Paper and Board Manufacture and Properties Workshop

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Summary of Workshop

- Overview and terminology of paper and board grades that are extrusion coated
- Properties of paper and board used for extrusion coating
- Paper and board manufacturing variables that impact extrusion coating
- Trends and developments
- General group discussion

Extrusion Coated Grades

- Extrusion coating is applied to a wide variety of paper and board grades depending on the properties sought
- Extrusion coating/lamination can be used to bond foil to paper or paperboard for enhanced barrier properties

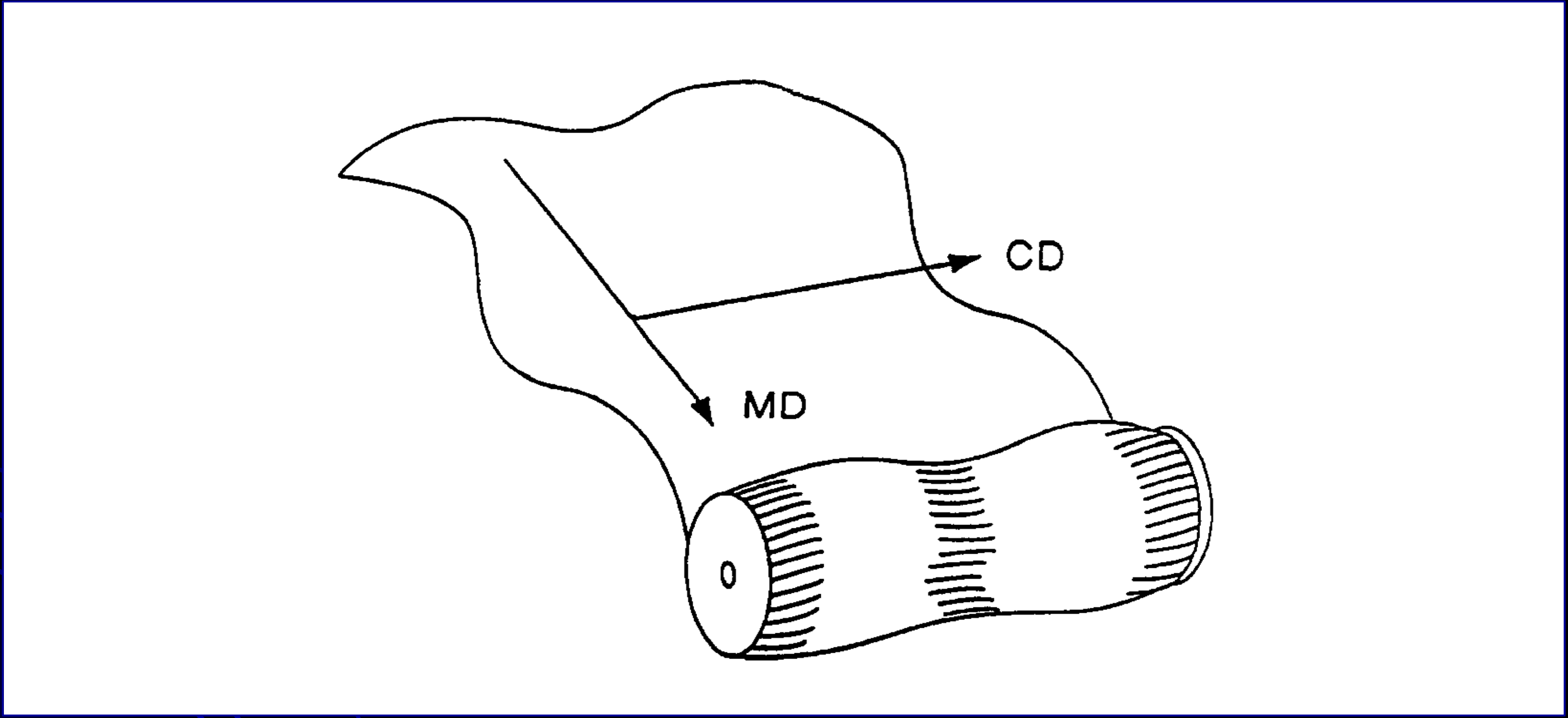
Extrusion Coated Grades

Substrate	Property Sought	End Uses
Bag and wrapping paper	MVTR, OGR, liquid resistance	QSR, bakery, carry-out, multiwall sacks
Bleached board	Liquid resistance	Cups, milk cartons
Linerboard	MVTR, OGR, liquid resistance, release	Frozen food & other packaging

Variability of Paper

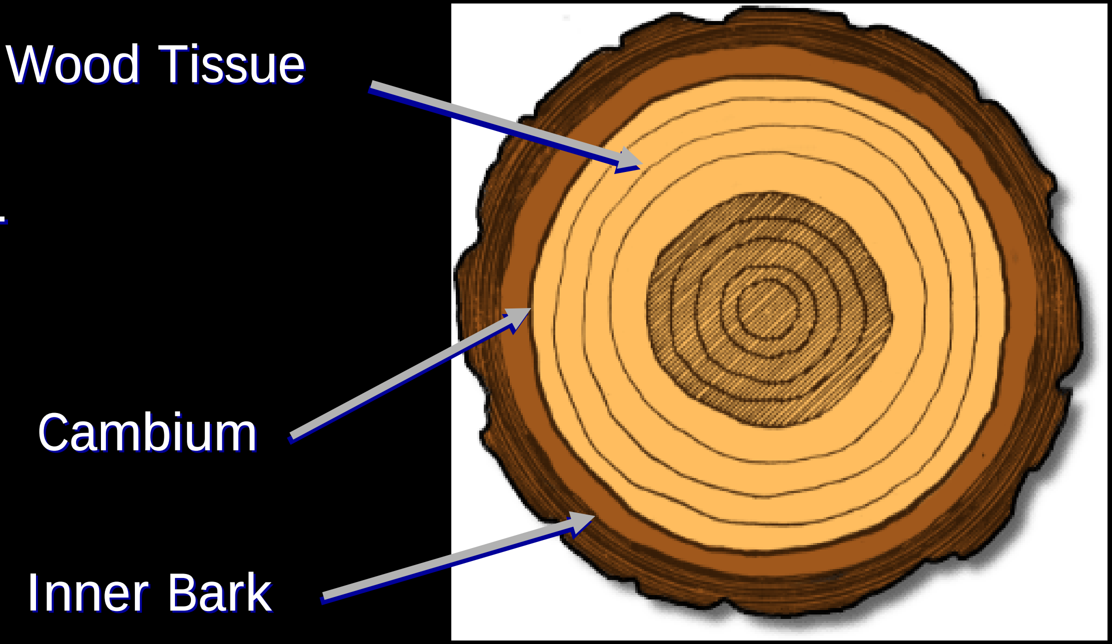
- Paper is not a homogeneous material.
- Varies in the machine direction (MD), cross-direction (CD), Z-direction, and over time.
- It is also reactive to changes in its environment. Shrinks and expands and usually not uniformly.
- Its structure depends on the process that produced it and even the location across the width of the paper machine.

Variability of Paper

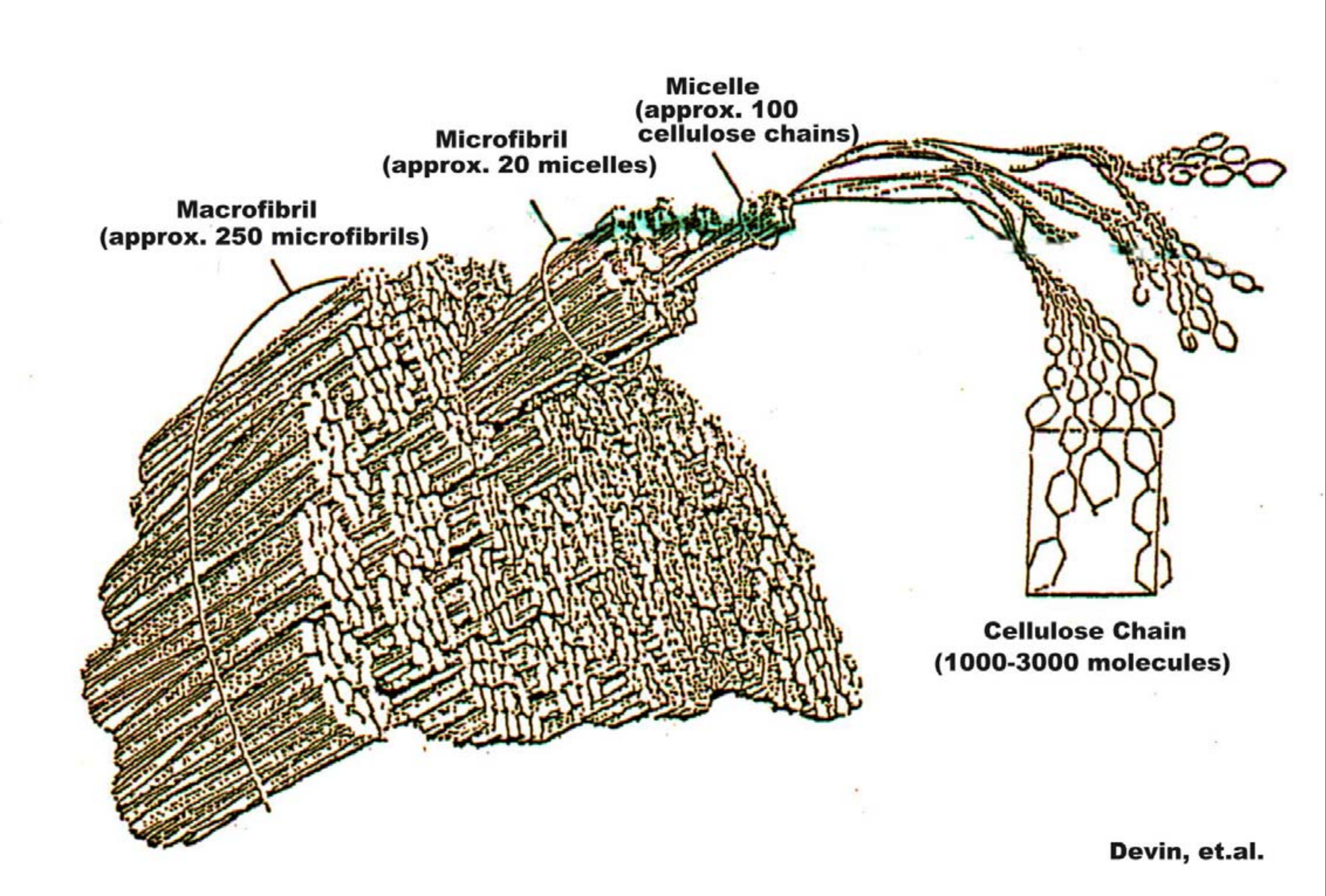


Components of Wood

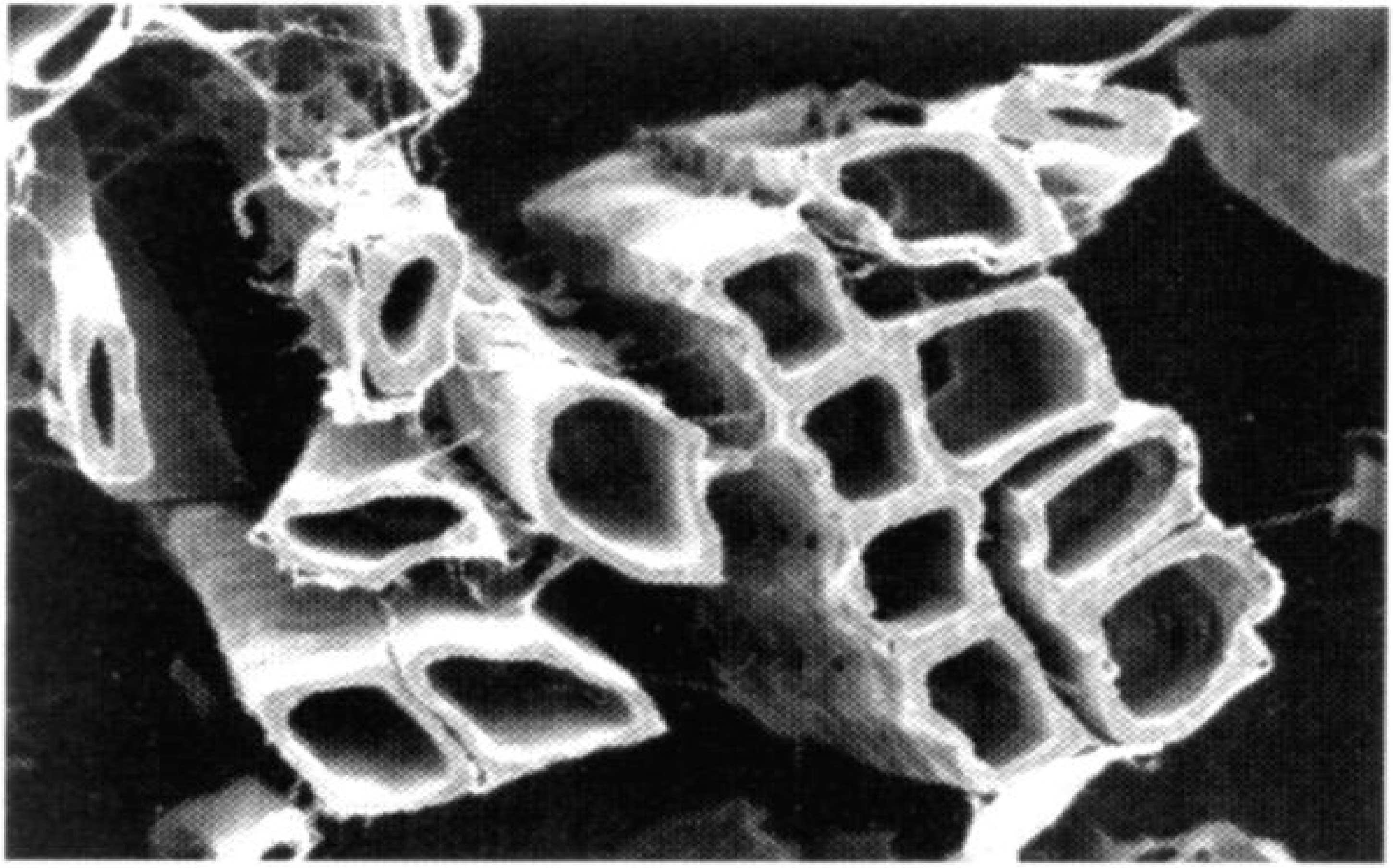
- Cellulose – 45%
- Lignin – 25%
- Hemicelluloses – 25%
- Extractives – 5%



