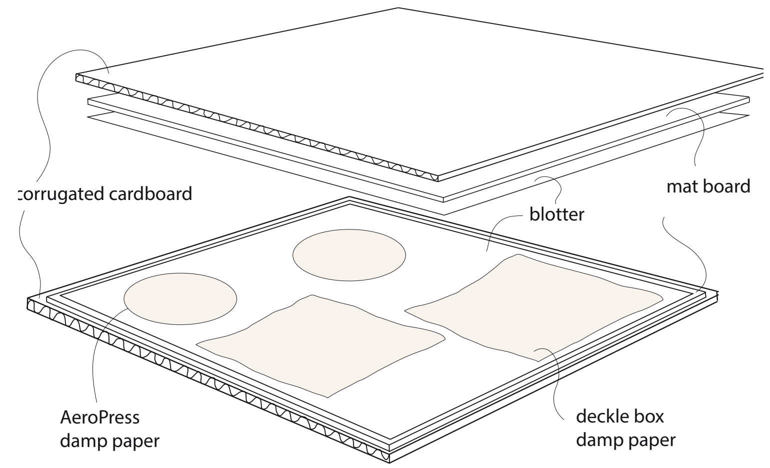
2c. Use a book press, a lever press or a heavy weight to apply pressure to hold the paper flat under a firm surface; next, position a crossflow fan to blow air through the corrugated flutes. The moisture will migrate up through the blotters and mat board to the cardboard while the moving air will evaporate the moisture. In 4 to 12 hours the paper will be dry and flat, but never overly dry.

Other paper drying techniques include friction drying, stretch drying (i.e. watercolor stretching), humidification chamber drying, and screen drying (between two stretched screens).

