

Higher National Certificate
In
Technology and Management
of Paper and Board making.

SURFACE MODIFICATION

The surfaces of Paper and Board are modified to improve either the aesthetic, or the functional properties of the sheet. Since the move away from acid sizing, there have been considerable changes in the industry. This module charts the changes in chemistry, equipment, and marketing strategies.

This section of the Surface Modification Module discusses:-

- A brief history of the development of alkaline Papermaking
- The influence of the base sheet and raw materials on coating
- Coating formulations and grades
- Equipment

INTRODUCTION

Surfaces of paper and board are modified either to increase uniformity, or to provide barrier properties.

Uniformity improvements include, surface smoothness, porosity, colour, and absorbency. Barrier coatings include resistance against moisture, grease, and oil.

The so-called aesthetic improvements are actually driven by the advertising companies, who want a better surface to print on. The surface of paper is relatively rough, and any processing, or additive used, subsequent to the formation of the sheet, is there to make up for the deficiency of the process before it, and in turn introduces its own weaknesses.

This is particularly true for pigment coating.

No matter how well calendared a sheet of paper is, it is too rough for the advertisers taste, and so to make up for this deficiency, we add pigment. Unfortunately the pigments have no particular affinity for the fibre web, and so we need to add a binder. Some binders do not have the right rheological characteristics, and so we need to add a co-binder. Most co-binders, and some binders, are water sensitive, which would cause problems when going through the printing process, were it not for the addition of insolubilisers. Then of course, some coatings are not bright enough, and so OBA's are added. And since there is so much digestible organic material around, there is an obvious need for biocides.

Up until the late 60's early 70's calcium carbonate was excluded from pigment coating because of the acid nature of the base sheet. That fact, and the difference in mineral distributions between the America's and Europe has led initially to significant differences in paper grades. However, with the constant drive to export, and the consequent need to mimic the competitors grades, this gap is becoming less clear.

THE DEVELOPMENT OF ALKALINE PAPERMAKING

One of the early paper sizes was gelatin; this was later replaced by rosin/alum systems. Up to the late 1960's and early 1970's, the internal sizing of sheets was almost exclusively based on rosin alum systems. Because the sheet was acid, the main filler had to be clay rather than calcium carbonate, and because this did nothing to reduce the acidity of the sheet, calcium carbonate was also excluded from the coating.

Then along came AKD, and we saw the birth of neutral papermaking. In the first instance, this allowed the use of calcium carbonate fillers in the base sheet, and then calcium carbonate pigments in the coatings.

By the mid 1980's some 70% of European mills had converted to alkaline papermaking, while the USA lagged behind at around 30%

One of the reasons for this gap was the differences in paper grades that already existed, and another, the differences in mineral deposits/extraction.

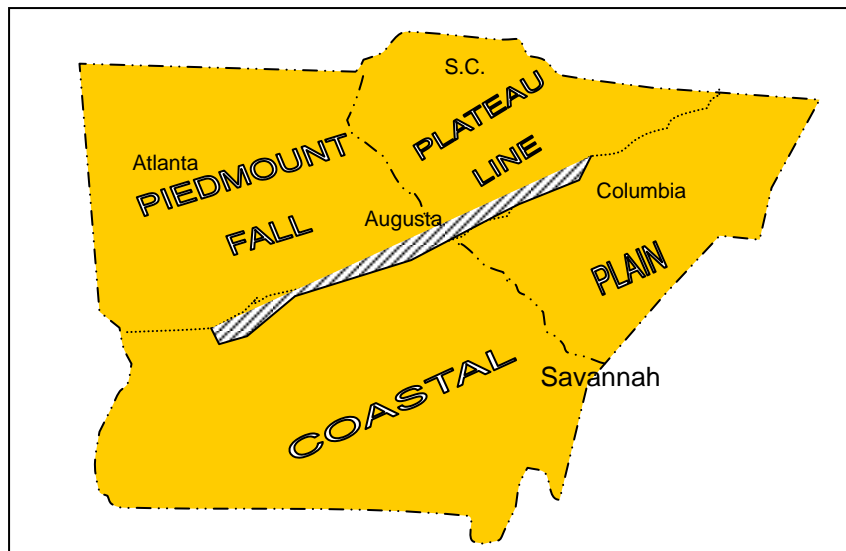
US v Europe

Minerals

The USA has deposits of primary, (1^o), and secondary, (2^o), clays, as well as vast quantities of titanium dioxide, but any deposits of calcium carbonate have never really been exploited.

For this reason, the American grades, historically, have grown around the philosophy of opacity.

Europe has no secondary deposits of clay, but plenty of calcium carbonate. Therefore European grade producers have concentrated less on opacity and more on whiteness.



Grade Changes

Europe had large deposits of easily exploitable calcium carbonate, and because of their preoccupation with brightness, they were the first to take advantage of the alkaline papermaking process. The willingness of so many mills to produce a neutral sheet gave them the opportunity to develop calcium carbonate based coating formulations.