Cellulose $(C_6H_{10}O_5)_n$

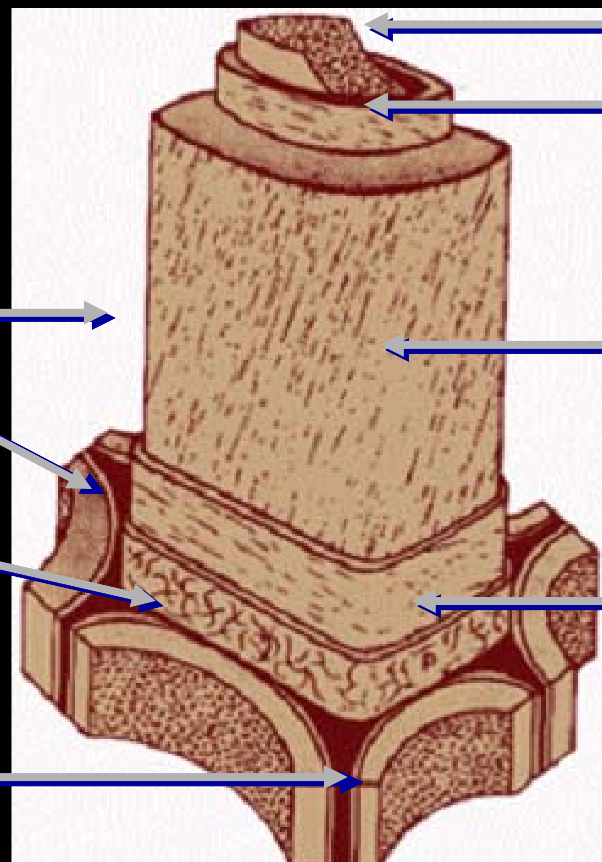


Fiber Structure



PAPRICAN

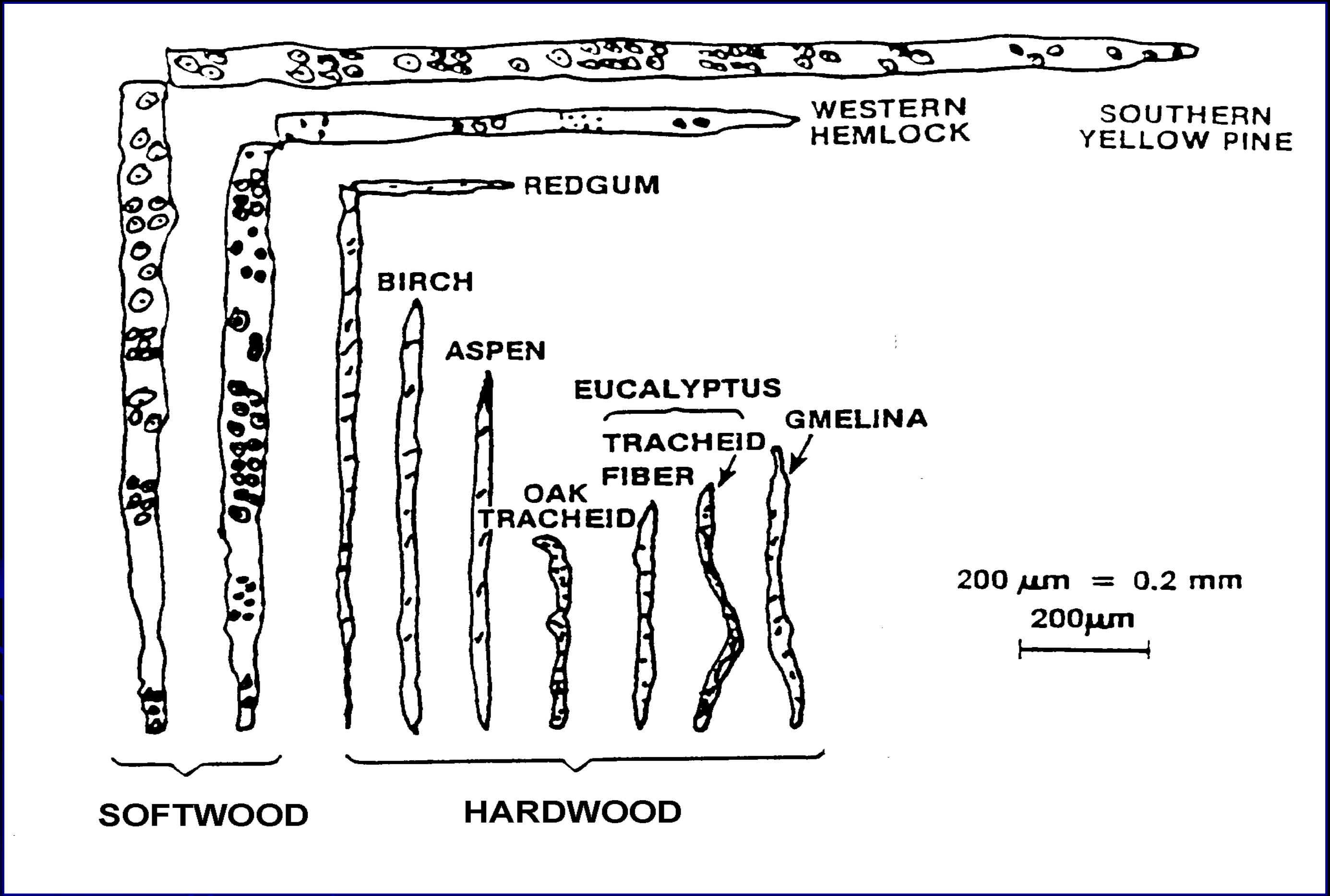
Fiber Structure



Fiber Structure

- Like a drinking straw
- 1/32” (0.75mm) to 1/4” (6mm) long
- Length to width ratio of 50 to 140

Fiber Structure



Fiber Structure

Pine sheet

Eucalyptus sheet

Fiber Structure

- Softwoods for strength and runnability
- Hardwoods for uniformity, smoothness, formation, and printability
- Inherent strength requirement of the converting process dictates the amount of softwood that is included in the furnish

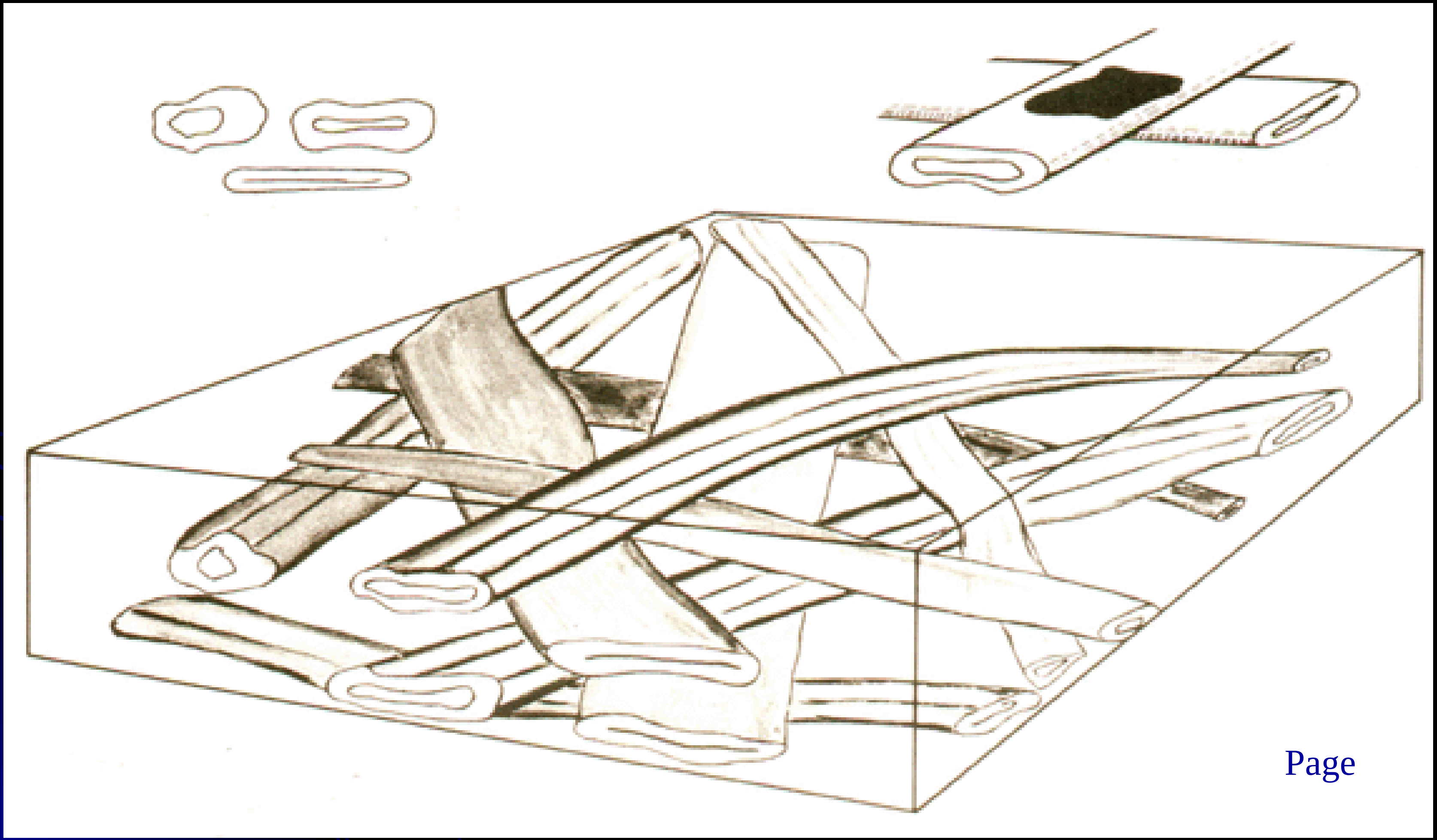
Pulping and Bleaching

- 65% of the pulp produced in the world is made by the kraft process.
- Chemical pulping removes most of the lignin and hemicelluloses and all of the extractives.
- However, chemical pulping results in dark brown pulp that must be bleached.
- Nearly all extrusion coated paper and board is made from kraft pulp.

Paper Structure

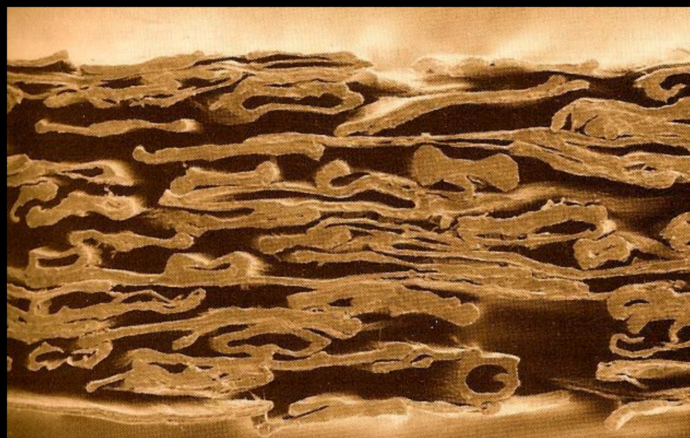
- Cellulose molecule is aligned more or less parallel to the long axis of the fiber.
- Fibers are hydrophilic.
- Fibers expand and shrink based on the water content in the fiber walls.
- Fibers can swell up to 25% in width but only slightly in length.
- Hydrolysis results in fiber swelling, greater fiber flexibility, and fiber collapse.

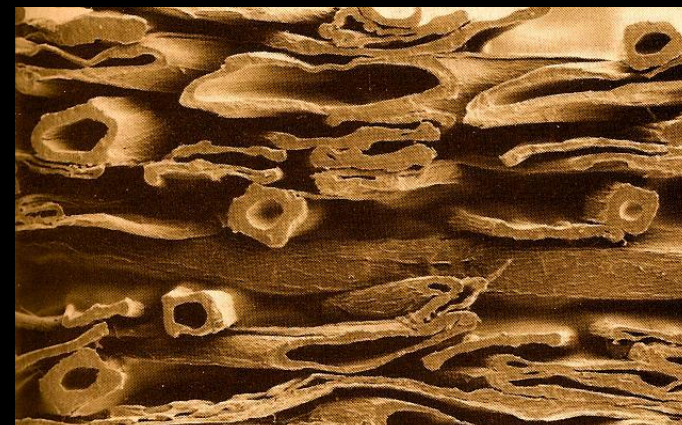
Paper Structure



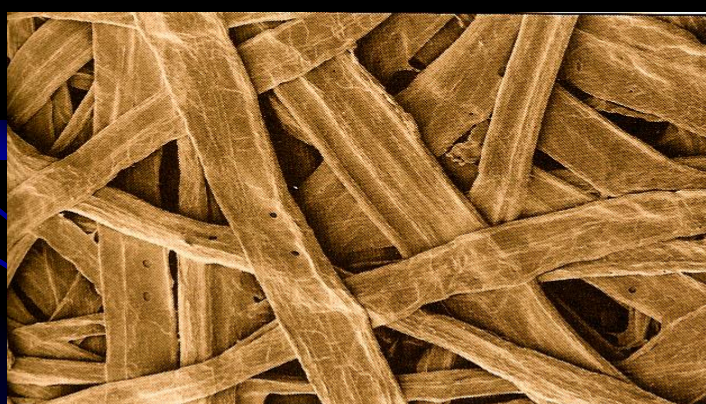
Paper Structure

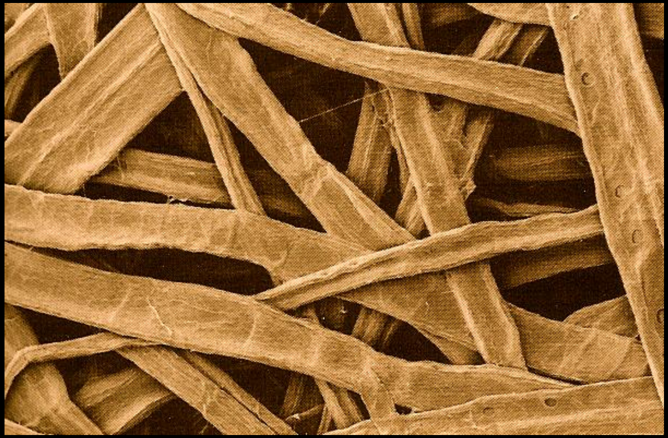
Side view





Top view





More fiber collapse

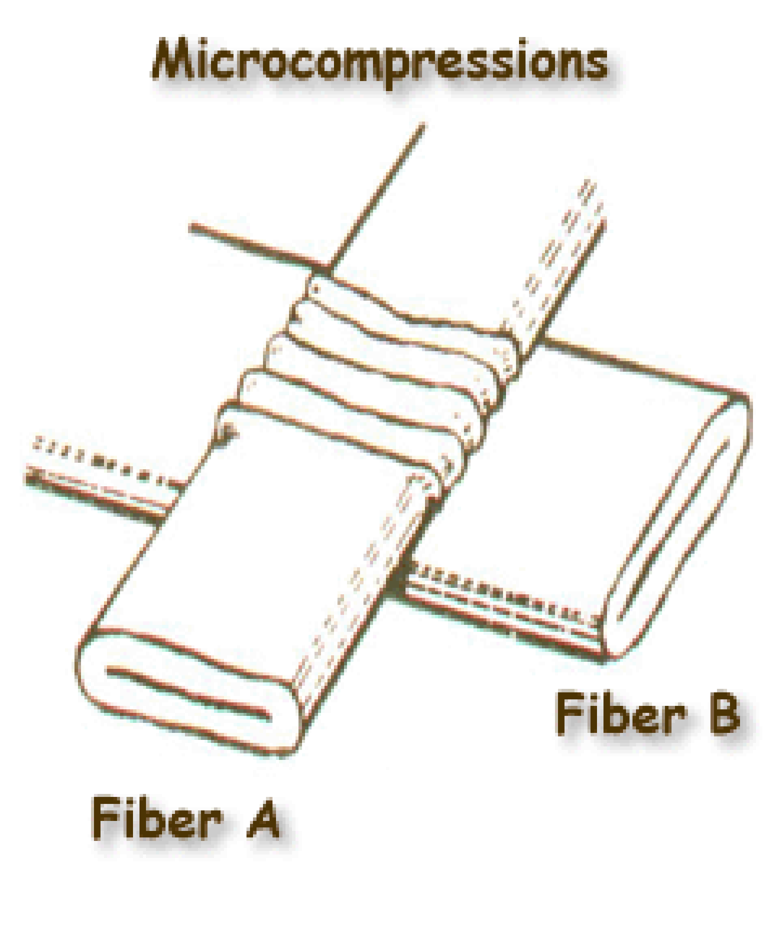
Less fiber collapse

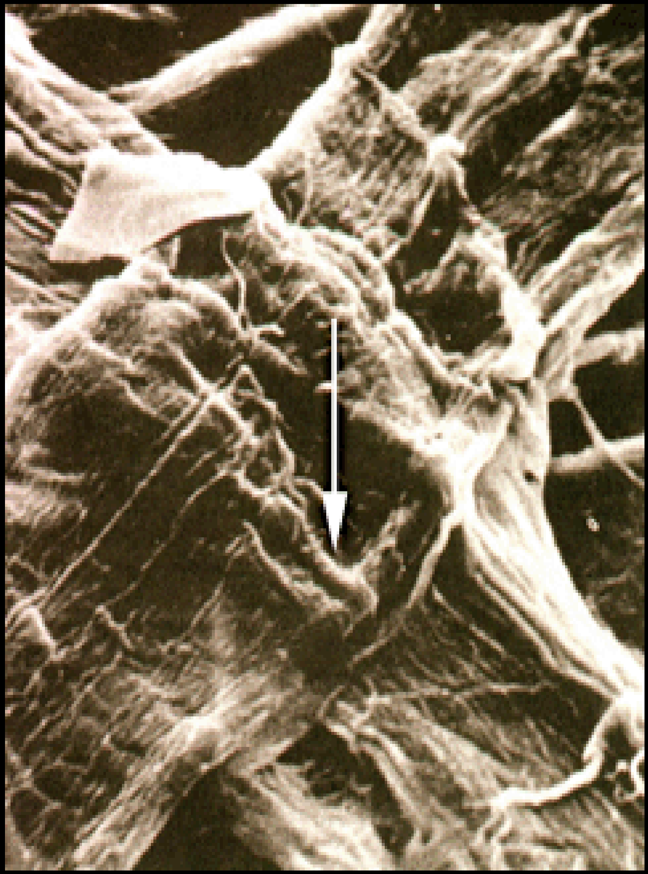
Paper Structure

Fiber collapse depends on:

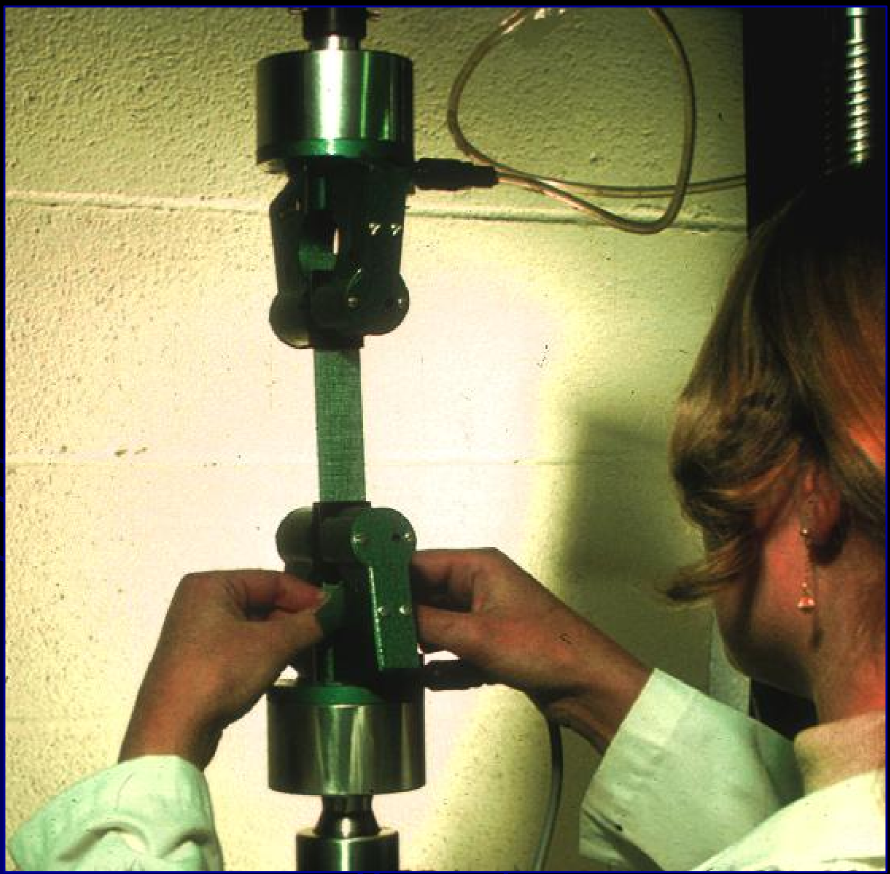
- Thickness of the cell walls
- Ratio between fiber wall thickness and fiber width
- Amount of lignin left in the fiber wall
- Amount of mechanical action
- Pressure on the paper machine

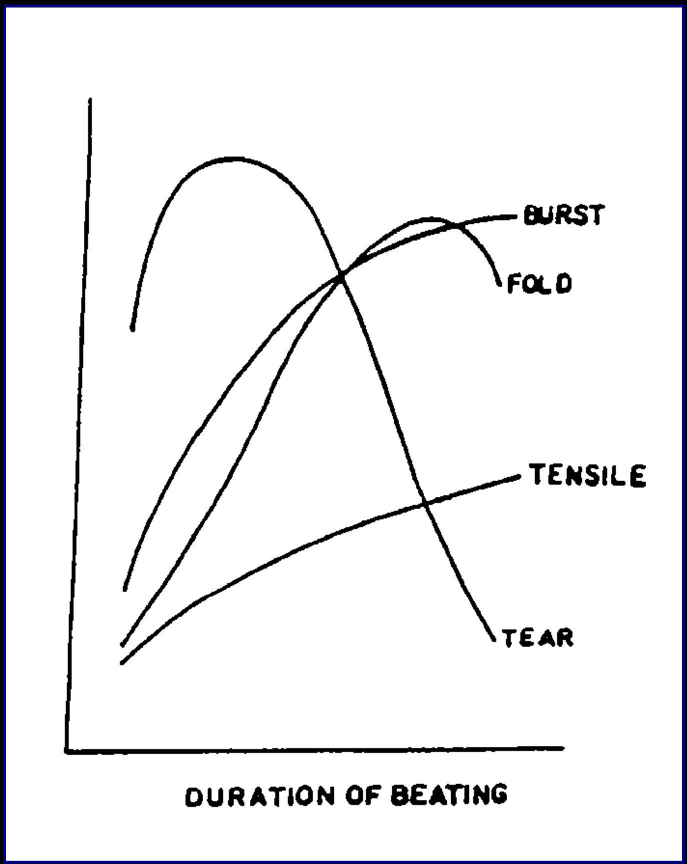
Paper Structure



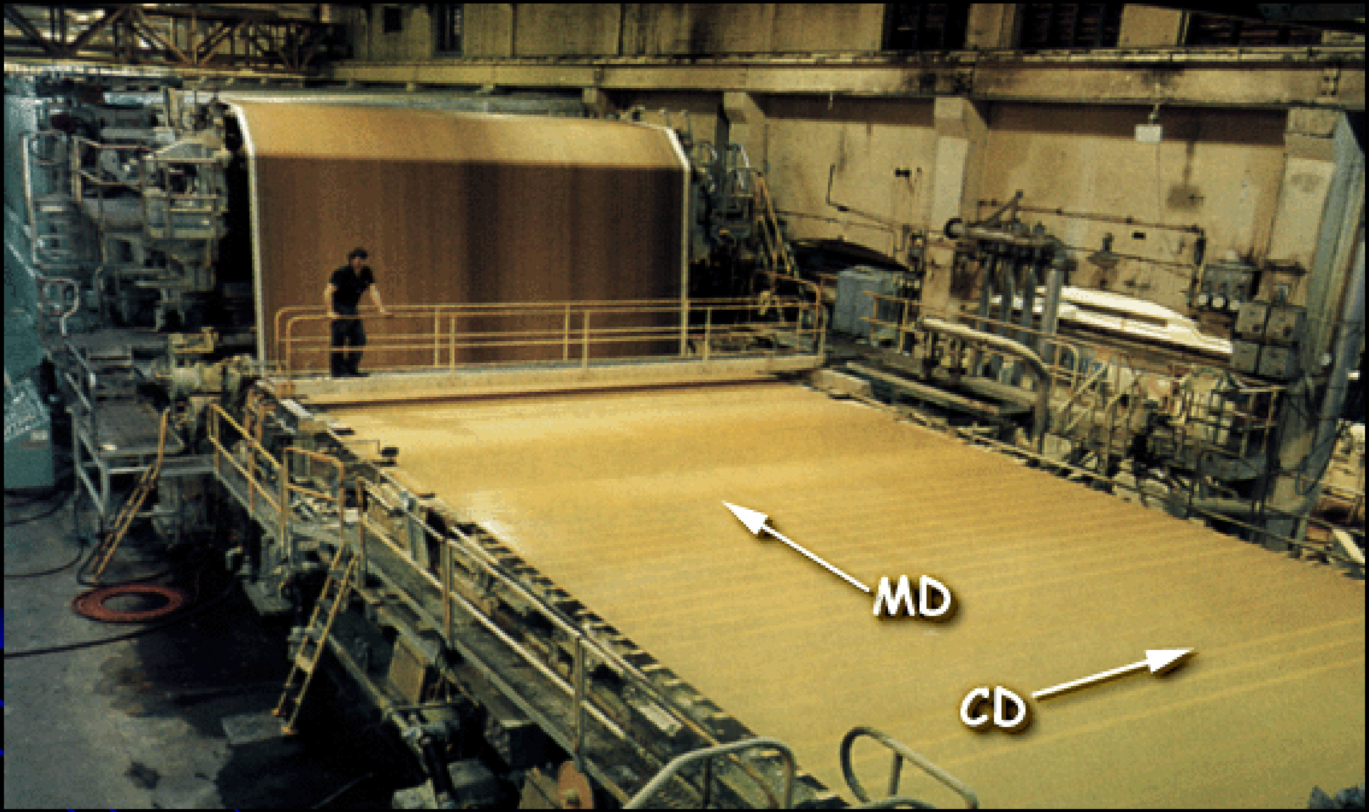


Paper Structure



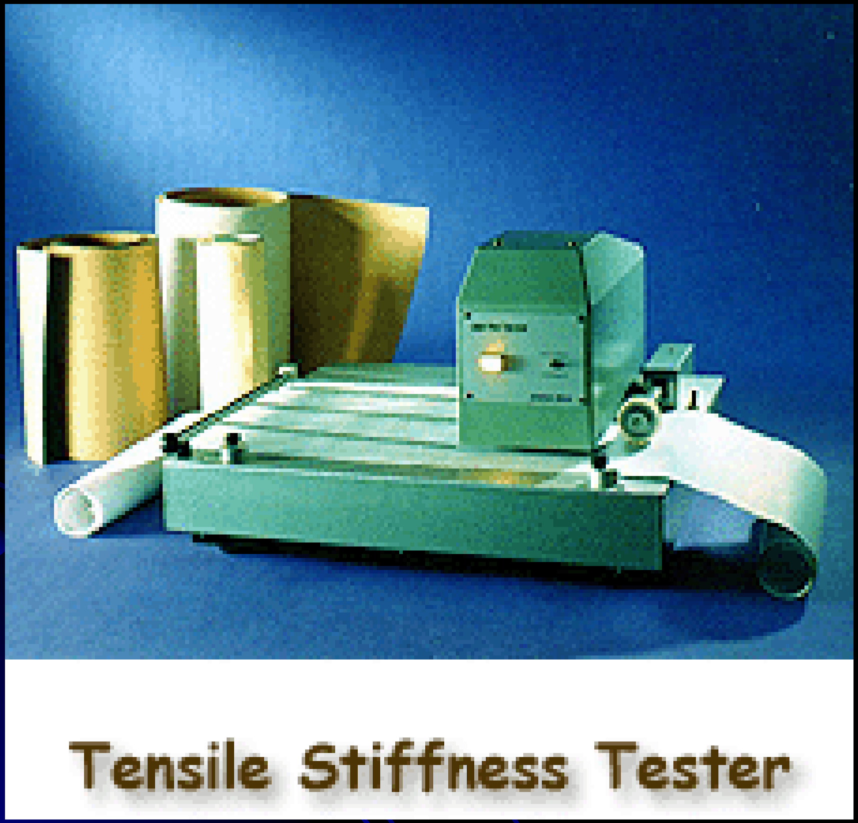


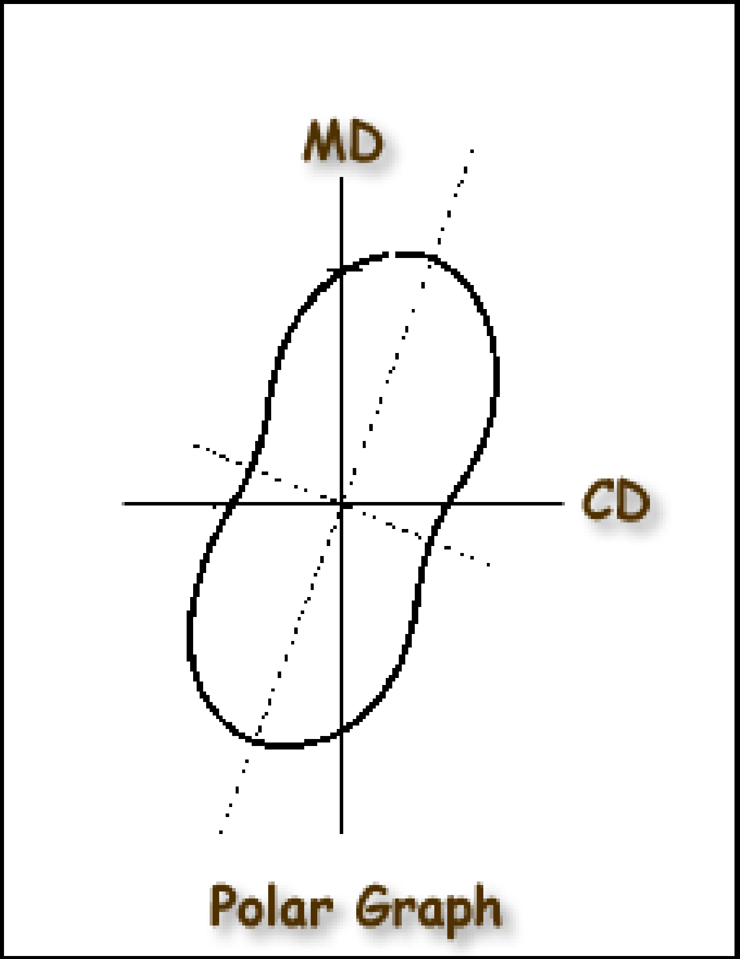
Paper Structure



Fiber orientation means that paper is stronger in the machine direction than in the cross machine direction.

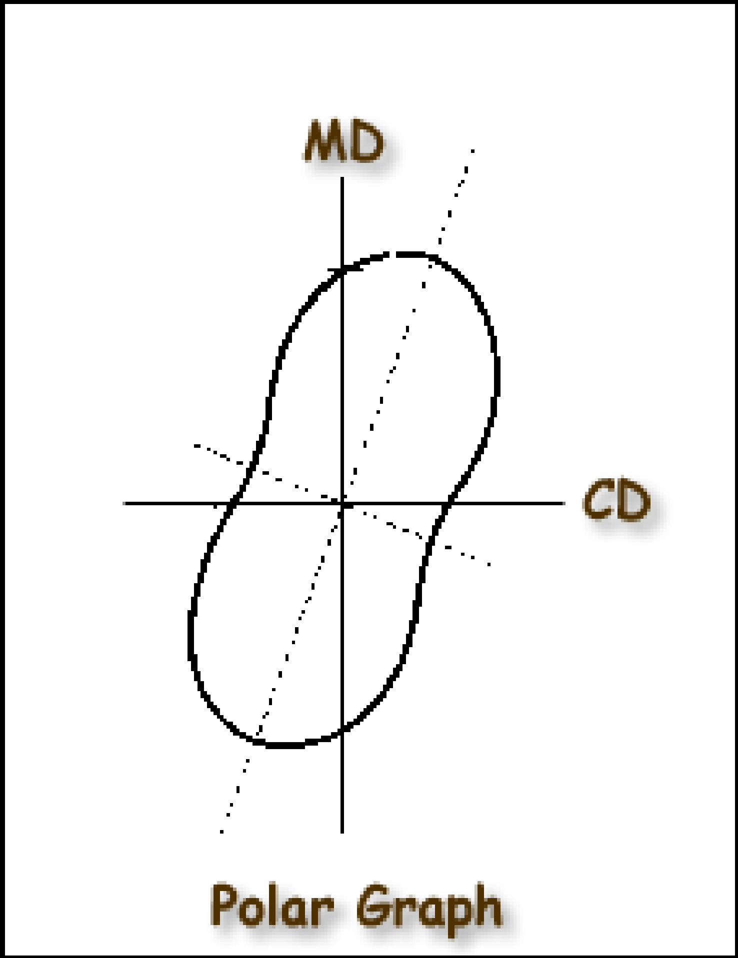
Paper Structure





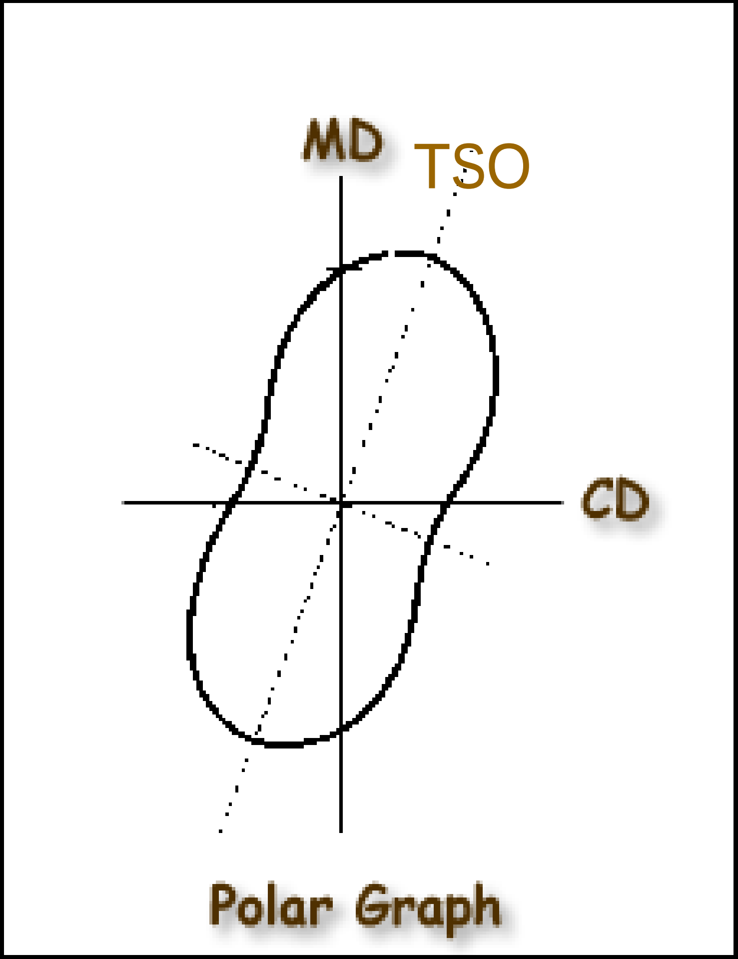
Paper Structure

- More fiber alignment in the MD is called anisotropy.
- Sonic modulus relates to tensile stiffness index (TSI).
- TSI relates to fiber orientation.