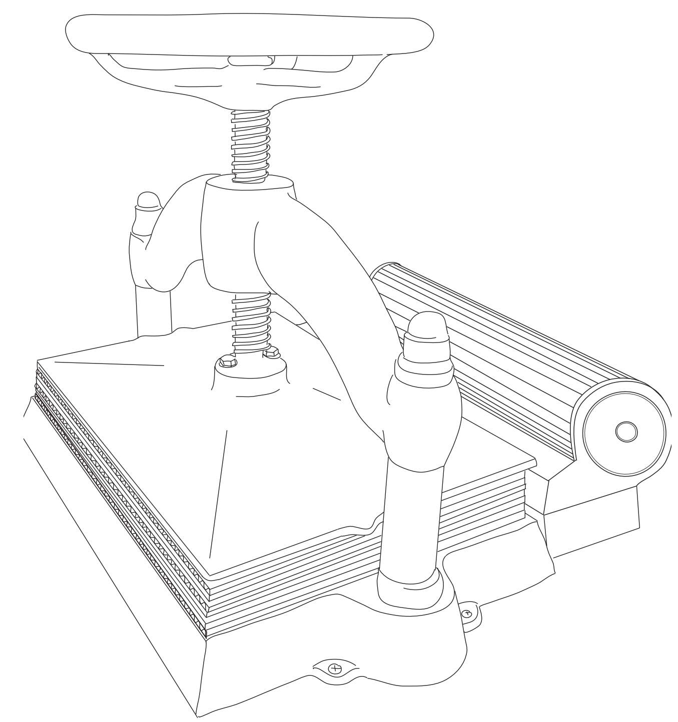


Weighted stack dryer

Stack dryer, drying under pressure while removing moisture



Force air through cardboard flutes with a fan

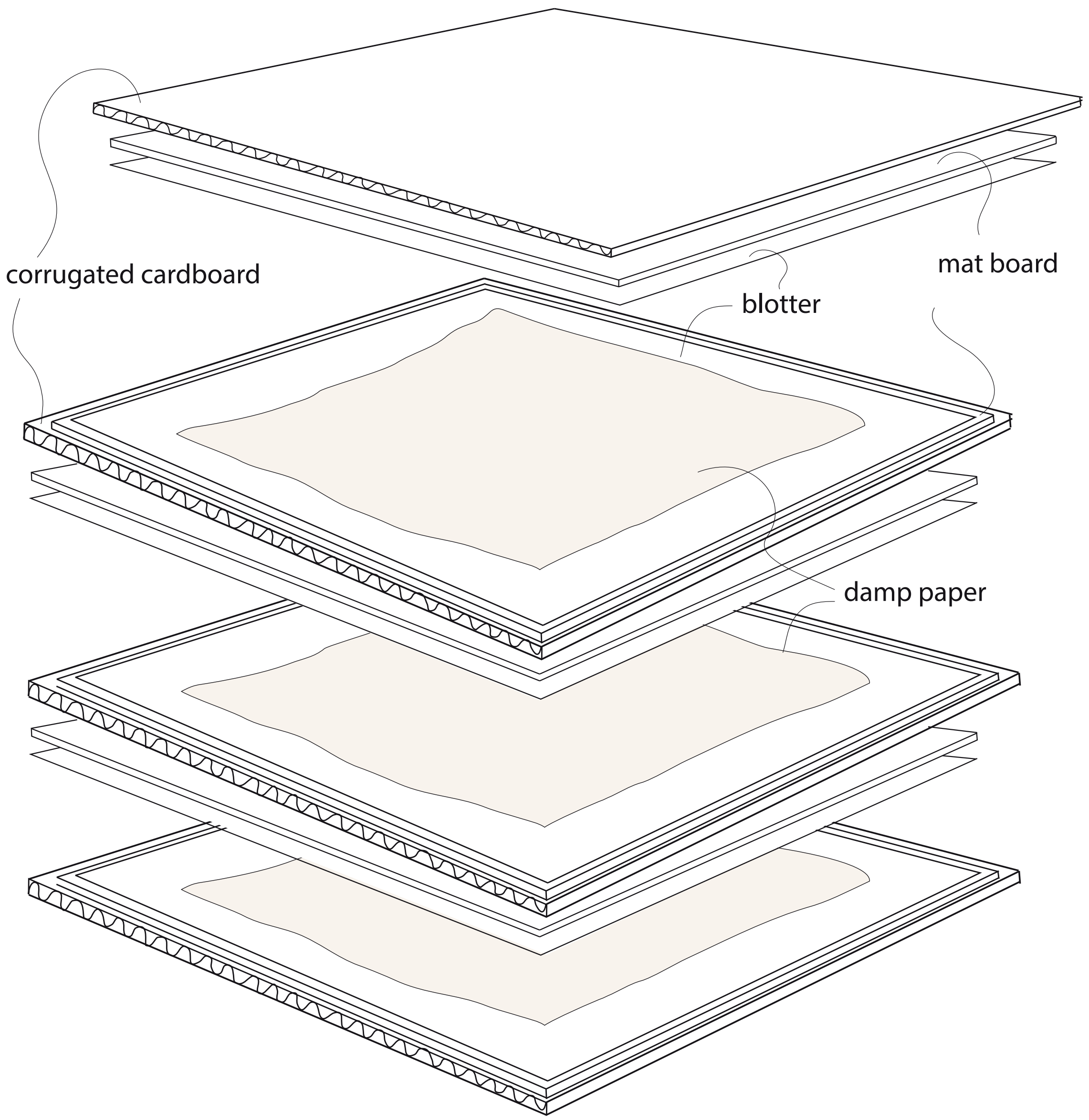


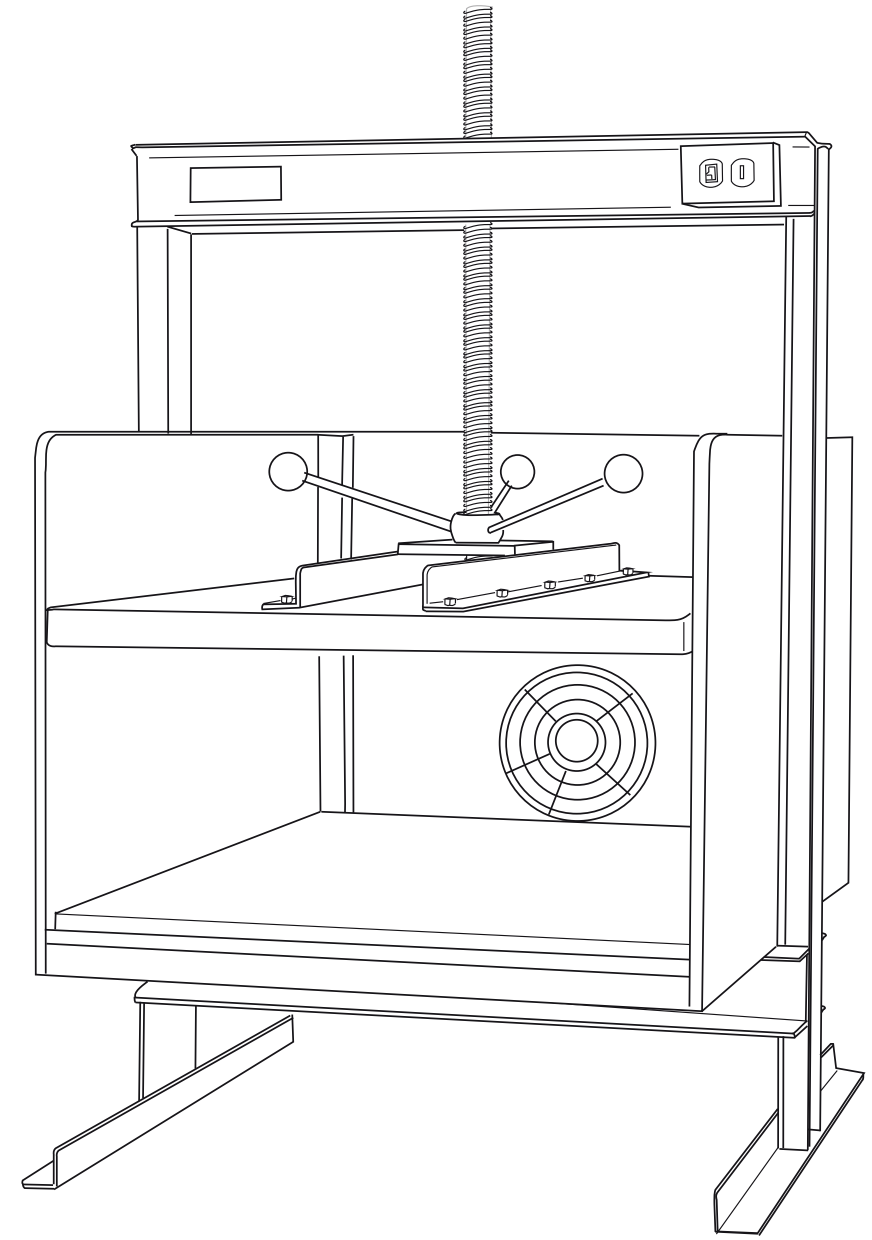
Book press stack dryer with crossflow fan

Box or Stack Dryer Configuration

Drying under pressure while removing moisture
Corrugated cardboard configuration (constrained drying)

With precisely cut sheets of double-wall acid free corrugated cardboard, blotters and mat board a multi-layered high rise stack of air permeable layers interlaced with damp sheets will dry paper under pressure (constrained). Pressure is needed to keep the stack firmly held in place as air is blown through the flutes drying the paper overnight.



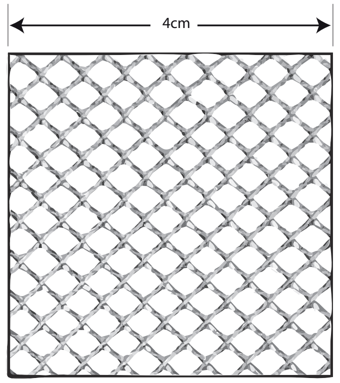


Box Dryer built by David Reina

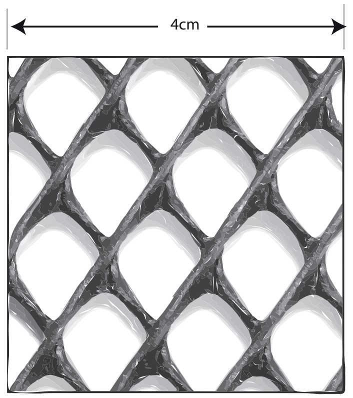
Insert stack (alternating acid-free and buffered corrugated double-wall board, mat board, blotters and damp paper), apply screw pressure and turn on fan. Expect paper to be dry by the next day.

Alternate stack drying system

8 x 10 inch paper, dry in 1 hour with no heat



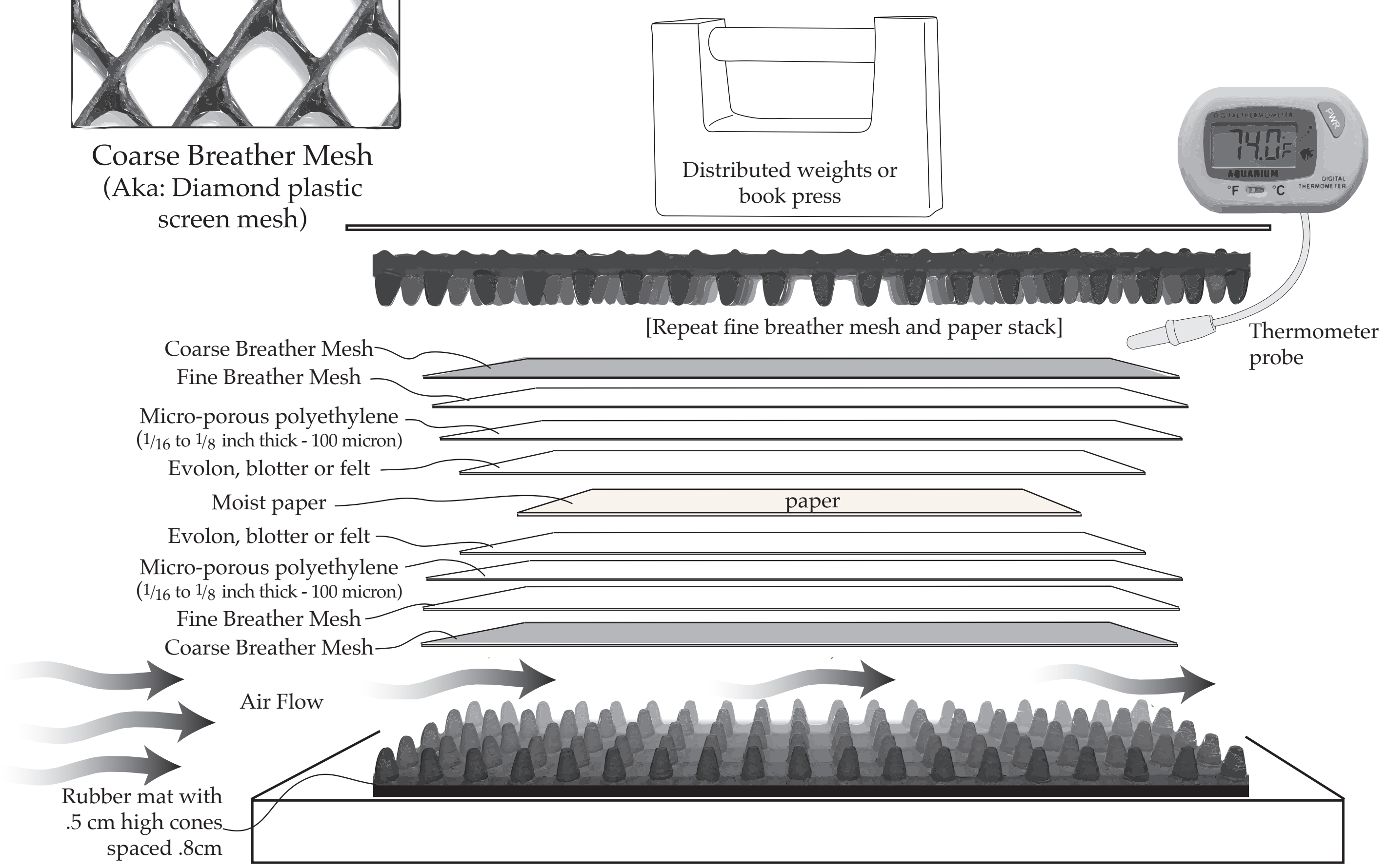
Fine Breather Mesh



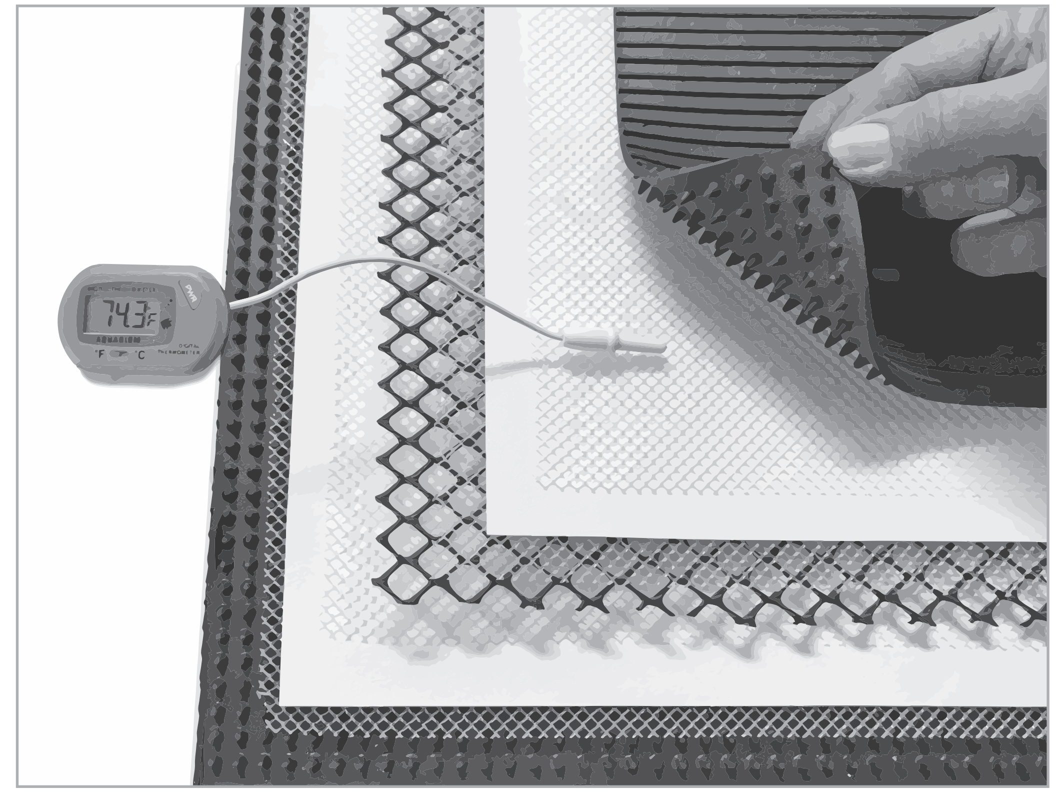
Coarse Breather Mesh
(Aka: Diamond plastic screen mesh)

Drying paper under pressure and flat without the use of heat can be done using a stack dryer with easily procured mat board and cardboard components. However, use of corrugated cardboard in the stack as described has some disadvantages including fluted texture transfer, possible pH migration, and slow drying time. A more efficient stack dryer can be built with rubber mats, breather mesh and polyester blotters, using a fan to pull or blow air through the veins of the stack. The stack described below is very effective: a 50gsm hand-sponged, 8 x 10 inch paper dried flat in one hour.

Determining when the paper in the stack is dry:
Using a digital thermometer, place its probe in the path of the exiting air to monitor air temperature (see illustrations below and opposite page). Moisture evaporating from the sheet(s) of wet paper cools the exiting air; when evaporation has ceased, the thermometer indicates room temperature and the paper is dry.



Stack dryer without the use of corrugated cardboard



Drying stack illustration

Pressure on the drying stack ensures that the paper dries flat. Depending on sheet size, distributed 5 kg weights may be adequate. On the other hand, excessive pressure (for example, in a book press) can transfer breathing mesh texture or interface texture to the sheets being dried. Take care to test and analyze your stack composition and pressure. Add to the moisture-permeable buffer between paper and bumpy textures of the airflow passages (by adding interfacing, Evolon, felt, 4-ply and/or fine screen) to compensate for added pressure. Be sure to use archival materials which will not transfer acid to your sheet.

Further reading:
Study of the Effect of Drying Methods on the Physical, Chemical, and Microbiological Properties of Various Kinds of Paper, National Library of the Czech Republic, Prague State Central Archives in Prague:
http://www2.caslin.cz/fondy/e_suseni.htm

Fundamentals of Paper Drying – Theory and Application from Industrial Perspective:
http://cdn.intechweb.org/pdfs/19429.pdf

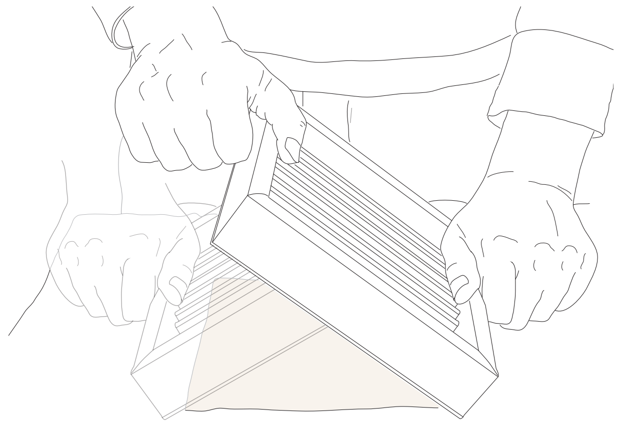
Drying strategies for coarse texture

If coarse, felt-hair-textured paper (similar to 15th - 16th century Italian paper) is desired, couch using non-woven felt made of coarse heritage wool (if using small deckle box, glue the felt to the tip of the pressing block). Use shorter drainage times after forming sheet, essentially couching as soon as possible. Press using the most pressure you have available – a hydraulic press is best.

If pressing in a post (multiple sheets and felts) separated each sheet from the damp felt it was pressed on (using a slice), then immediately replaced each sheet on the same damp felt and racked them to dry along with the felt it was separated from. The moisture in the felt slows the drying process, allowing the paper to dry evenly. Though it may seem counter-intuitive, I must stress here that ***sheets must be released from the felt*** (i.e., lifted with a slice after pressing) ***for the felt hair texture to develop***. Paper left to dry stuck to the felt after pressing will dry slightly constrained, producing an undesirable pitted texture. Further, a slightly oversize felt produces better anticockling results.

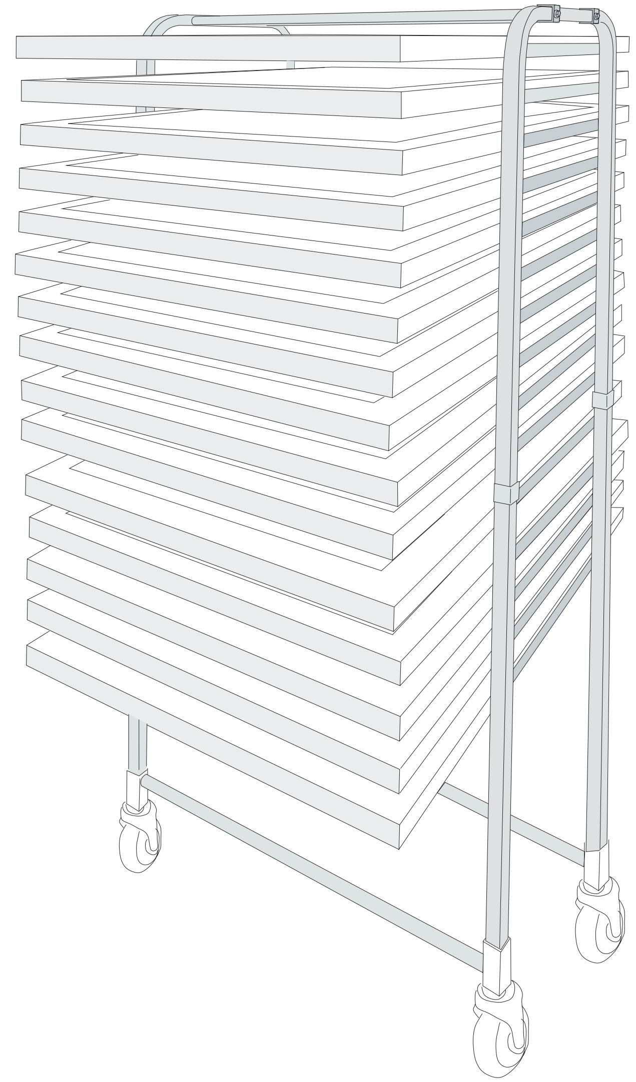
For a more opaque paper with a less porous surface, add kaolin clay, magnesium, and/or calcium carbonate and titanium dioxide to the furnish. **Blend in retention aid if you feel that too much of the additives are falling out in the white water and if you want a furnish that is more free.**

Air dried sheet (dried unconstrained for maximum surface texture)