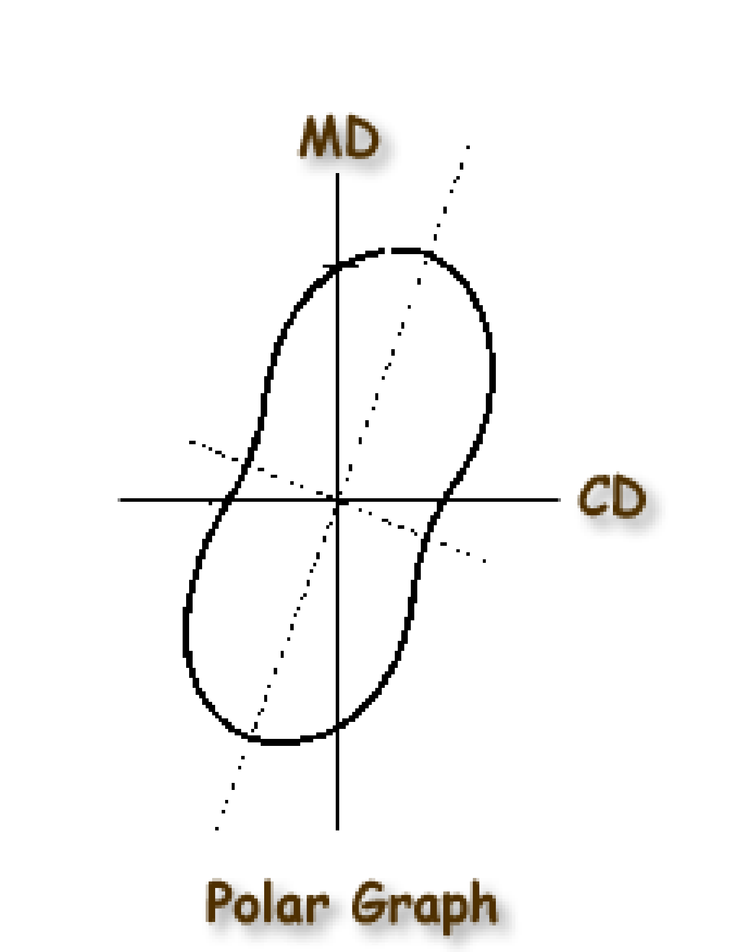
Paper Structure

- TSO is the angle of max TSI.
- Might not be in the exact MD.
- Varies across the sheet.
- Called asymmetrical anisotropy.



Paper Structure

- Fibers swell in width, but not in length.
- Humidity changes affect the CD more than the MD.
- Same problem if top and bottom of the sheet is different.
- Paper curls.



Summary of Papermaking

- Paper is a record of all the processes that have occurred in its production, and those processes are inherently unstable.
- The physical properties of paper are based on the structure of the cellulose molecule, the type of fiber, and how that fiber was separated from the other components of the wood.
- The way the fibers are reassembled strongly affects how the paper reacts to further converting operations and other changes in its environment.

Base Stock Questions

- End use requirements?
- Is the base stock made to be coated?
- Are you making or buying?
- Can you specify or must you adapt?

Roll Quality for Off-Machine Coating

- Clean slit edges
- No edge cracks
- Uniform tension - no wrinkles
- No holes
- Splices
  - Minimal number
  - Properly made and marked

Specifying Base Stock Physical Properties

- Basis weight
- Moisture
- Caliper
- Strength
  - Tensile
  - Tear
  - Internal bond
  - Folding endurance
- Porosity
- Smoothness/roughness
- Coefficient of Friction (COF)
- Scoring and bending properties

Specifying Base Stock Optical Properties

- Brightness
- Shade
- Gloss

Paper and Board Testing Strength Properties

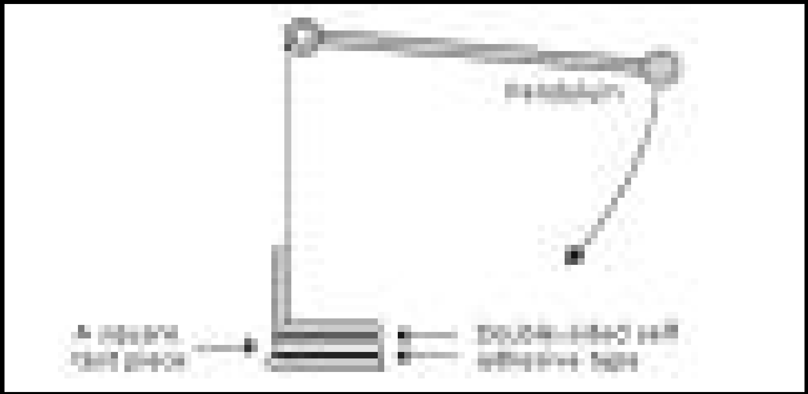
- Folding Endurance
- Scott Bond (Internal Bond)
- Stiffness
  - Bending Resistance of Paper – Gurley Method
  - Stiffness of Paperboard – Taber Method
- Tearing Resistance
- Tensile Strength

Folding Endurance

- Folding endurance is tested using the MIT tester
  - A strip of paper is mounted under tension in the tester
  - The tester rotates back and forth through 270°
  - The number of double folds is reported – either as raw data or $\log_{10}$
- ISO 5626 and TAPPI T 511 are the folding endurance test methods

Scott Internal Bond

- Measures the internal bond strength
- Very critical for offset printing – especially sheet fed offset with high tack inks
- Resistance to fiber picking
- TAPPI T 569



Gurley Stiffness for Paper

- Bending resistance is important for sheet fed offset
- Sample is clamped and used to deflect a pendulum with weight
- Data is reported in Gurley stiffness unit
- TAPPI T 543

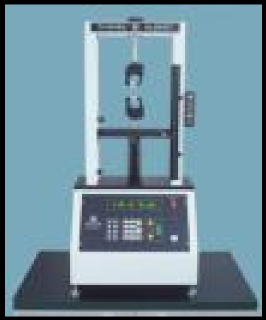
Taber Stiffness for Paperboard

- Determines the bending moment in gram centimeters required to deflect the free end of a 38-mm wide sample 15° from its centerline with a load applied 50 mm away from the clamp
- TAPPI T 489

Elmendorf Tear Tester

- Paper sample is torn through a fixed distance by means of a pendulum
- The work done in tearing is the loss in potential energy of the pendulum
- Data reported in grams force
- TAPPI T 414

Tensile Strength



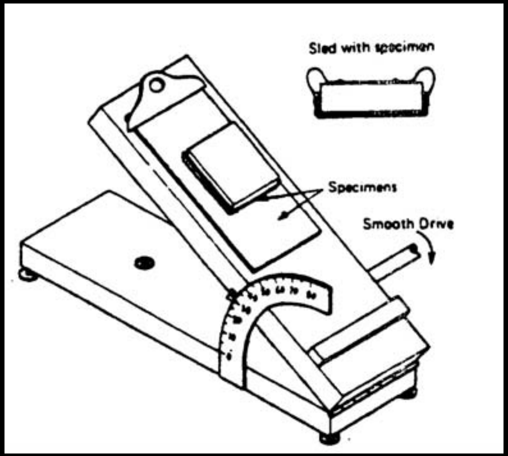
- Tensile strength is the maximum stress developed in a sample before rupture
- Sample is clamped in a tensile tester and force applied to separate the jaws
- Tensile strength is reported in Kn/m
- Breaking length is the calculated limiting length of a hanging strip of paper that would break it
- Tensile Index is tensile strength in N/m divided by grammage
- ISO TC6 and TAPPI T 494

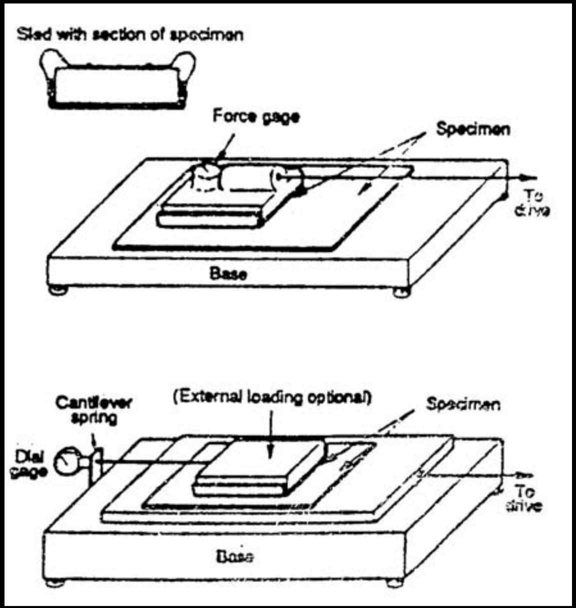
Paper Surface Property Testing

- Coefficient of Friction
- Porosity
  - Air Resistance – Gurley Method
- Roughness
  - Sheffield Method
  - Parker Print Surf Method
- Wax Pick
- Wet Rub

Coefficient of Friction

- Static Coefficient of Friction by slide angle
  - Slide angle correlates to COF
  - TAPPI T 548
- Static and Kinetic COF by horizontal plane
  - Calculate COF by forces required to move
  - TAPPI T 549





Air Permeability – Gurley Test

- Gurley tester consists of an outer cylinder partially filled with liquid and an inner cylinder with a 6.4 cm^2 orifice and clamp
- Paper sample is mounted in the clamp and the inner cylinder released to force air through the sheet
- Time required for 100 ml of air to pass through the paper is recorded as Gurley seconds density
- TAPPI T 460

Sheffield Smoothness/Roughness

- Measures air flow between the sample – backed by a smooth glass – and two pressurized, concentric annular rings impressed into the sample from the top side
- Lower number means smoother paper
- Reported in Sheffield units
- TAPPI T 538

Parker Print Surf Roughness

- More precise air leak measurement
- Clamping pressure can be varied
  - 10 Kg is standard

- Annulus is 0.051 mm
- Air flow gives an indication of surface roughness is reported as µm with pressure, e.g. PPS_{10} = 1.2 µm
- Developed for gravure but widely used for many types of paper and paperboard

Wax Pick Test

- Measures surface strength
- Calibrated sealing waxes with increasing adhesive power are pulled from the paper surface
- Highest number that does not tear fibers from the surface is recorded
- TAPPI T 459

Wet Rub Test – Adams Wet Rub

- Measures the resistance of the paper surface to wet abrasive action
- Key test for offset papers
- Sample is mounted on wheel and rubbed with wet roll

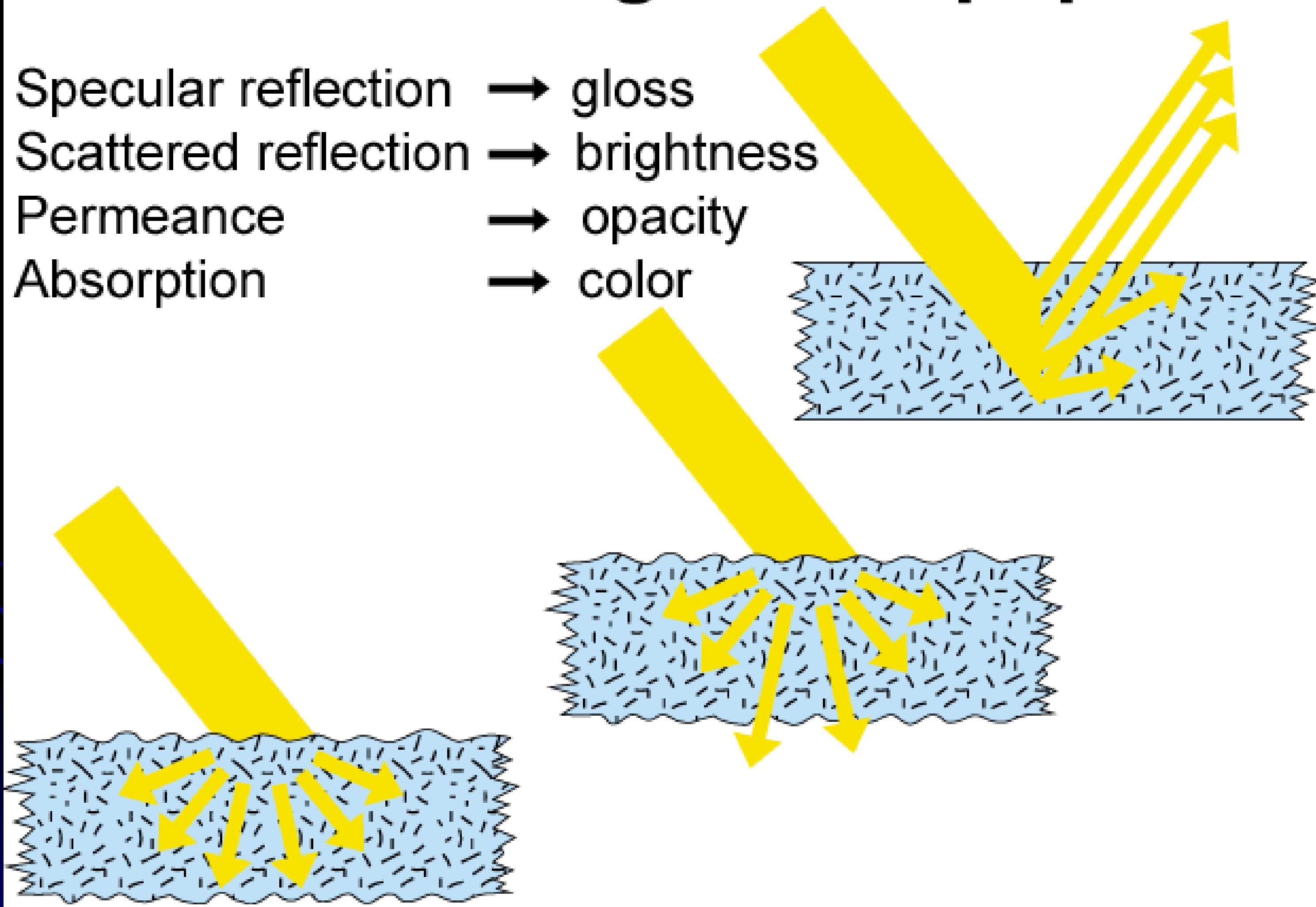
- Material abraded form surface is washed into bottle with water
- Turbidity of water correlates to material rubbed off and is reported as wet rub value

Paper Testing
Optical Properties

- Brightness
- Whiteness
- Color
- Dirt Count
- Fading
- Fluorescence
- Gloss
- Opacity

Contact of light and paper

Specular reflection → gloss
Scattered reflection → brightness
Permeance → opacity
Absorption → color



Brightness

- Brightness is percentage reflectance of light at wavelength 457 nm
- ISO and TAPPI (GE Brightness) methods differ
- TAPPI T 452 measures through a 457-nm filter and is based on magnesium oxide being 100%
- ISO2469/2470 measures over a range of wavelengths
- TAPPI (GE) brightness values are usually a point or two lower than ISO brightness values