Couch on coarse heritage wool felt

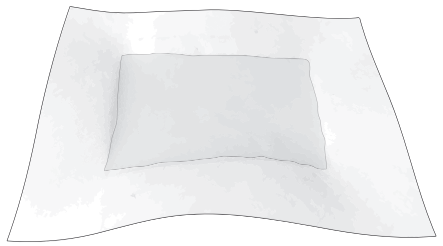
After pressing, lift sheet using a slice, separating it from the felt; then lay it right back down on the same damp felt and let it air dry – for multiple sheets, use rack as seen on opposite page



A re-purposed bakery rack filled with polyester stretched "silkscreen" frames is useful for allowing sheets to dry on damp felts (after lifting and separating sheet from felt)

Criteria for maximum felt hair marks:

- *Linen/hemp-based rag pulp*
- *Thoroughly retted*
- *Soak fiber overnight prior to beating*
- *Minimally hydrated – a freeness of 260 to 400 CSF (beat 25 minutes or less)*
- *Couched a little early (minimal drainage)*
- *Use as much pressure as your press will exert*
- *Air dry individually, unconstrained (lifted from the felt it was pressed on)*
- *High humidity, slow drying minimizes cockling. A simple technique for increasing the humidity as the sheet dries is to lay the sheet to dry on a damp felt, so that the felt and paper dry together (but not stuck together).* ***If you are drying on the same felt that the paper was made on be sure to lift the paper from the felt (and lay it back down in the same position)****. If you don't free the sheet and leave it stuck to the felt after pressing, the sheet will be slightly constrained and the felt hair marks will be minimized.*



Couched, **pressed** (sponged) and **air dried** adhered to felt or polyester blotter: I still consider this method "constrained drying" as the shrinkage is limited by the temporary adhesion to the felt/interfacing. Therefore, the texture will not be as pronounced as unconstrained air drying (above).

Drying strategies for smooth texture

Board drying

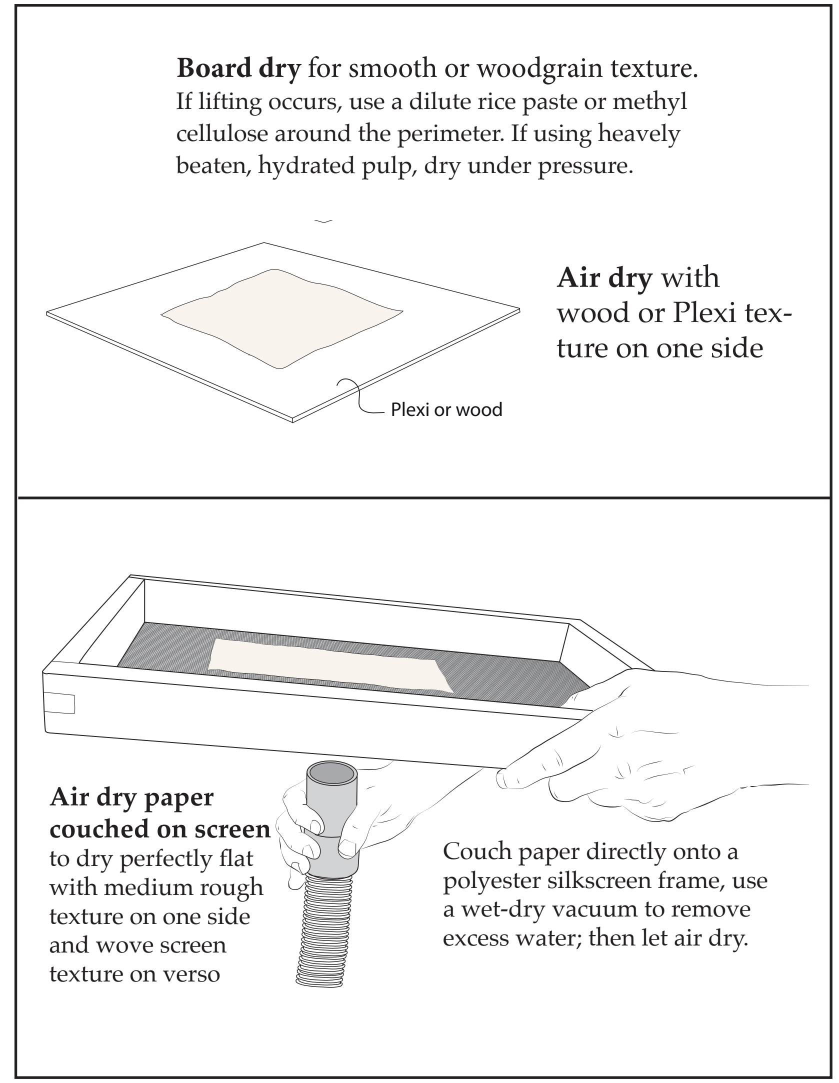
Using lightly processed, alkali cooked and hand beaten (free-draining) bast fiber, the Japanese have a simple board drying technique (*karibari*): after sheet formation and overnight pressing the sheet, the moist paper is brushed onto a flat board and allowed to dry slowly. We can follow this technique and roll or press moist sheets onto plexi or any clean, flat surface. Like the Japanese papermakers, we can paint a light coat of diluted rice paste around the edges of the paper so the drying paper will not lift as it dries. If done correctly, once dry, the paper will pop off the board smooth and flat. The drying boards are scrubbed with a wet cloth before the next paper drying cycle.

Paper has a memory in the form of the millions of hydrogen bonds that form when the sheet is pressed and dried. These types of polar covalent bonds between H-O (with an ΔEN of 1.4) are strong enough that recycled paper, for example, does not release its bonds; if it did, we could boil old paper in water to get back to the original pulp and recycle paper forever – but we cannot. Instead, reprocessing cuts paper fibers to shorter and shorter lengths each time the paper is recycled, requiring most papermakers to add "virgin fiber" to bolster strength.

This network of bonds within its constituent cellulose fibers defines the shape of the paper. Putting the variables of hydration and fibrillation due to the beating engine aside for a moment, let us simplify and say that if a sheet is dried flat it will tend to be flat all its life; if dried curled, it will tend to want to be curled all its days. Therefore drying under pressure is a preferred method where flat paper is the desired outcome.

Dewatering and air drying with vacuum and screen

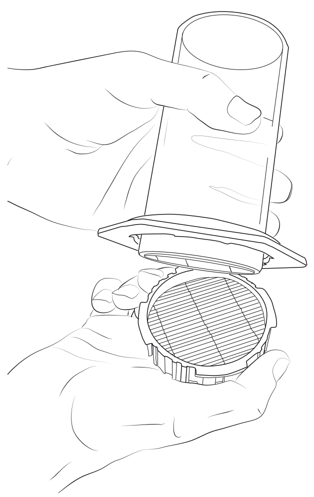
In the 1980s, Nance O'Banian, a paper artist and colleague at California College of Arts and Crafts (now CCA), introduced me to a fast and foolproof method for air drying paper flat. It involves couching directly onto a stretched screen. After couching, sponge or vacuum to dewater the wet sheet and let it air dry while stuck to the screen. This will produce a wove texture on the screen side and a rough texture on the other side. Burnishing or calendering can modify these textures when the paper is dry.

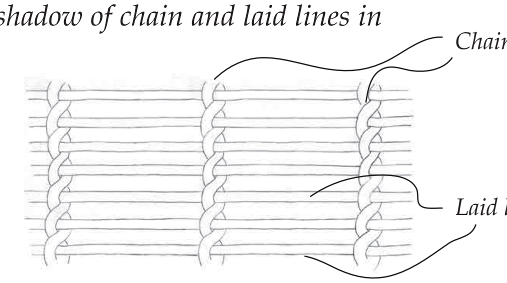


Drying strategies for laid texture

For a noticeable laid texture, apparent in the finished sheet when held up to a light, a shorter-fibered furnish creates more detail. (Sharper beater blades and added titanium dioxide also contribute to laid line visibility.) For more surface texture, leave the laid screen in contact with the paper and press again onto felt and/or blotter to remove more moisture; remove the laid screen and peel off the moist sheet for drying.

The "laid" pattern is caused by the copper wire screen (below) on which the paper is formed, leaving a shadow of chain and laid lines in the finished sheet.

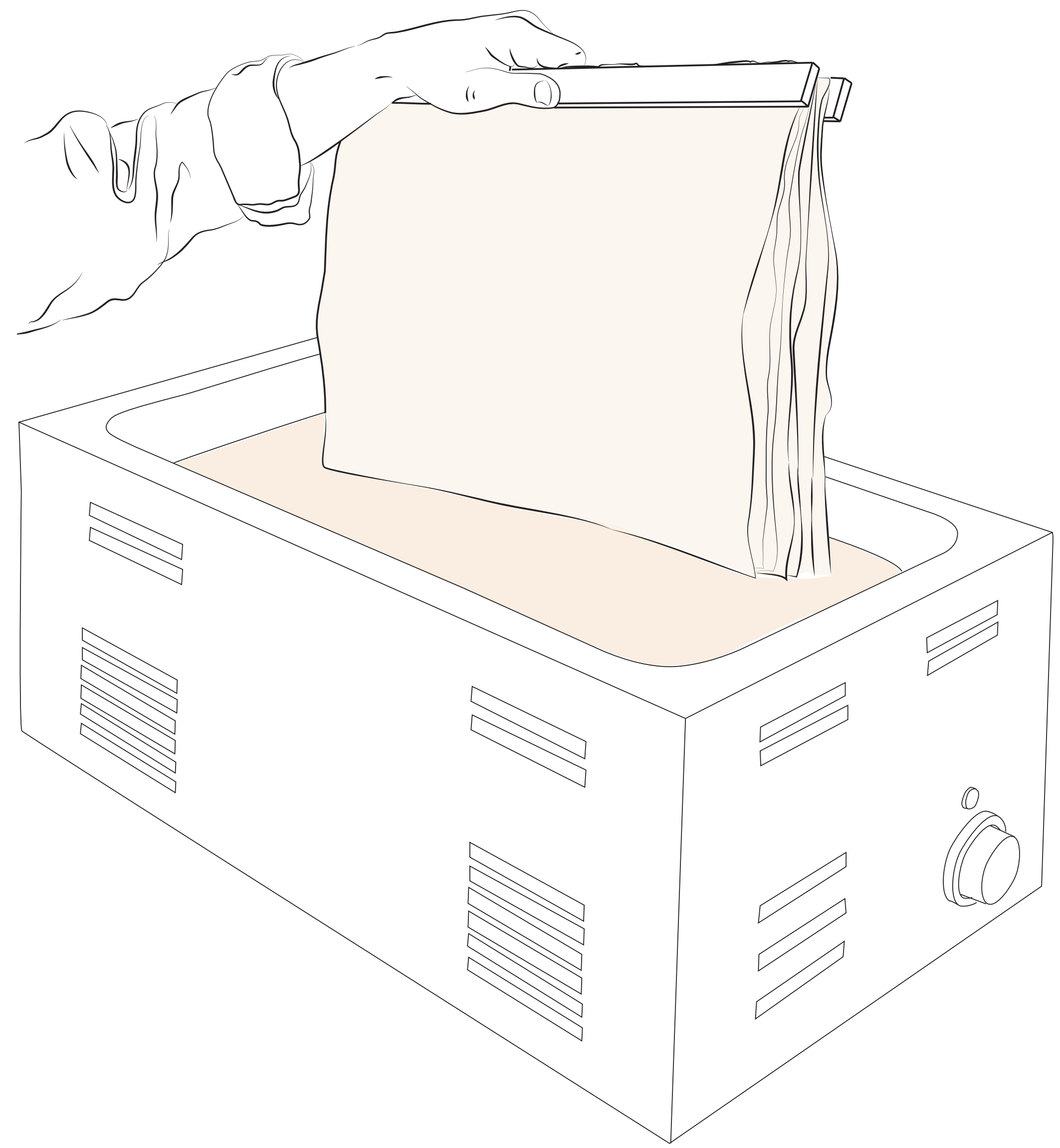




Laid lines from **UV-printed screen** on pressed paper

X

Sizing and Finishing



Sizing, Curing and Finishing

As we will put into practice below, paper is made stronger and more water resistant and therefore better suited for pen and ink, by dipping the dried sheets in hot animal hide glue. Many flaws are likely to occur during this process, causing early European papermakers to referred to the sizing room as the “slaughter house.”

Once dipped in hot gelatin, the warm, aromatic sheets were gently “pack pressed” to remove excess size, allowed to rest for a day, then hung on rope to dry or dried flat on stretched open-weave fabric.

Once dry, the sized sheets were weighted for a few days under a heavy board then cured in a standing press where an increasing degree of pressure was applied over time and the sheets shuffled to remove the cockle and smooth the paper’s surface.

After sheets have been made and dried, they are referred to as waterleaf or unsized paper. These sheets will soak up water like a blotter. Sizing will impart resistance to liquids on the paper surface, creating a paper that slows water and ink penetration.

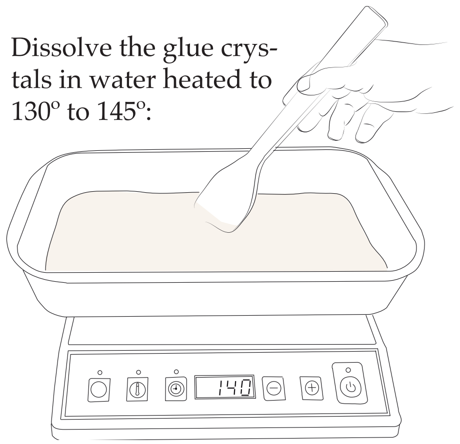
External sizing is done with dilute hide glue (such as rabbit skin glue). Other external sizing includes starches. These days various unseemly chemicals, aluminum sulfate, activated rosin, and synthetic alkaline resins are added to the pulp before sheet formation. This type of sizing is called “internal sizing.”

To size with rabbit skin glue, use a 2 to 6% solution by weight of solids to water[6] (e.g., 40g of hide glue crystals for 1 liter of water for a 4% solution). Dissolve the glue crystals in water heated to 130º to 145º. Heating at higher temperatures degrades the efficacy of the size. Adding a pinch (.1%) of alum (potassium aluminum sulfate) to the hot size bath will make a more water-resistant paper, but too much added can negatively affect the paper’s pH.

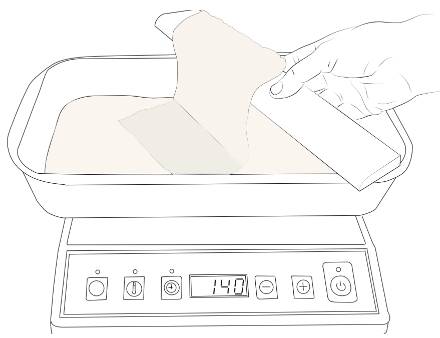
Once brought to temperature and the hide glue crystals have dissolved, submerge the paper into the hot liquid, soak for 15 to 30 (longer if multiple sheets are sized at a time), lift from the tub and let the sheets drain, then set on a blotter or porous surface. Air dry, moving the paper from time to time to stop it from sticking to the blotter.

6. *There are various recipes and methods of sizing; several are documented here:* ***http://imcclains.com/productinfo/documents/SizingPaper.pdf***

Dissolve the glue crystals in water heated to 130º to 145º:

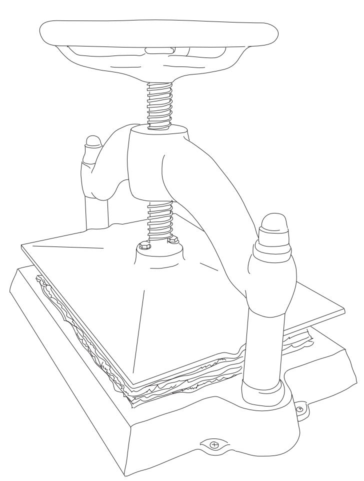


Saturate paper with the hot hide glue:



Caution: Be safe around hot liquids.

Air dry sized paper and press to cure and flatten:



Gradually increase pressure every 12 to 24 hours.

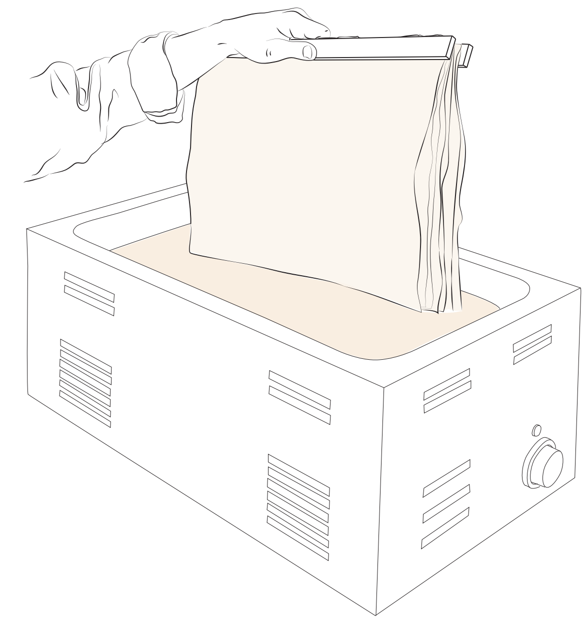
Sizing multiple sheets:

The traditional method for sizing multiple sheets at a time is to hand clamp 8 to 12 sheets between two slices and lower them into the hot size as a unit. Once submerged, slack off on the slices and let the *pack* of paper soak in the hot size for a few minutes. Next, reposition the slices into the opposite edge, clamp and lift the pack out, holding the group above the tub and allowing the sheets to drain. Carefully lay the group flat avoiding wrinkles. Cover the sheets with Pellon, and blotters. Press the pack gently (no more than 5 psi) to remove excess size and hang or lay flat to dry. Peel and hang each sheet on stretched horse hair rope or pole to dry (as per below).