Brightness With and Without UV Fluorescence

- Brightness is measured with and without a UV filter to determine fluorescence and the effect of optical brighteners
- Modern brightness testers are all equipped with UV filters and also measure color in terms of L,a,b values and also measure whiteness

Color

TAPPI Test Methods for color are T 442, T 524 and T 527

Whiteness

- Whiteness is measure of reflectance at all visible wavelengths of light
- Measurements are made using a standard D65 light source to get color coordinates
  - UV component of the D65 source is controlled to adjust for effect of fluorescent dyes
- Calculation of whiteness is based on these measurements
- ISO 11475:2004 is used for papers without OBA
- ISO 2469 is used for papers made with OBA

Gloss

- Gloss describes the mirror-like property of coated paper
- Gloss is defined as the percentage reflectance at an angle equal to the angle of incidence compared with a standard surface
- TAPPI T 480 measures at 75° and is the standard test
- TAPPI T 653 measures at 20° and is commonly referred to as "Low Angle Gloss"

Opacity

- Opacity is a measure of the amount of light transmitted through paper
- 100% opacity means no transmitted light
- Measurement is made by comparing the reflectance of a single sheet over a black background to an opaque stack of sheets
- Opacity test methods are ISO 2471 and TAPPI T 425

Where Grades Are Produced

Regional % of U. S. Production

Grade	South	NE/NC	West
Uncoated Free	65	26	9
Coated Paper	23	73	4
Coated SBS	95	0	5
Coated SUS	100	0	0
Kraft Linerboard	83	0	17

U. S. Pulpwood Fiber Characteristics

Species	Specific Gravity	Fiber Dimensions Length mm	Diameter µm	Wall Thickness µm
Loblolly P.	0.47	3.5-4.5	35-45	4-11
Doug. Fir	0.43	3.5-4.5	35-45	3-8
W. Hemlock	0.38	2.5-4.2	30-40	2-5
Spruce	0.37	2.5-4.2	25.-35	2-3
White Oak	0.59	1.4	14-22	5
Sweet Gum	0.44	1.7	20-40	8
Birch	0.48	08.-2.7	20-36	2-3
Aspen	0.35	0.4-1.9	10-27	2-3

Properties of Kraft Pulps by Species

Species	Coarseness µg/m	Tensile Index N·m/g	Maximum Tear Index mN·m²/g
Spruce	140	135	20
W. Hemlock	190	120	18
Doug. Fir	264	90	30
Southern Pine	280	85	28
Oak	143	67	11
Gum	266	96	13
Birch	116	101	10
Aspen	129	103	8

Structural Properties by Species

Species	Maximum Bulk cm^3/g	Elastic Modulus kN·m/g	Edgewise Compr. Index N·m/g
Spruce	1.7	8.1-9.0	40-43
W. Hemlock	2.0	8.2	37-41
Doug. Fir	2.1	6.5-8.5	31-33
Southern Pine	2.1	8.7	36
Oak	2.4	6.4	28
Gum	1.8	8.6	30-40
Birch	1.5	6.1	36.5
Aspen	1.5		43

Bending Stiffness

$$S = kEc^3$$

Where:

S = Stiffness

E = Young's modulus of elasticity

c = Caliper

Paper Surface Properties

- Surface pore structure is important to get extrudate adhesion
- Overall structure performance is importance
  - Resistance to penetration by liquid or gas
- Measures that tighten the base sheet structure can adversely affect adhesion
- May require a pretreatment

Recycled Fiber Base Stock Potential Problems and Concerns

- Dirt
- Blade scratches and streaks
- Shade variation
- Spots and shiners
- “Bloom up” of stickies under infrared dryers
- Brightness reversion and/or yellowing
- Strength loss

Papermaking Additives

- Most extrusion coated grades are used for packaging – requiring strength
- Fillers are not commonly used
- Measures to improve sheet density
  - Refining to increase density
  - Surface sizing
- Internal sizing
- Calender sizing on paperboard

Wet End Additives/Chemistry Base Stock for Extrusion Coating

- Fillers seldom used
- Starch or strength additives
- Retention aids
- “Cycle-up” potential with recycled fiber, especially in tightly closed systems
- Internal sizing
- Wet strength

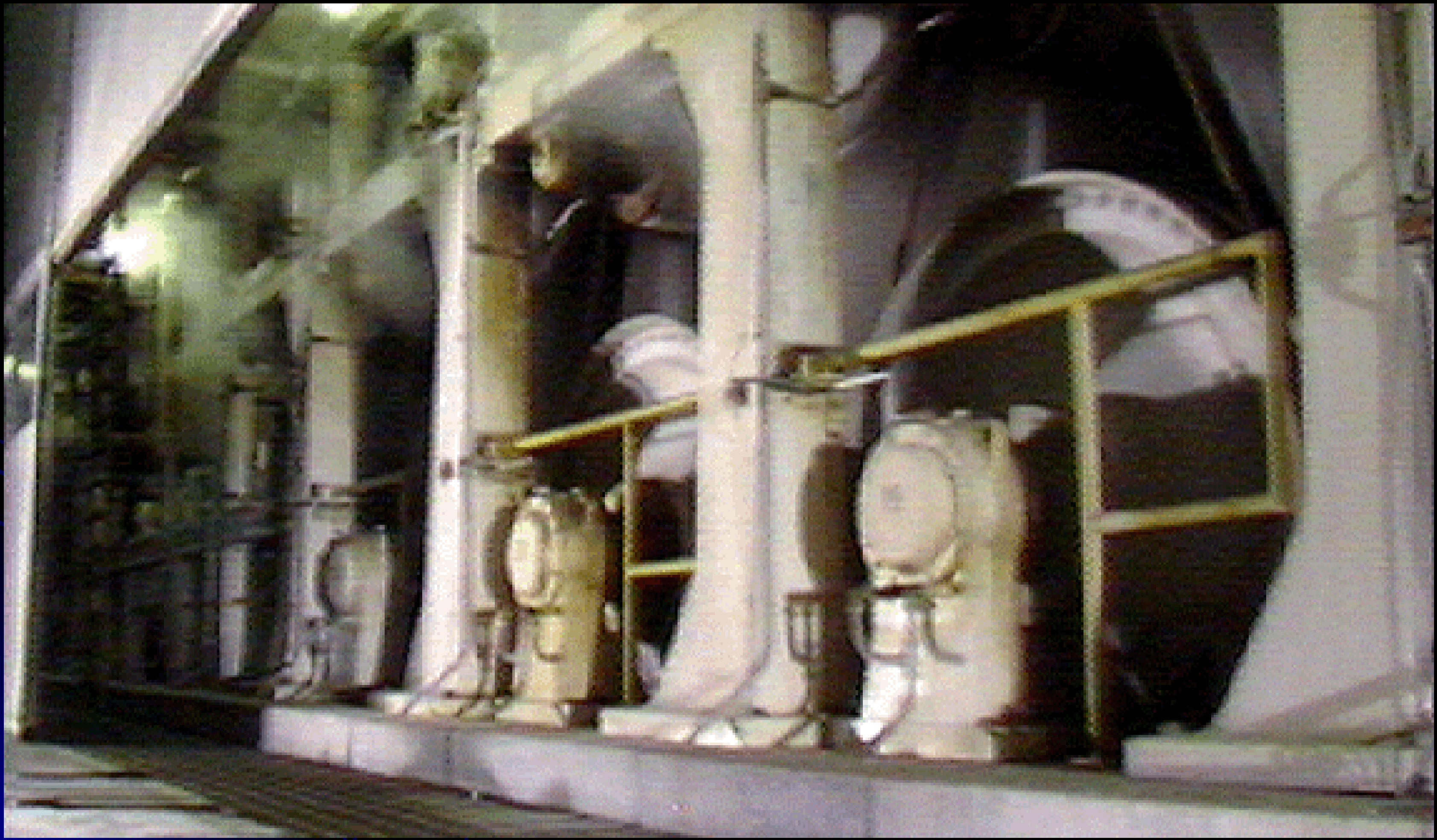
Wet End Operations
Base Stock for Extrusion Coating

- CD profile - **from the headbox or former**
- Formation and microcontour
- Fourdrinier board
  - Dandy roll
  - Top former
- Cylinder board
  - Uniflow top liner vat

Pressing

- Minimize open draws for paper
- Effect on bulk and stiffness
- Double sided dewatering for paper
- Flow controlled nip
- Split top felt on cylinder machines
- Felts - stratified batt
- Felt conditioning

Paper Structure



Drying

- Slalom felt run desirable, especially for paper
- Conventional cylinders

  - Warm up dryer temperatures

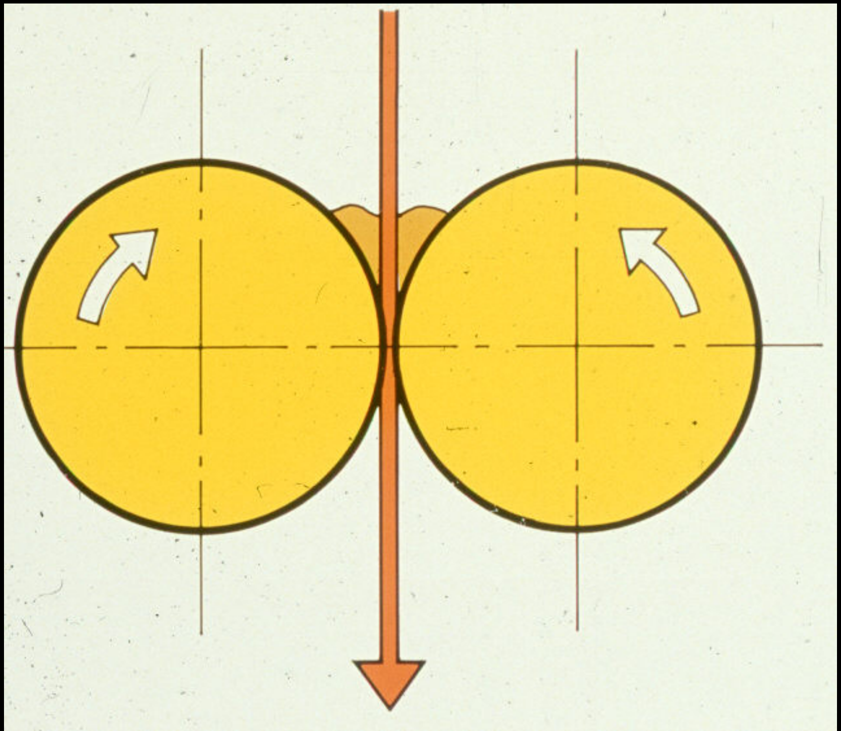
  - Picking/fiber lifting - streaks
- Yankee dryers

  - Machine glazed surface
- Breaker stacks - bulk loss

Surface Sizing Chemicals

- Starch
- Film formers other than starch
  - CMC
  - Polyvinyl alcohol
  - Alginate
- Other specialty surface sizes
- Pigments
- Latex and other binders

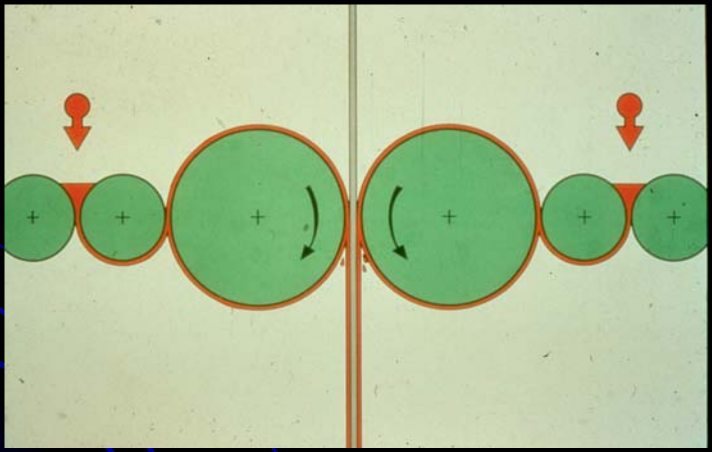
Size Press



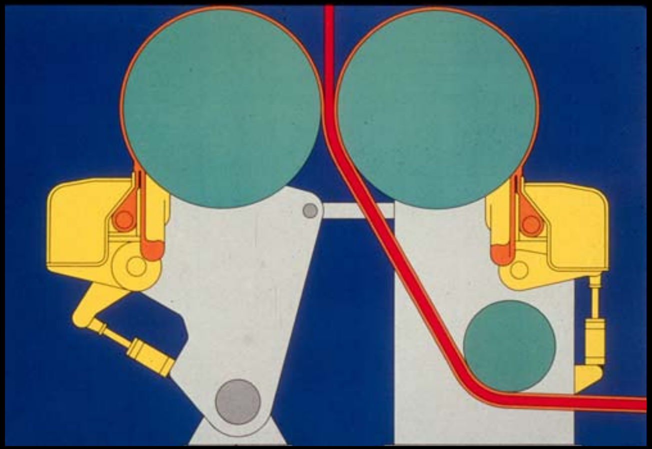
Simultaneous application, metering and distribution