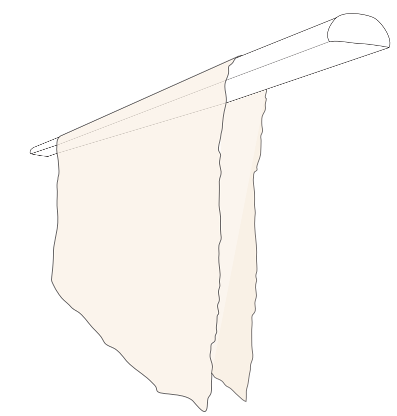
Prolonging the shelf life of animal skin size (isopropyl alcohol)

Animal skin size is notorious for its short shelf life; this can be inconvenient in a conservation context, where it may not be used regularly and only a small amount may be needed at a time. In an effort to create a small quantity of longer-lasting, faster-drying size, I had the idea to dilute prepared animal skin size by substituting half the water in the formula with alcohol. At the studio, I heated and mixed an 8% solution of odorless hide glue. Once to temperature (130° F), I added an equal part of alcohol. Sadly, the instant I added the alcohol, the dissolved collagen coagulated and turned to a gooey mess.

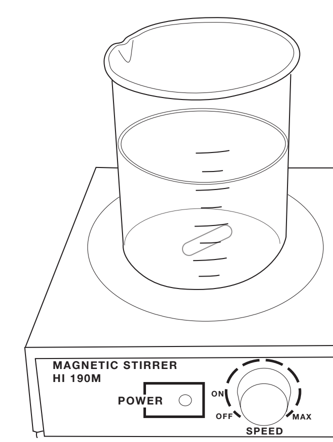
On the next try, I added the alcohol to the hide crystal first and let them soak for a few minutes. Then I added water, and mixed while heating (using a magnetic stirrer). This second approach won the day. The size works well and is very convenient when working on but one or two leaves, like document repair sizing. This formula uses less water, has a long shelf life and seems less likely to grow bacteria and seems to survive just fine without refrigeration. When I need to use a small amount of size, I simply place the bottle containing my mixture in a bowl of hot water to warm up.



Waterleaf paper being dipped into sizing tub



Sized sheet hung on rounded pole to dry

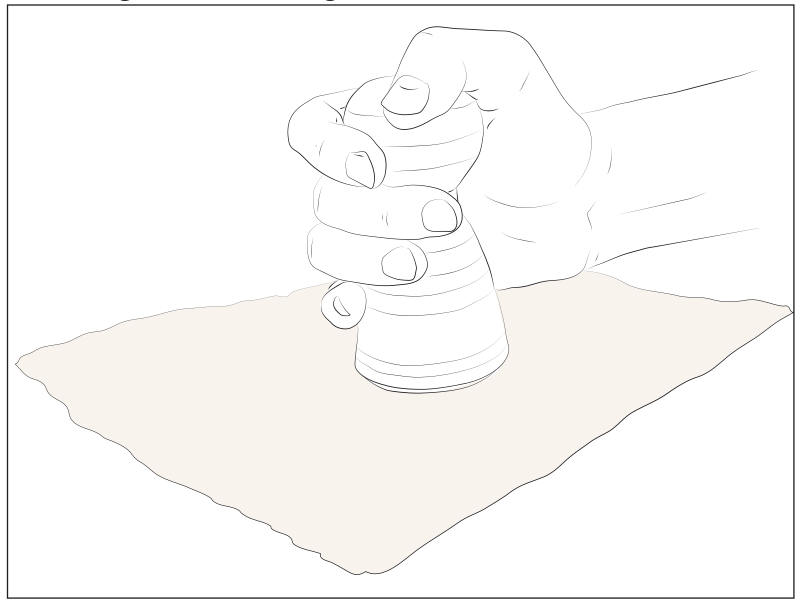


A magnetic stirrer used to mix small batches of hide glue sizing.

Curing & Flattening

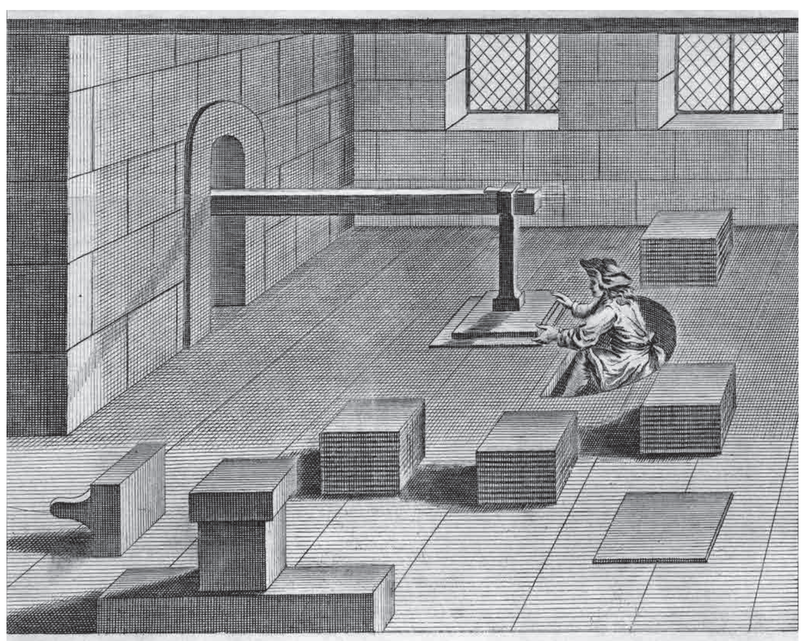
Once sized and dried, place the paper under weight or in a book press to cure the paper and coax it flat. Start with gentle pressure, shuffle the papers every 12 hours and gradually increase the pressure. Repeat the process 3 or 4 times until flat.

Finishing & Calendering

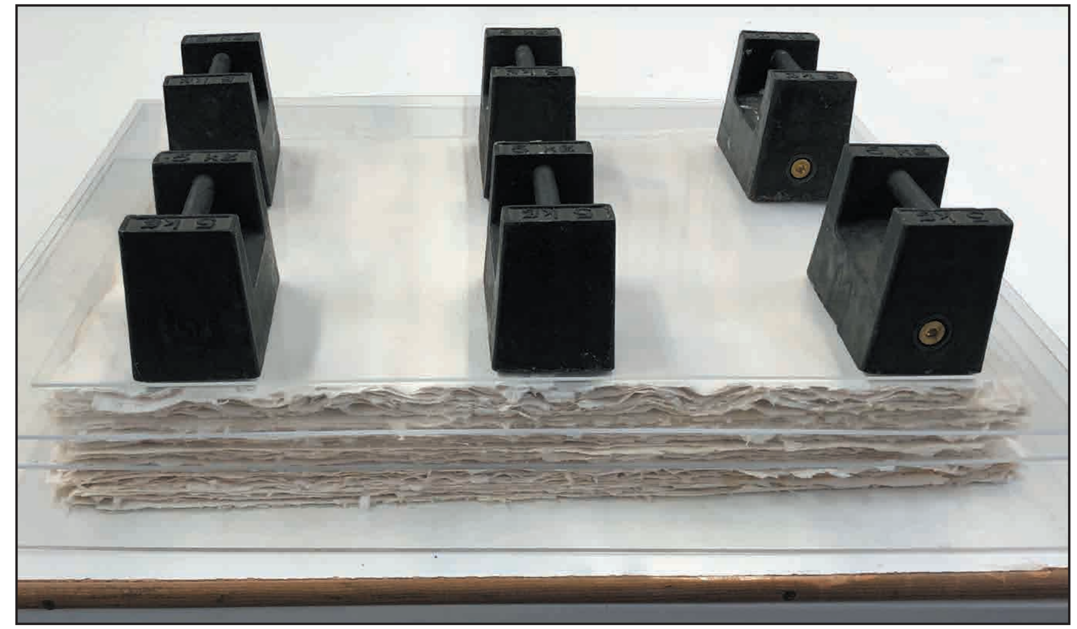


Hand burnishing

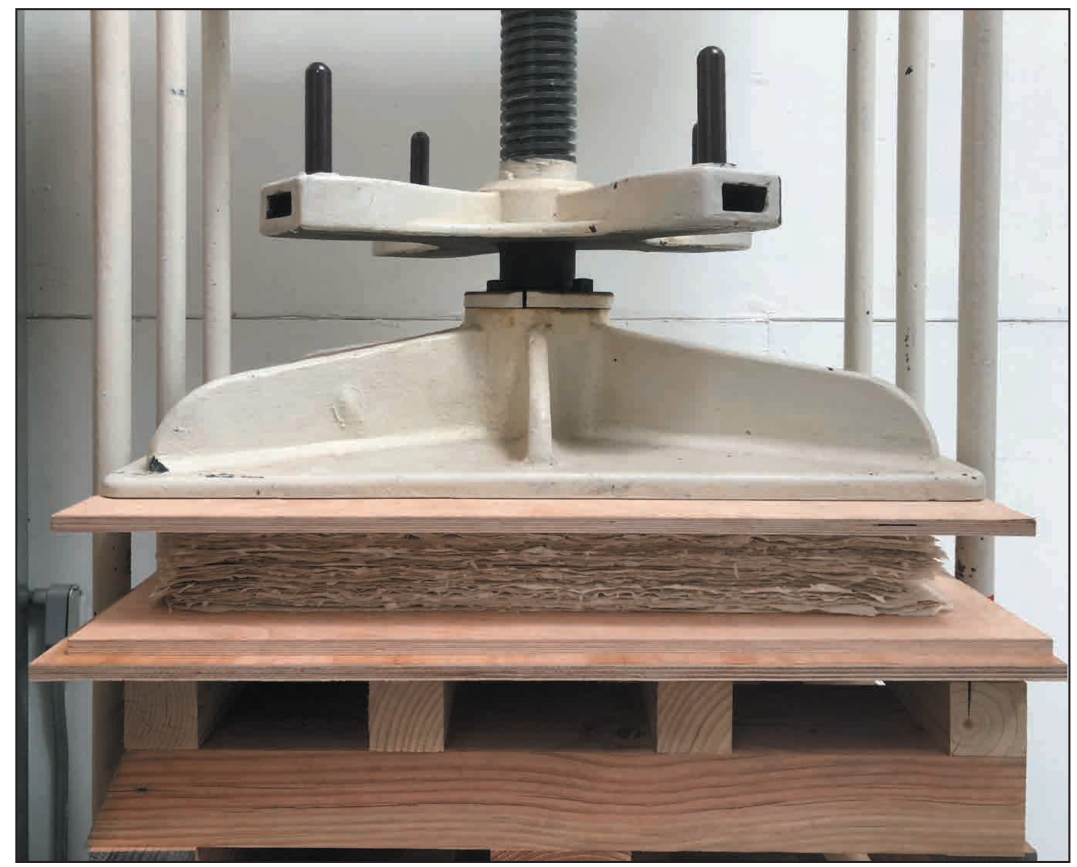
For additional textural possibilities, burnish the finished sized paper with a smooth turned hardwood burnisher, a polished stone, or between platens in an etching or litho press.



Traditional calendering



Curing paper under gentle pressure with weights



Curing paper under pressure in a standing press

Flattening Cockled Sheets - an expedient method

Air dried paper (waterleaf or sized) has a tendency to be wavy, cockled and difficult to flatten. The process described below controls moisture and minimizes drying time with the use of alcohol. My goal here is to flatten the sheet while preserving the surface texture - the felt hair marks.

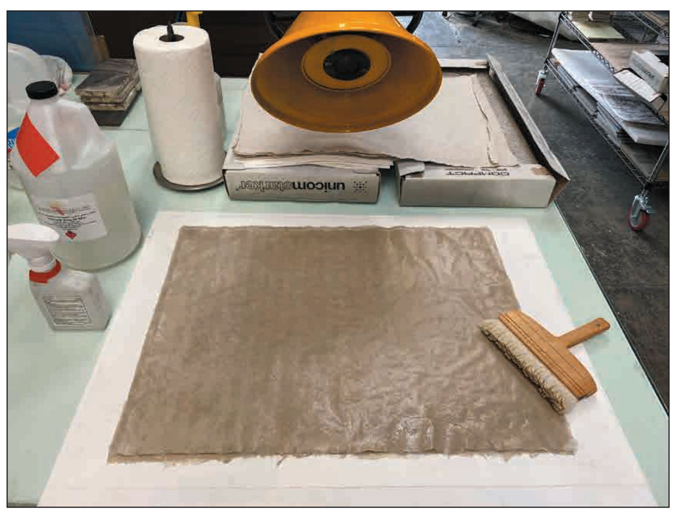
Before and after expedited flattening

Relaxing sheets with 50/50 alcohol and water.

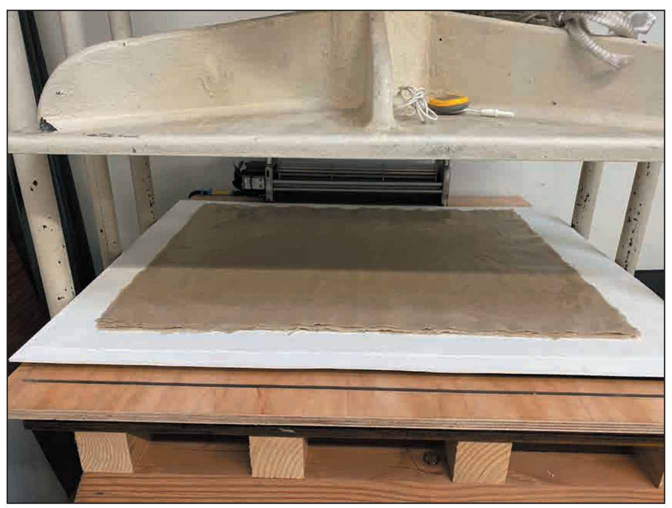
In a well ventilated area or under a fume hood: Moisten cockled sheets with a 50/50 mixture of isopropanol and water (sprayed or submerged in a tray) one at a time. As each sheet "relaxes," smooth and coax the sheet flat using a Japanese water brush (*mizubake*). Brush the moistened sheets from the center outwards until the sheet lays flat. Working quickly, moisten and flatten one after another and stack the moistened sheets to build a stack similar to a spur (4 to 8 sheets). This moist (water and alcohol) spur is placed in a stack dryer under pressure and dried overnight.

Stack Dryer with micro-porous polyethylene

Although any stack dryer may be used, I have a configuration I favor (see page 138): a standing press with a cross-flow fan, layered with alternating micro-porous polyethylene sheets, fine and coarse breathing mesh (diamond mesh plastic). The spur of moist paper is placed between the micro-porous polyethylene sheets with Evolon or felts as padding onto and under the stack depending on the amount of surface texture desired. Once the layers of breather mesh, sandwiched paper and micro-porous polyethylene sheets have been built, apply pressure to the stack with the cross-flow fan turned on blowing through the breather mesh. The spurs will normally be dry by the next day. Heavy pressure and Evolon padding will produce a smoother paper than less pressure and wool felts as padding. Paper dried in a stack dryer is, as mentioned earlier, considered "constrained drying" in that the paper cannot move (shrink) as it dries as it is held in place. This produces a slightly larger and more dimensionally stable paper. With linen paper beaten to a freeness of 300 CSF, an 18 x 24 inch sheet can shrink one inch or more in length if air dried and yet not shrink at all if dried constrained. Even an air dried paper that shrank an inch, hide glue sized and air dried a second time, then alcohol/water moistened will expand slightly if dried constrained in this flattening process.