Transfer Roll Coaters

- Premeter and distribute - then apply
- Similar to a printing press

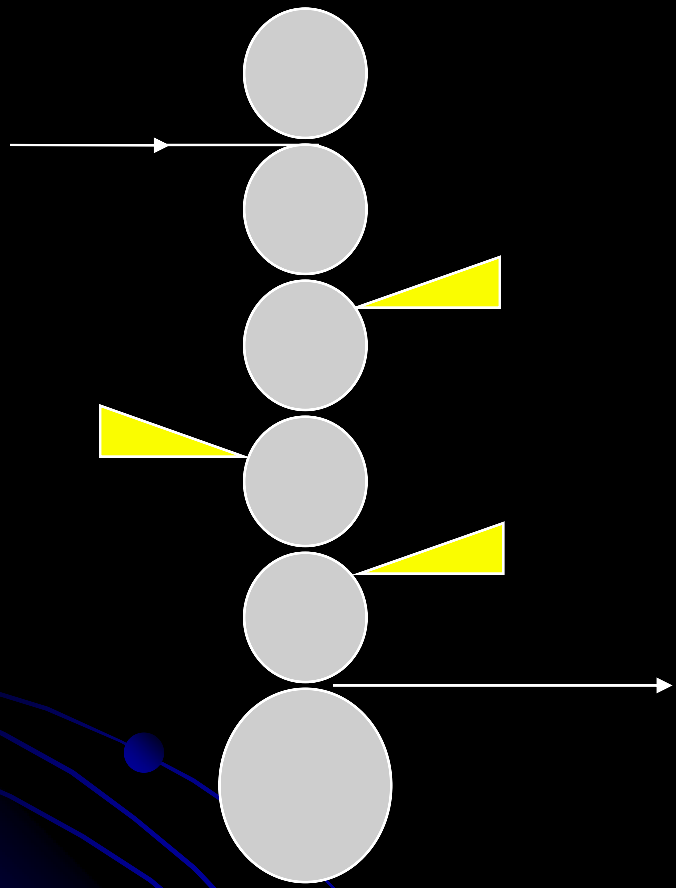


Gate Roll Coater



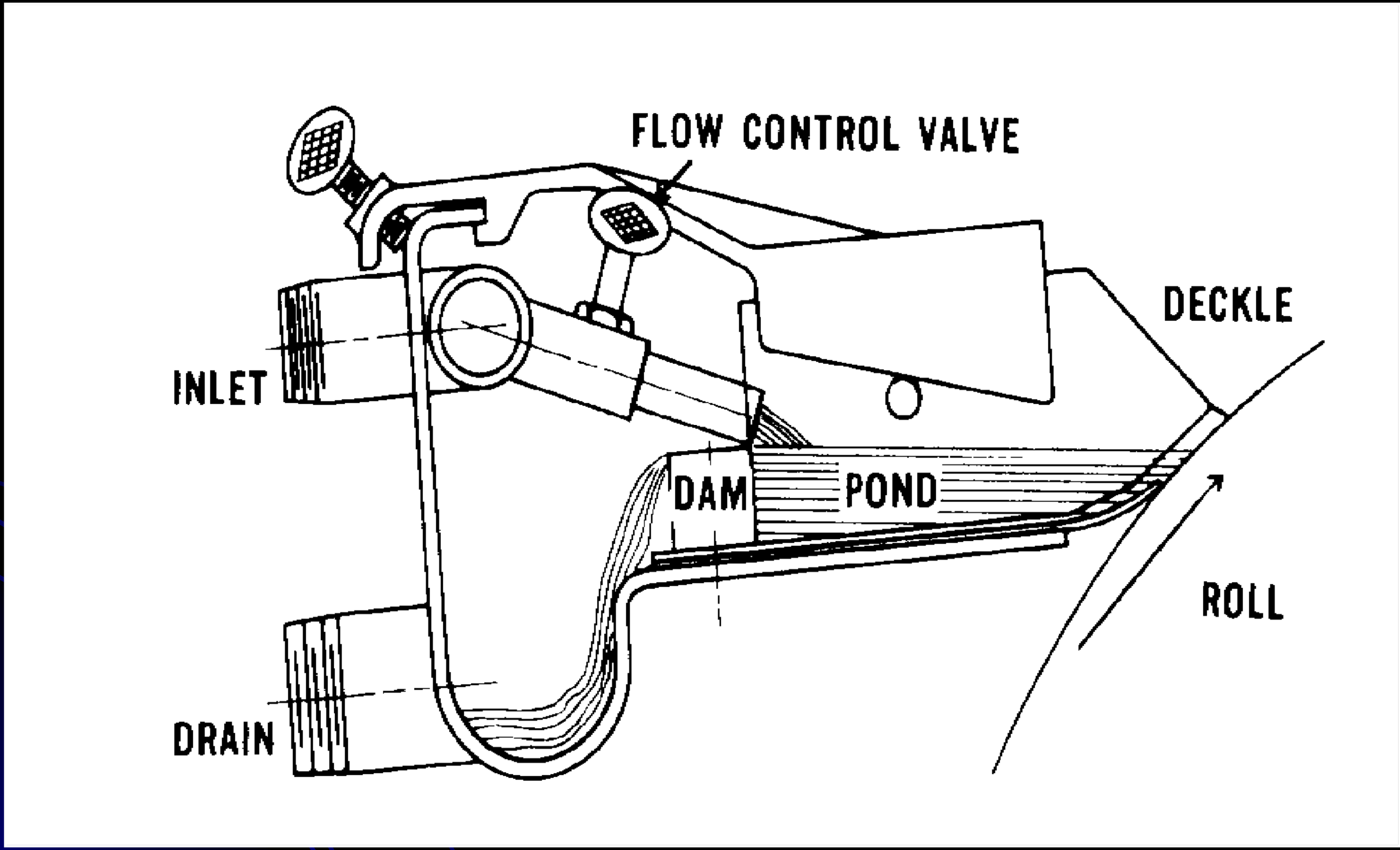
Metering Size Press

Calender Sizing



- Pickup dependent on moisture profile
- Crushes and compacts sheet
- Reduces bulk and stiffness

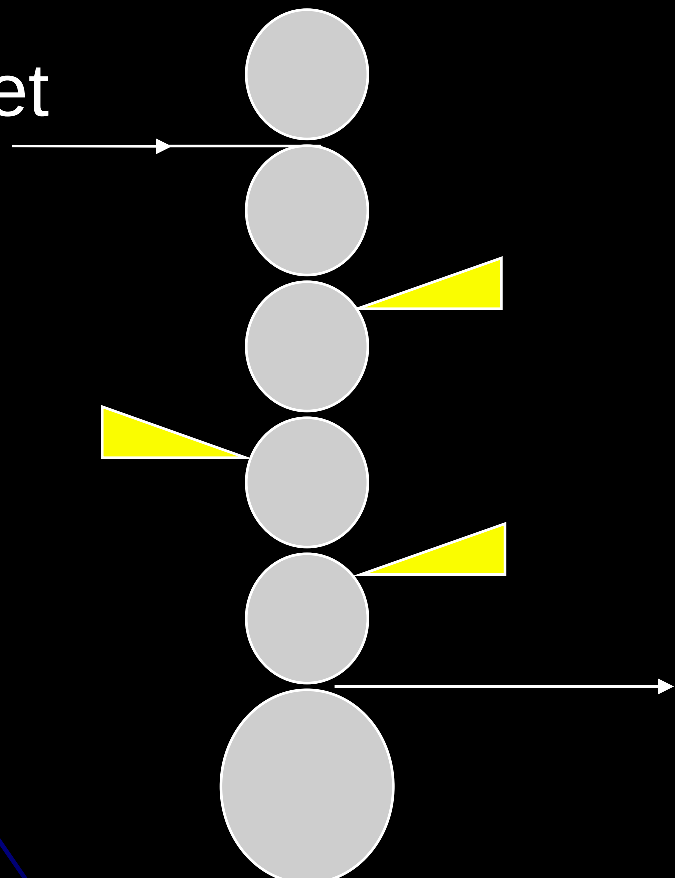
Calender Box



Calender Sizing Pickup Variables

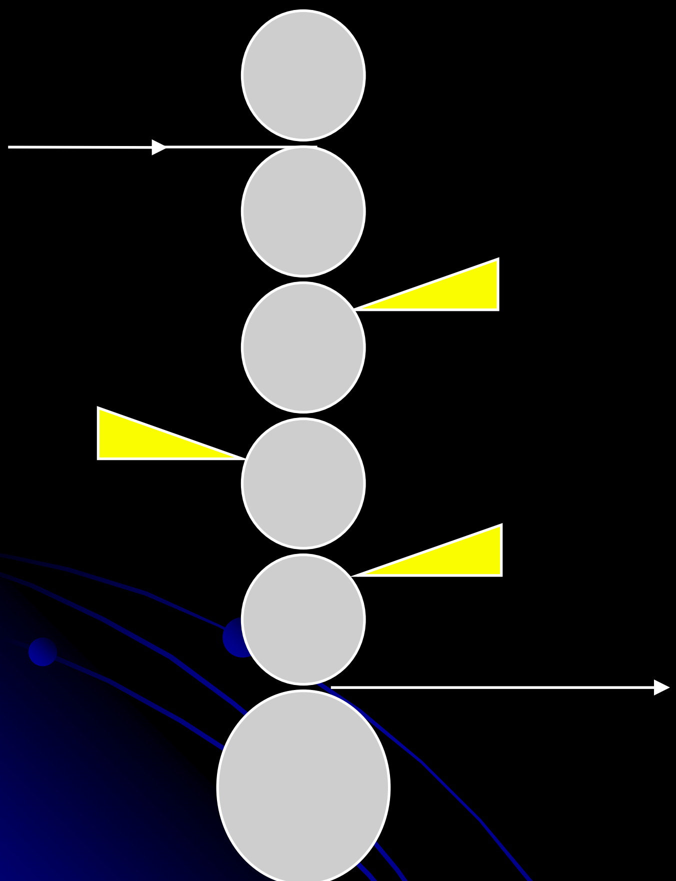
Incoming Sheet

- Moisture
- Sizing
- Roughness
- Formation
- Porosity



- Speed
- Loading
- Material applied
  - Viscosity
  - Solids
  - Temperature

Troubleshooting Calender Sizing

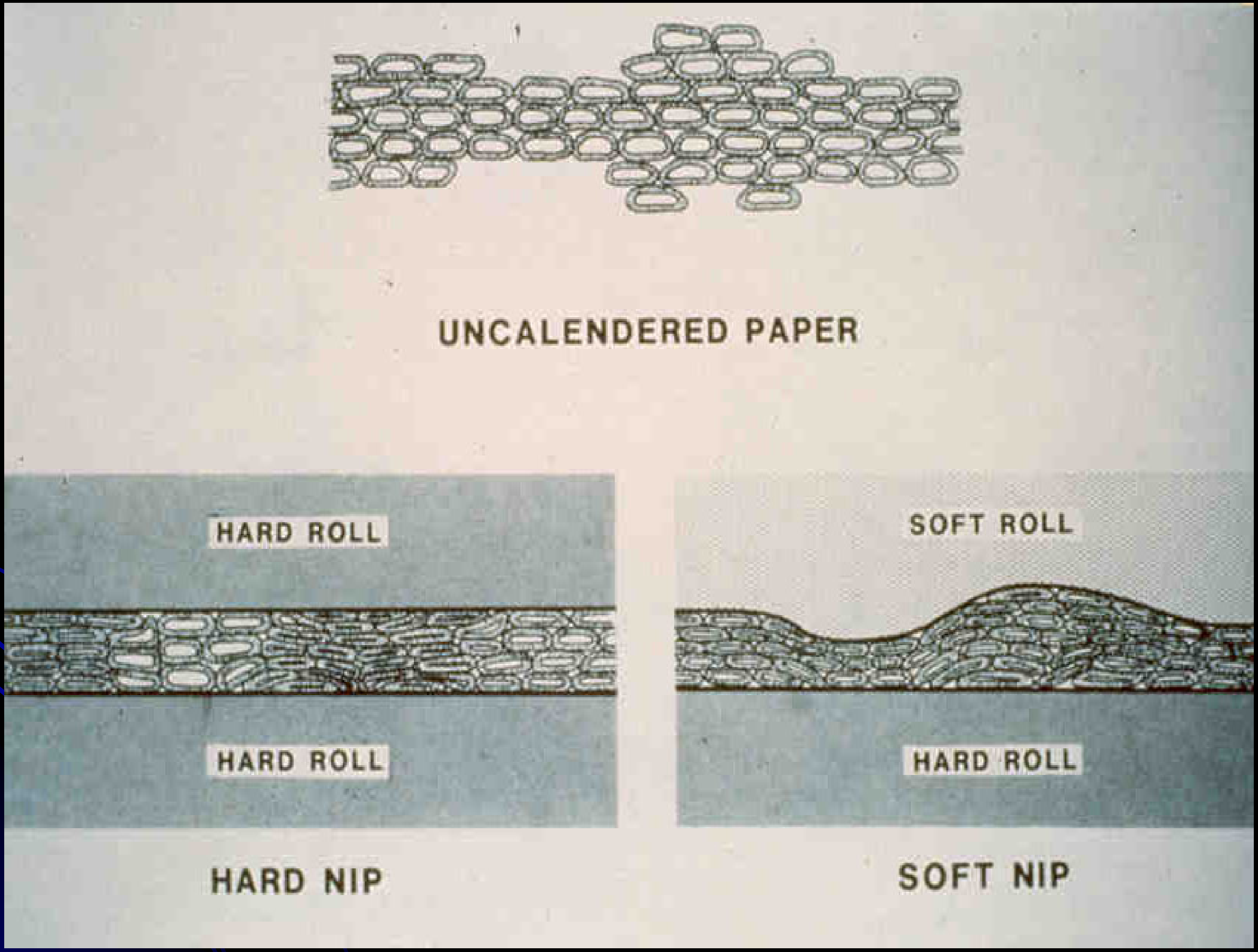


Foam	Non-uniform application
Too tight film	Gluability problem
Excessive ZDT	No fiber tear
Soft binder	Back side picking

Calendering Techniques

- Hard nip gives uniform caliper but can cause localized density variations and mottle
- Soft nip gives uniform density
- Both improve smoothness

Effects of Hard vs. Soft Nip Calendering



Paper and Board Coating For Extrusion Coating Base Stock

- Open coating structure is desirable to promote extrudate adhesion
- Coating pigments
  - Calcium carbonate
  - High aspect ratio clay
- Coating binders
  - Latex
    - Acrylics and acetates
    - Biopolymer nanoparticle latex
  - Soy protein polymer

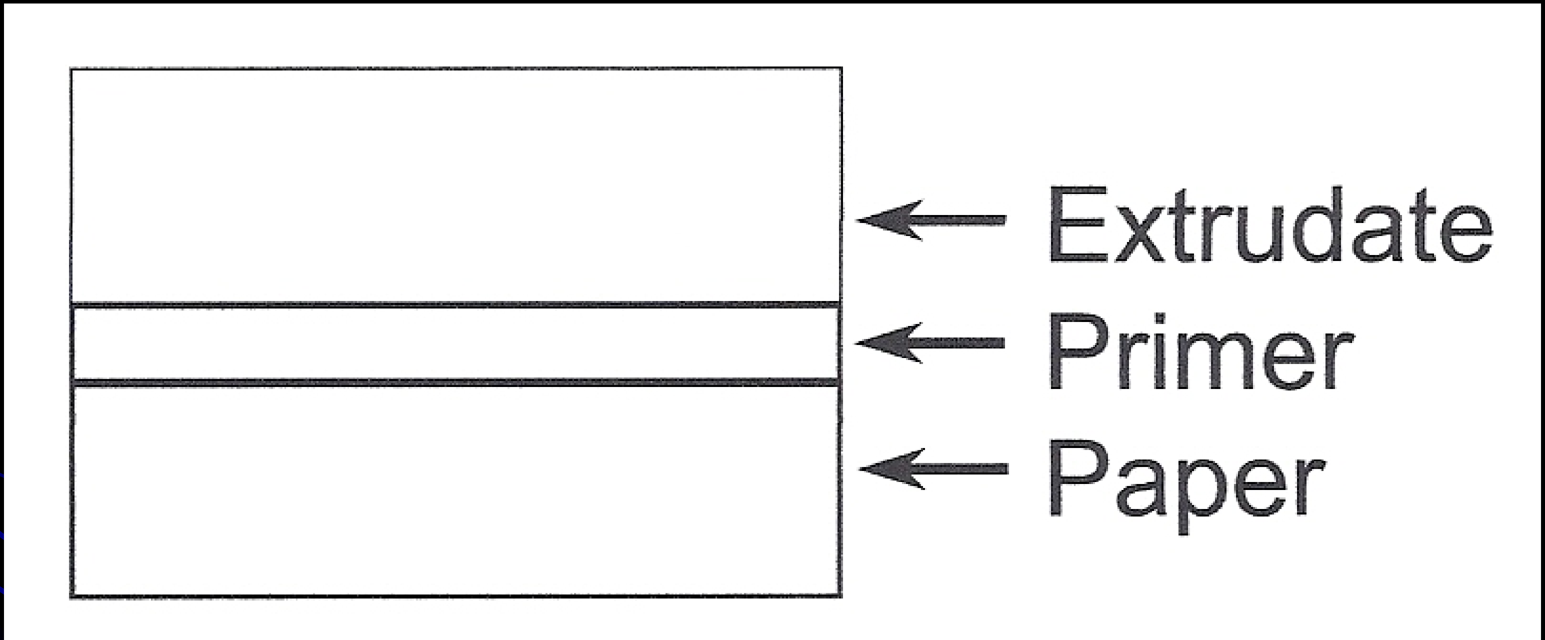
Promoting Adhesion and Developing Chemical Resistance

- Oxidation of the substrate
  - Corona treatment
  - Flame treatment
- Chemical primer
  - Surface modifier
    - increases energy
    - adds reactive sites
  - Facilitates extrudate wet out

Treatment vs. Wetability

- Treatment
  - Oxidizes the surface
    - makes chemical sites for bonding
  - Burns off contaminants
  - Improves wet out of the primer
- Wetability
  - Improving wetability in terms of contact angle doesn't always provide adequate adhesion

Primer on Paper Base Stock



Chemical Primers

- Surface modifier
  - increases energy
  - adds reactive sites
- Facilitates extrudate wet out
- Provides adhesion between substrate and extrudate
- Contributes to the chemical resistance of a structure

Primers for Paper

- Ethylene Acrylic Acid
- Crosslinked Polyethylenimine
- Vinyl Acetate/Ethylene
- Polyester
- Amine
  - Melamine
  - Others