Sheets of paper moisened with water and alcohol and mizubake (water brush)

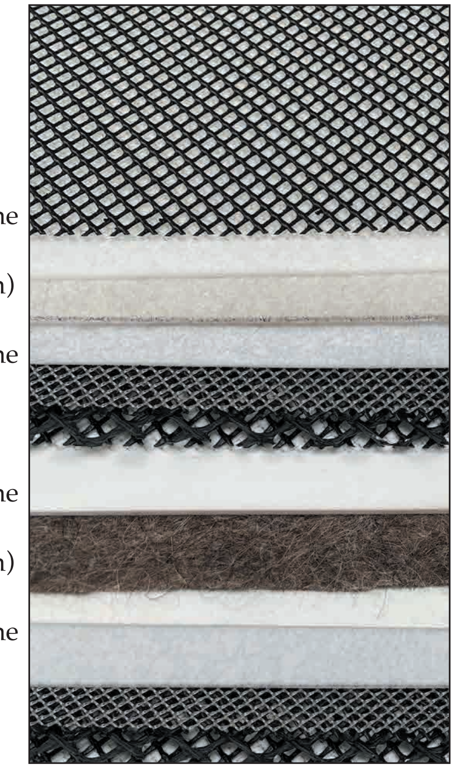


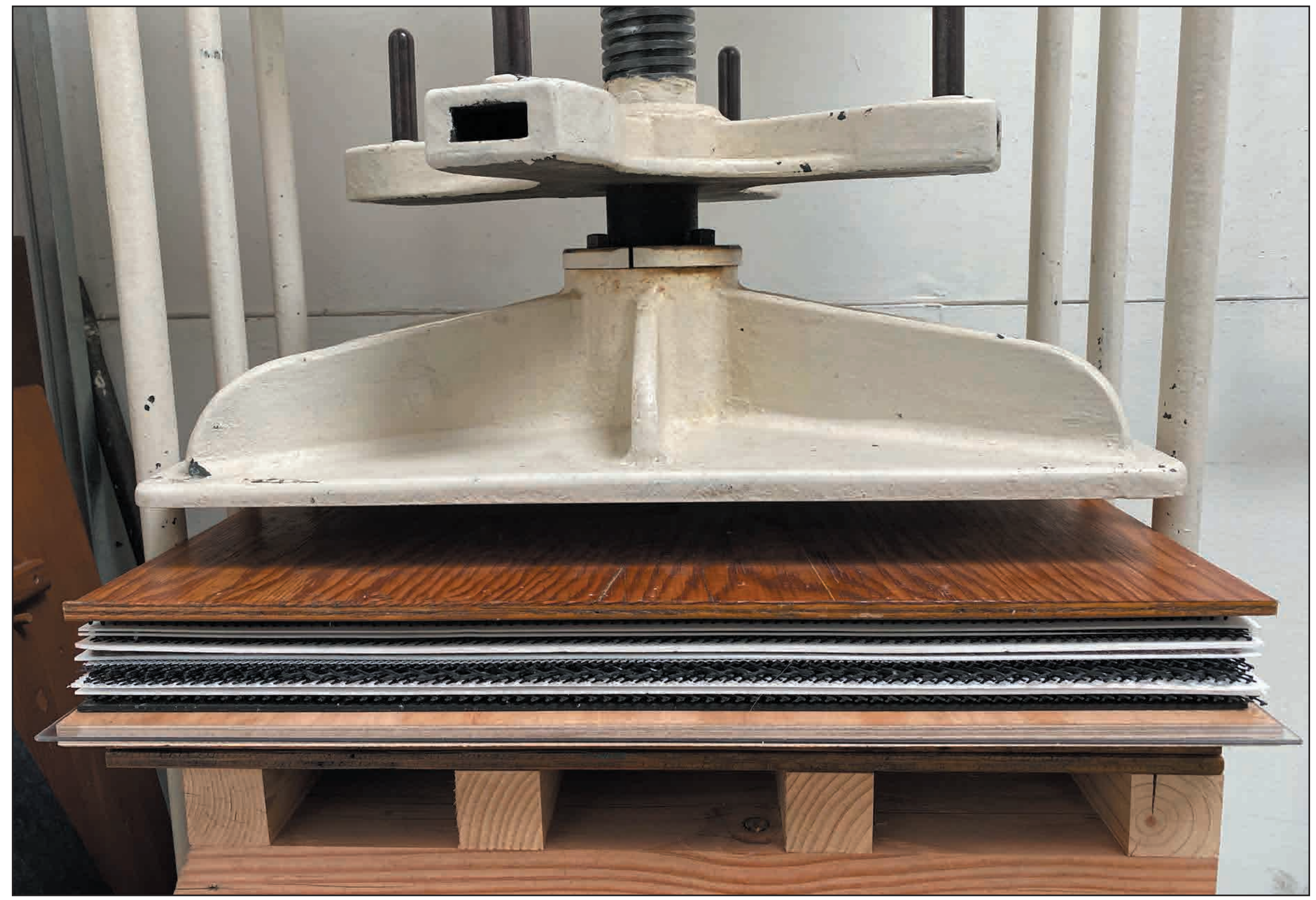
Sheets of paper moisened paper being loaded into a stack dryer. The cross-flow fan can be seen at far side of press.

Stack Dryer configuration

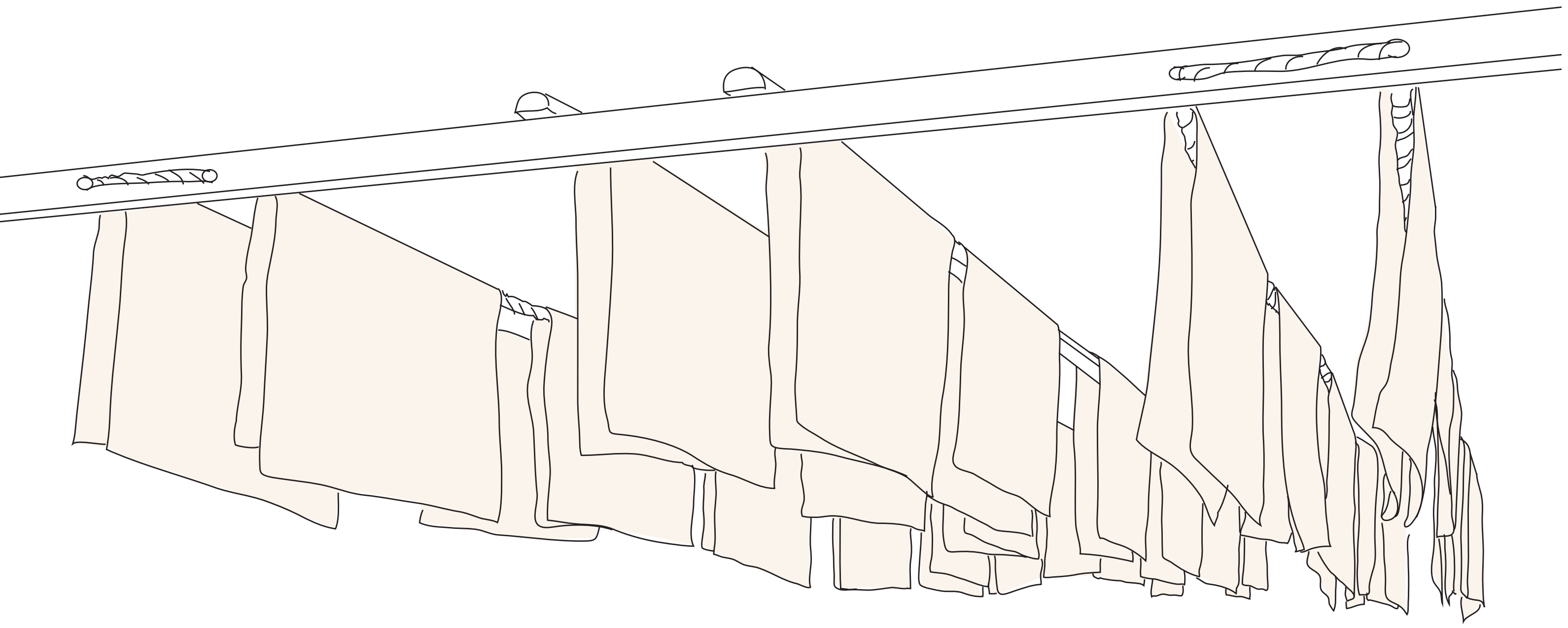
From top to bottom:

- Coarse Breather Mesh
- Fine Breather Mesh
- Micorporous polyethelyne
- Felt
- Moistened paper (hidden)
- Evolon (hidden)
- Micorporous polyethelyne
- Fine Breather Mesh
- Coarse Breather Mesh
- Fine Breather Mesh
- Micorporous polyethelyne
- Felt
- Moistened paper (hidden)
- Evolon
- Micorporous polyethelyne
- Fine Breather Mesh
- Coarse Breather Mesh





Stack dryer loaded with three layers containing moist paper - 8 sheets per layer. Pressure yet to be applied.



Sized sheets hung on rounded pole to dry

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