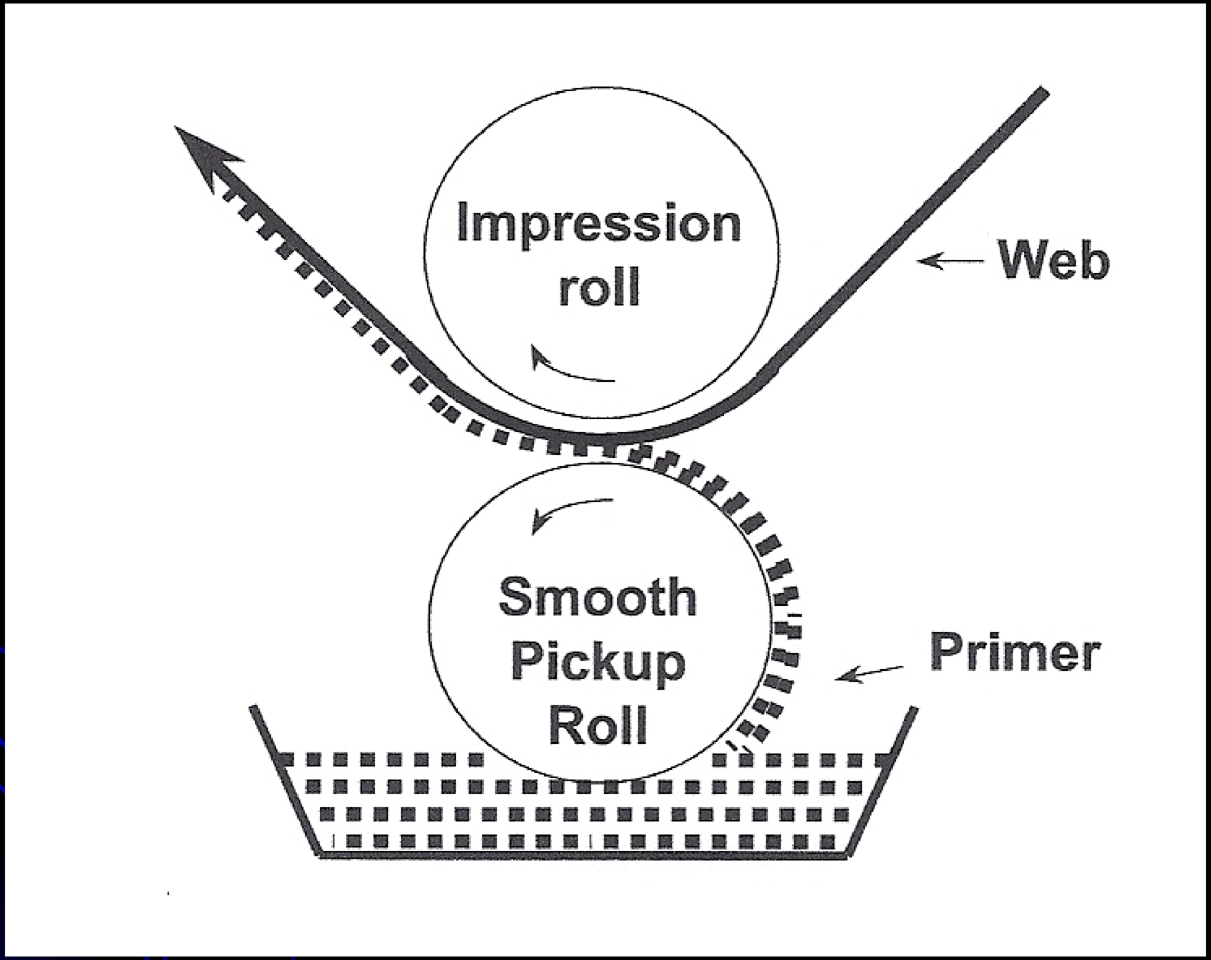
Pigments in Primer

- Addition of pigment to the primer can improve performance and reduce cost
- Kaolin clay pigments
  - High aspect ratio clay opens pore structure
- Calcium carbonate
  - Ground calcium carbonate
  - Precipitated calcium carbonate - aragonite

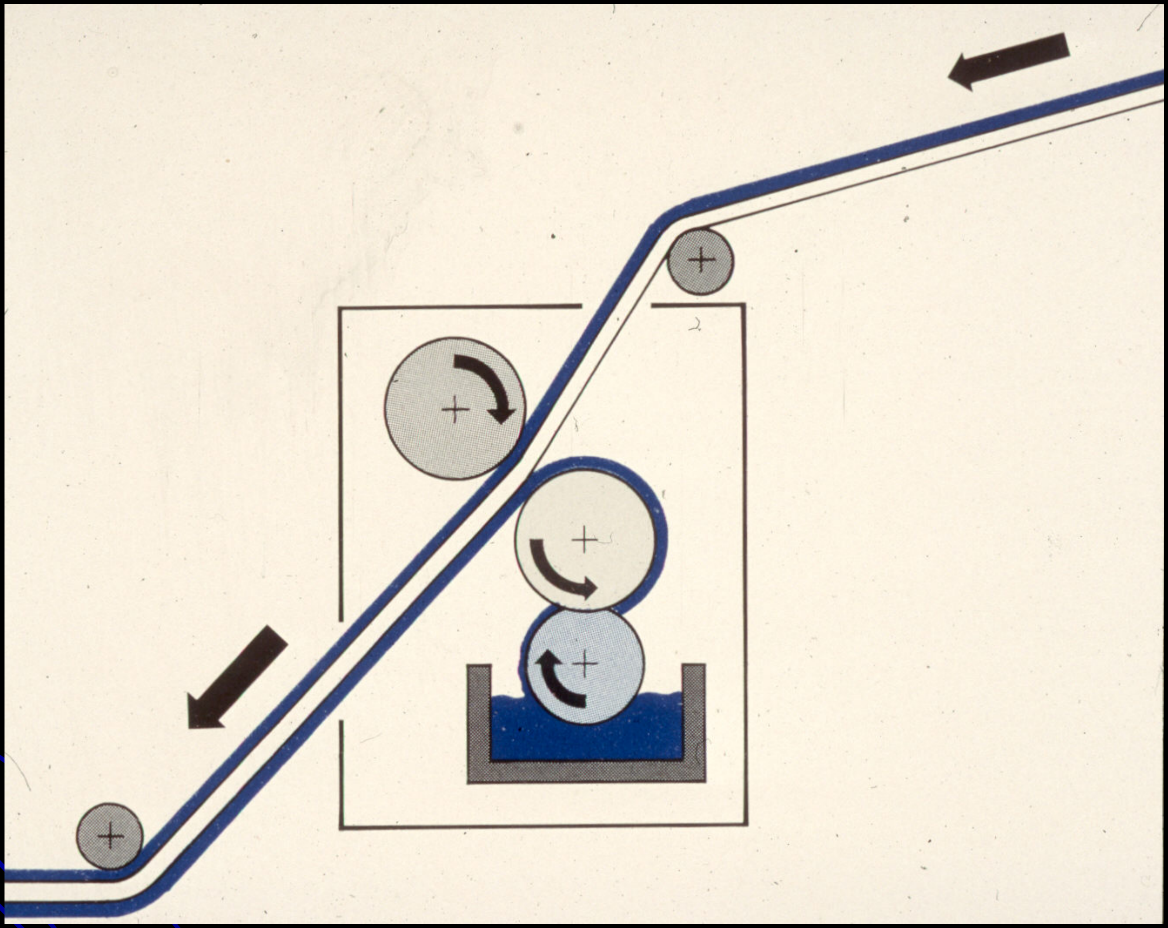
Primer Application Methods

- Gravure, Direct/Reverse
- Offset Gravure, Direct/Reverse
- Flexographic
- Smooth Transfer Roll, Direct/Reverse
- Wire Wound or Grooved Rod Coater

Smooth Roll Applicator

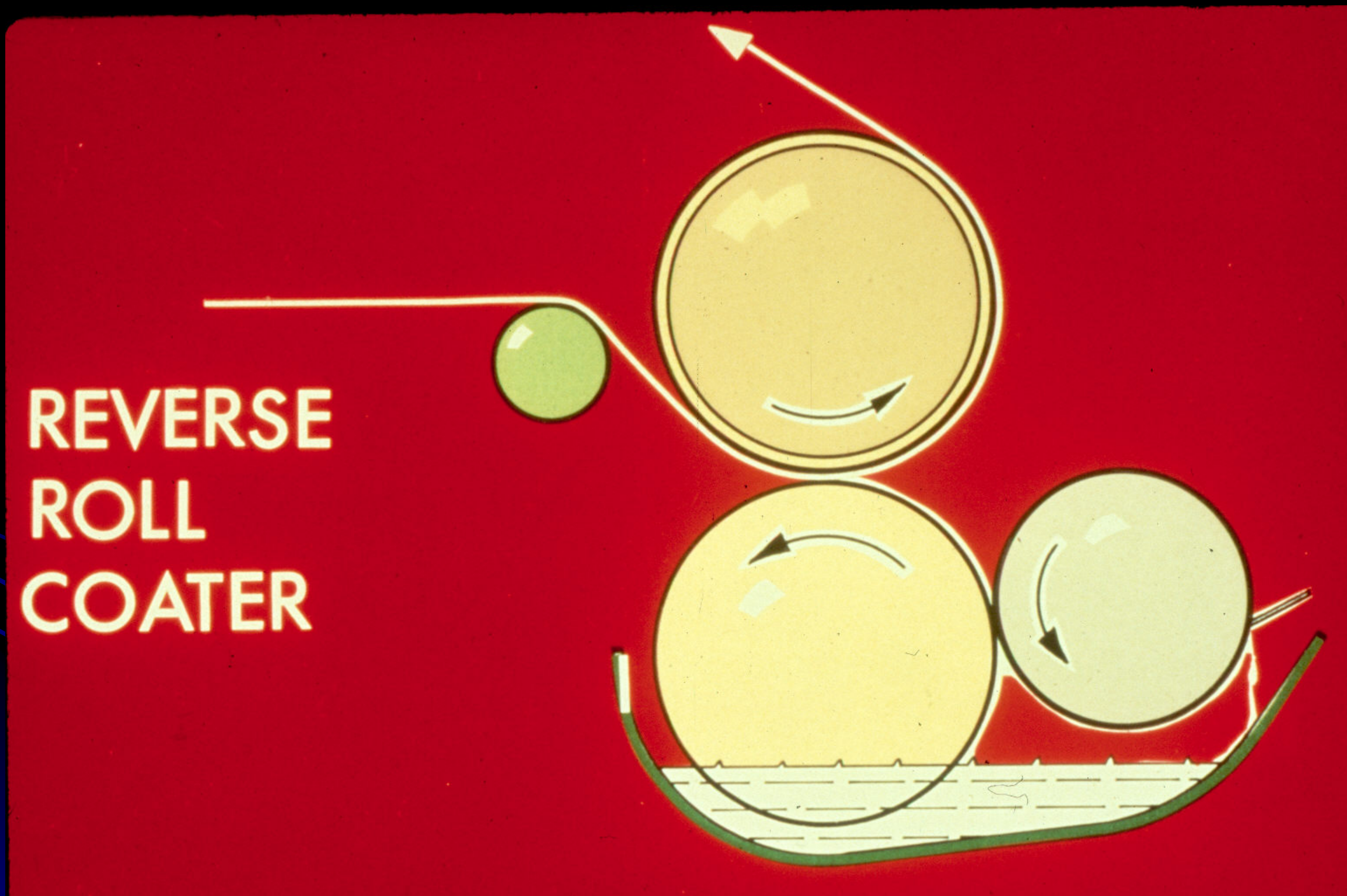


Transfer Roll Coaters

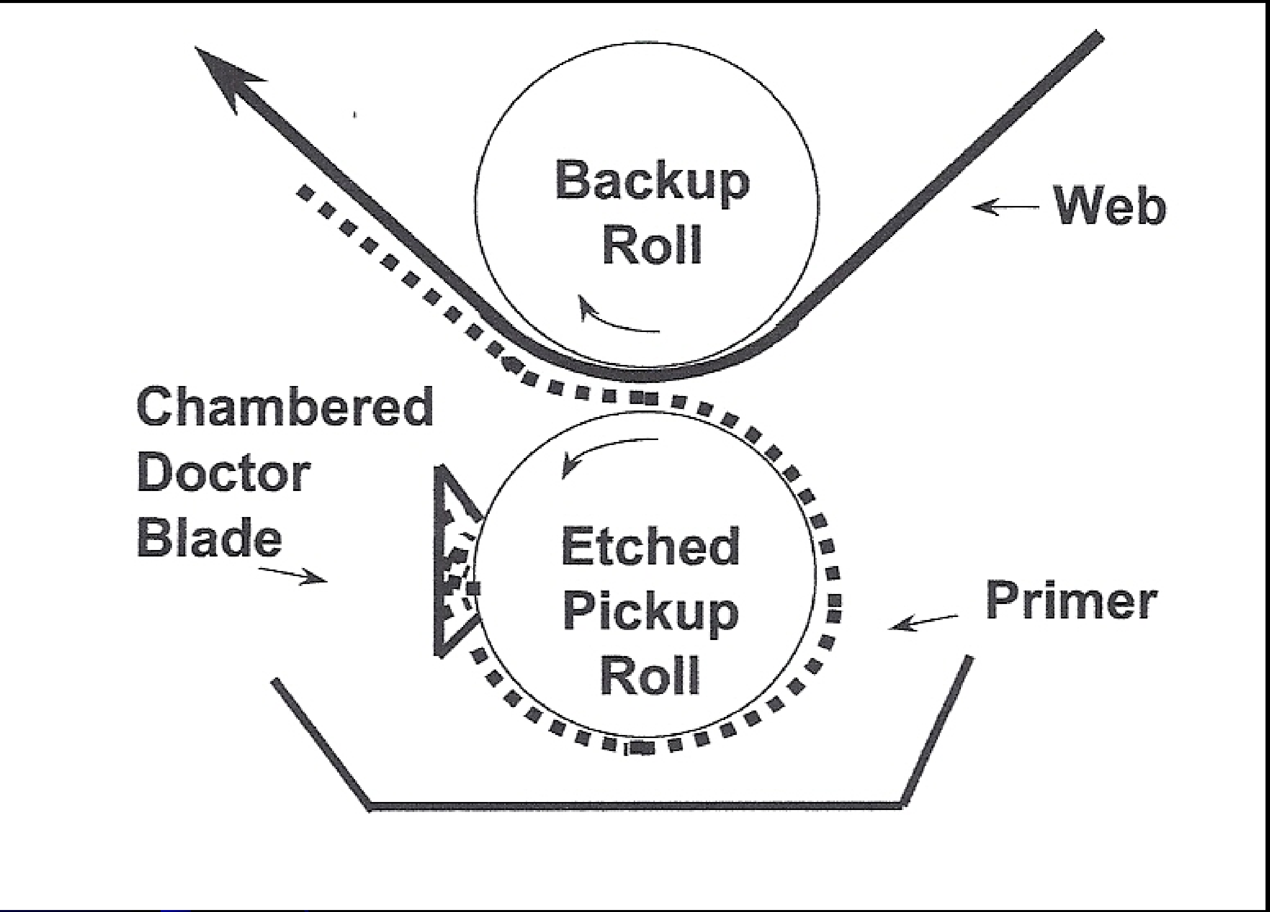


Hydrophilic Transfer Roll Coater - LAS

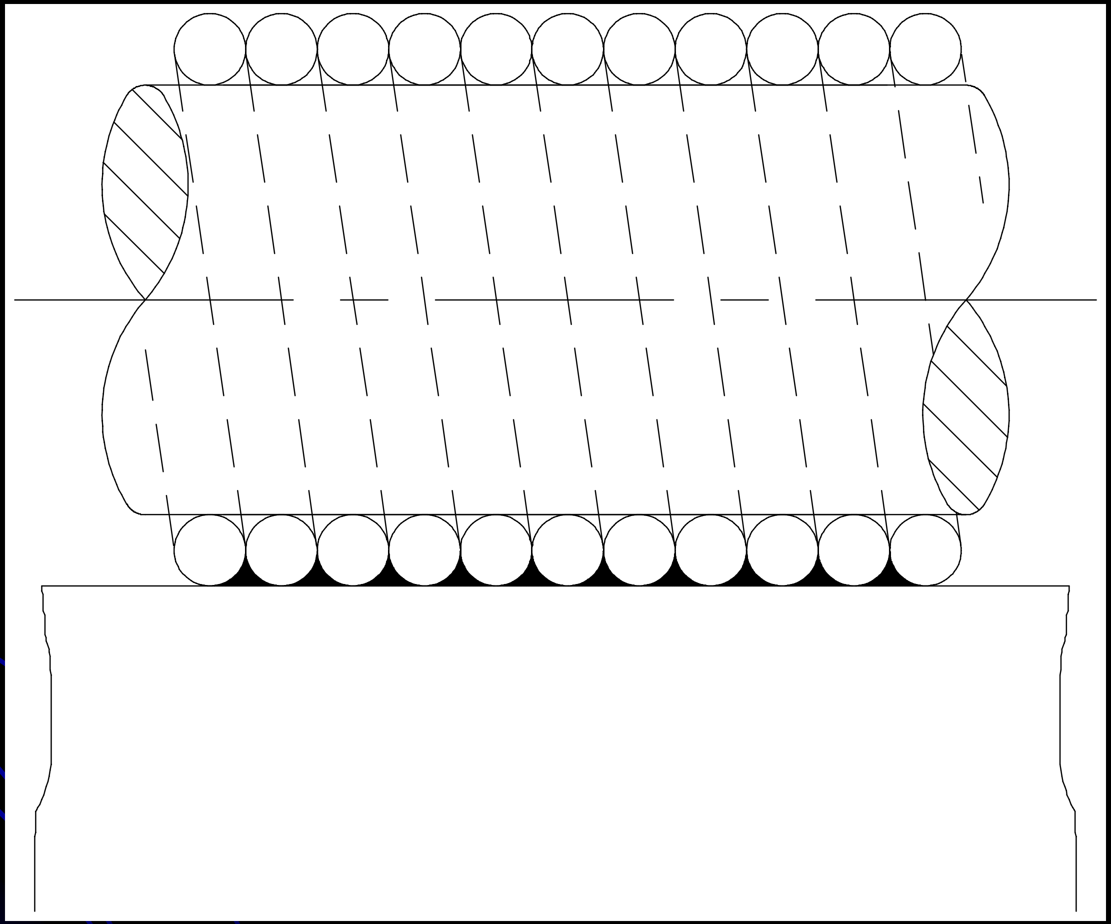
Transfer Roll Coaters



Gravure Applicator
With Enclosed Doctor Blade



WIRE WOUND ROD



WIRE WOUND ROD COATER

- **Applies excess of coating to the web with an applicator roll**
- **“Deckles” wipe the coating off the roll at the edges.**
- **The substrate can be run with a dry edge for cleanliness.**

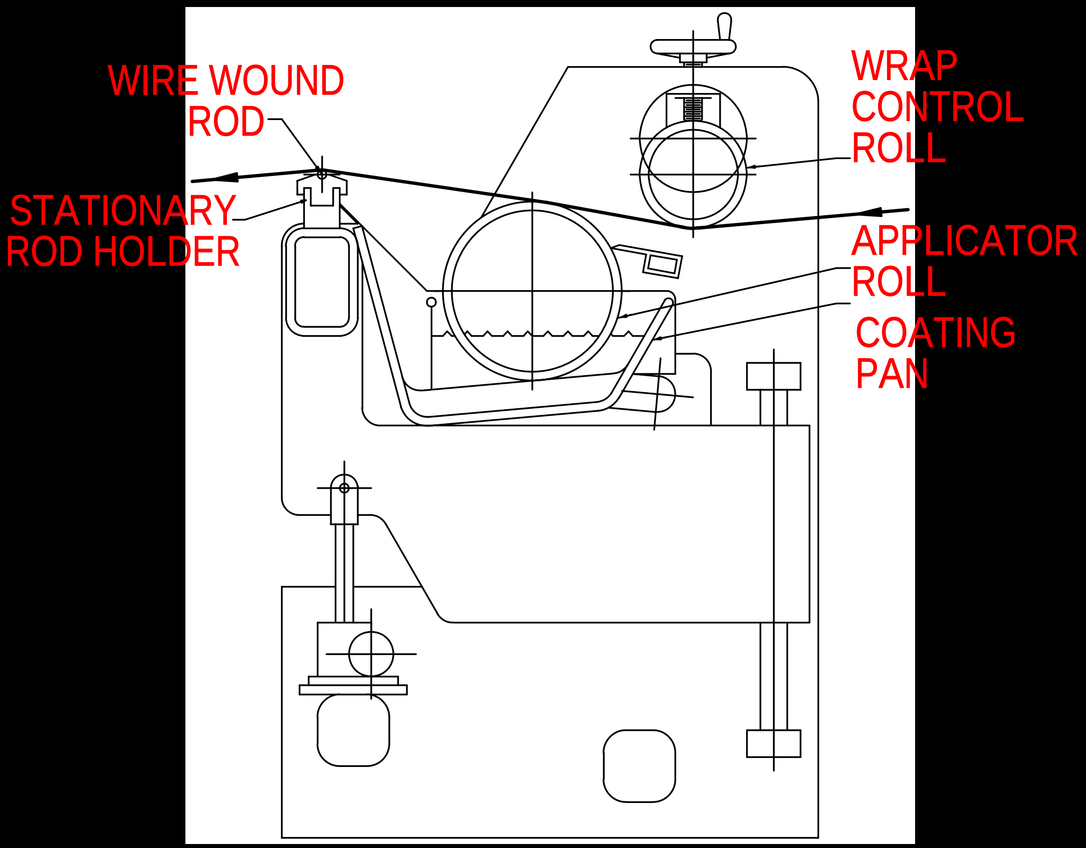


Figure 1

LOW SPEED AIR LOADED ROD COATER

The main difference between the coaters shown in Figure 1 and 2 occurs after the web leaves the applicator roll. Air-loaded rod coaters support the web with a backing roll.

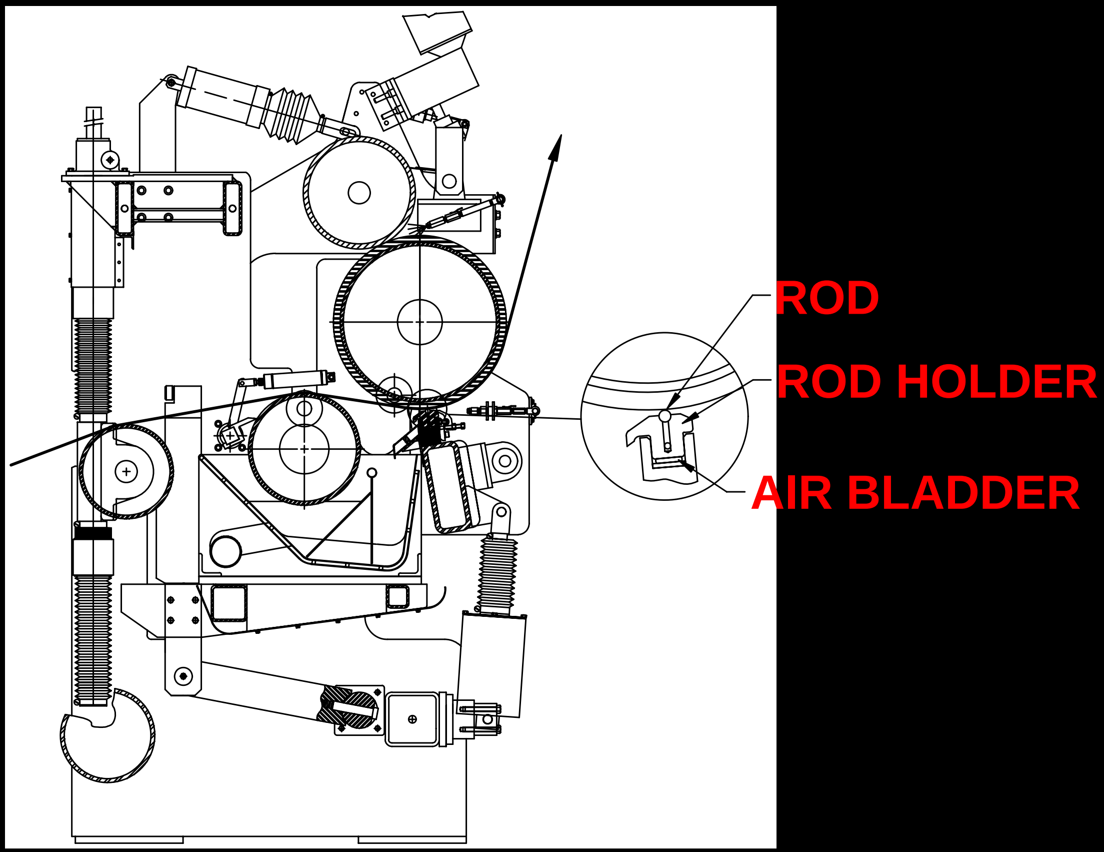
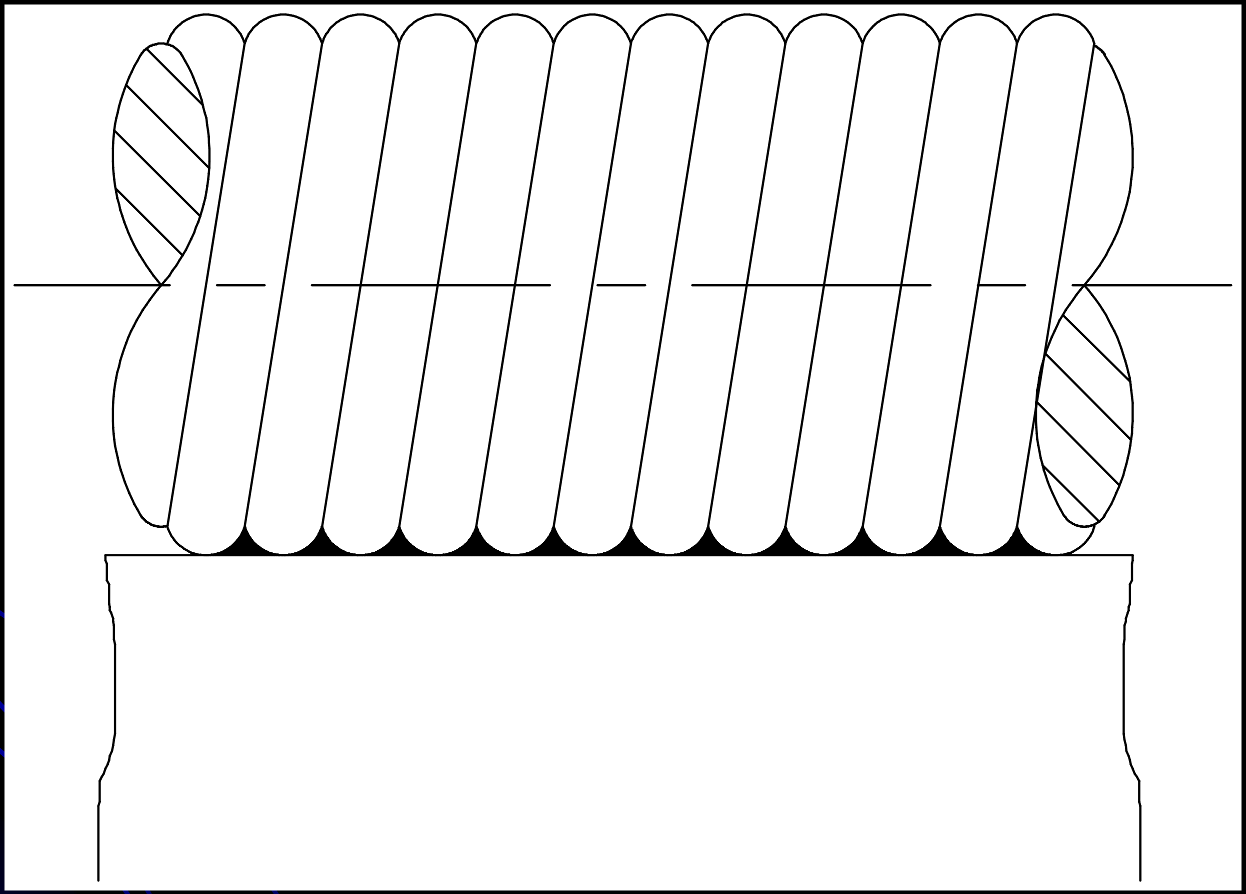


Figure 2

GROOVED ROD



Trends and Developments

- Sustainability focus
  - Wal-Mart packaging scorecard
- Desire for paper-based packaging to be:
  - Recyclable
  - Biodegradable
- “Plastic Coated” paper and board considered problematic
- New biodegradable resins
  - PLA

Recyclability of Extrusion Coated Paper and Paperboard

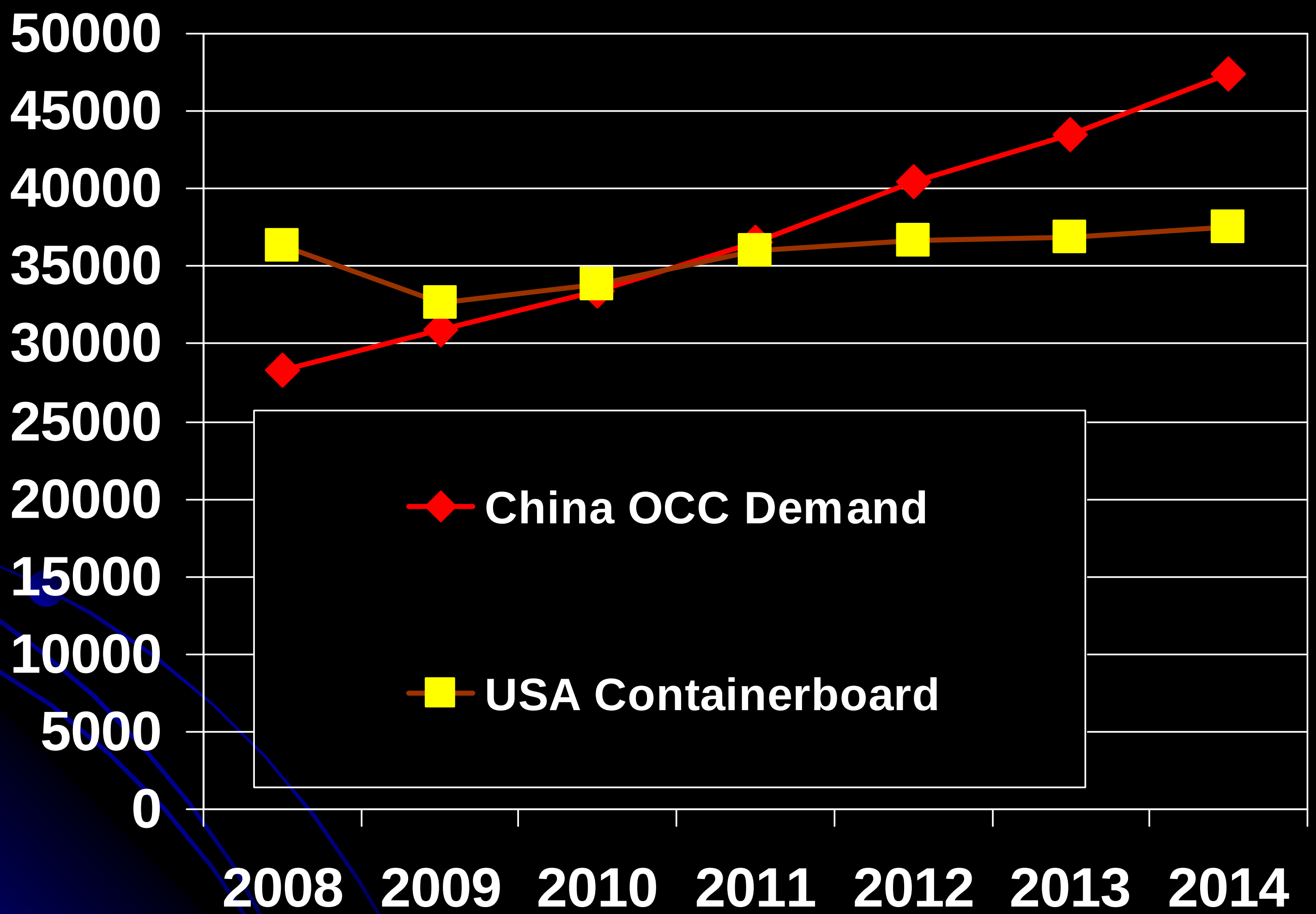
- Dedicated de-poly systems have been used for decades
- Work is progressing toward processing extrusion coated paper products in OCC and tissue systems
- Global Green Initiatives
  - Starbucks cup program
  - CORR – Coalition for Resource Recovery

Recyclability of Extrusion Coated Paper and Paperboard

- Not just driven by environmental groups
- OCC supply crisis
- Chinese mills have state-of-the-art systems and can handle single side extrusion coated waste paper

OCC Shortage Due to Increased Chinese Demand

Thousand of Metric Tons



Data from RISI 15 Year Forecasts

Potential New Sources of Secondary Fiber

Potential Fiber Source	2007 Discarded Tons*
Paper Plates and Cups	1,310,000
Folding Cartons	4,020,000
Bags and Sacks	720,000
Total	6,050,000

* According to the EPA Municipal Solid Waste Report

Alternatives to Extrusion Coating

- Recyclable barrier coatings
- Gaining market acceptance – but progress is slow
- Initial successes are in replacement of waxed corrugated
  - Would add ~1.5 million tons/year of OCC
- Development of aqueous dispersions of
  - Olefins
  - PLA

Outlook

- Major consumer goods marketers have active programs to replace plastic packaging with biodegradable or recyclable paper based packaging
- Progress will be slow
- Extrusion coating is not likely to be replaced in the short or medium term
- Continued research on recyclable extrusion coating materials

Thank you for your attention!