Processing Influences

Both papermaking and paper coating processes are affected by the change from clay to calcium carbonate. These changes are brought about by the differences in: -

- pH
- Solubility

- Particle shape
- Hardness
- Hydrophilic/hydrophobic nature

Papermaking Process

- pH of backwater and sheet
- Slime and Bacteria
- Wire Wear
- Drainage

Coating Process

- Solids content
- Ink drying rate
- Ink holdout
- Roughness/Smoothness
- Gloss

RAW MATERIALS

- Base Sheet
 - Fibres
 - Fillers
 - Sizing system
- Coating Components
 - Pigments
 - Binders
 - Additives
 - ❖ Rheology modifiers
 - ❖ Crosslinkers
 - ❖ Biocides
 - ❖ OBA's

The Base Sheet

The three major physical components of the base sheet are, the fibres, the filler, and the size. Other things are present, but will not be discussed here.

As well as the physical components, there is also the way the base sheet is processed, These process parameters will affect the formation, porosity, smoothness, DMD, etc, and will influence how well and how evenly, a coating mix will be absorbed by, and adhere to, the surface of the sheet.

Fibres

When a sheet is being coated it is wet, and it is being subjected to tension, hence it need to be strong.

Fibre type

The basic strength is inherent to the fibre type used. Long softwood fibres are good for strength, but not particularly good for formation, and so we include hardwood fibres. In addition to improving formation, hardwood fibres also improve bulk. This is particularly useful for sheets destined for the sheet fed printing process, as stiffness is related to the fourth power of the caliper. Another disadvantage of hardwood, is the presence of vessel elements. These are very weakly bonded, and offer a potential site for pick, in the printing process.

Dimensional Stability

The degree of fibre curl can affect shrinkage and hygroexpansivity of the sheet, and can also result in out-of-plane defects.

Beating or refining promotes swelling and fibre flexibility. This can be seen in the water retention values. It might therefore be expected that the more a fibre swells, the more it is likely to shrink and therefore the greater the potential for hygroexpansivity, on rewetting. Interestingly, for sheets dried without restraint, this is true. But for sheets dried with restraint it is not true

Sheets dried under restraint have a lower hygroexpansivity, as the density of the sheet increases, but the converse is true for sheets dried freely.

Dimensional stability although closely associated with sheet curl, is not its only cause. The three types of curl are:-

- MECHANICAL
- STRUCTURAL
- MOISTURE

Pulp Type

There are two major categories in the coated paper sector, coated wood free, and coated mechanical. The structure of the coated mechanical sector, is much more well defined than that of the coated wood free, and will be discussed in more detail later.

Fillers

Fillers add nothing to the strength of a sheet; in fact they detract from it. However, they can improve the look of a sheet, but most importantly, they reduce the cost of the furnish.

As filler particles are much smaller than fibres, it follows that they will fill the voids between the fibres, which in turn will produce a smoother sheet.

Sizing

It is unlikely that anyone would try and coat a waterleaf sheet, therefore it will either be internally sized, or surface sized. Here we will only consider internal sizing.

In the early 1800's gelatine sizing was replaced by rosin alum sizing. In the 1970's , there was a move to replace that by AKD, and now the suppliers of rosin are fighting back with neutral rosin systems. Some mills also use ASA, although this is less common due to its instability.

Without good sizing, the sheet will not be pulled through the coating process, but if the level of sizing is too much, then it will affect the keying of the coating to the surface.

For all types of sizing systems, the general mechanisms are the same.

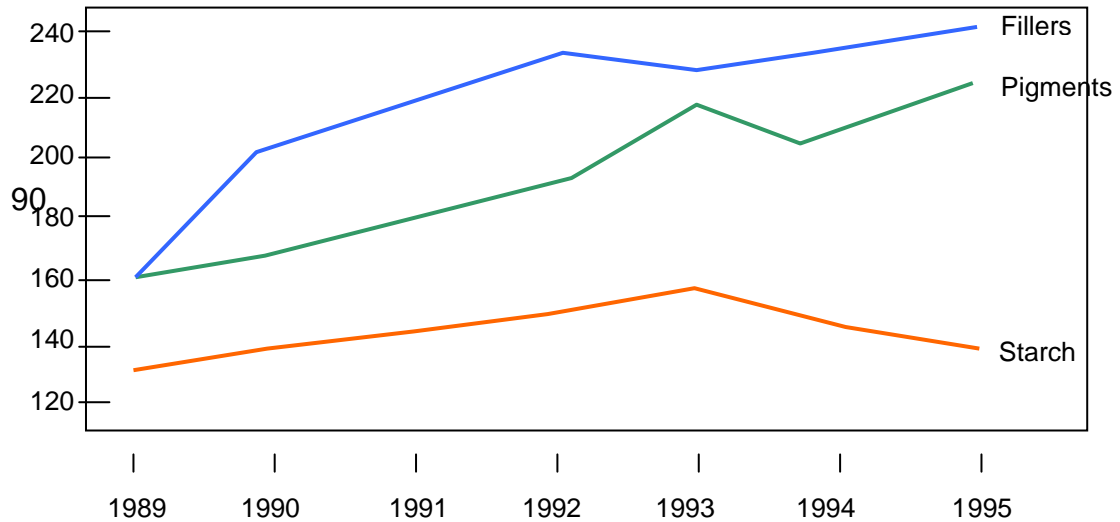
- RETENTION
- SPREADING
- ORIENTATION

Coating Components

Kaolin, calcium carbonate, titanium dioxide, satin white and talc, can all be used as pigments in coating systems. There is less of a trend away from kaolin in coating systems, than in the filler market.

The table below shows the growth of pigment coated paper world wide, while the graph shows trends within the UK.

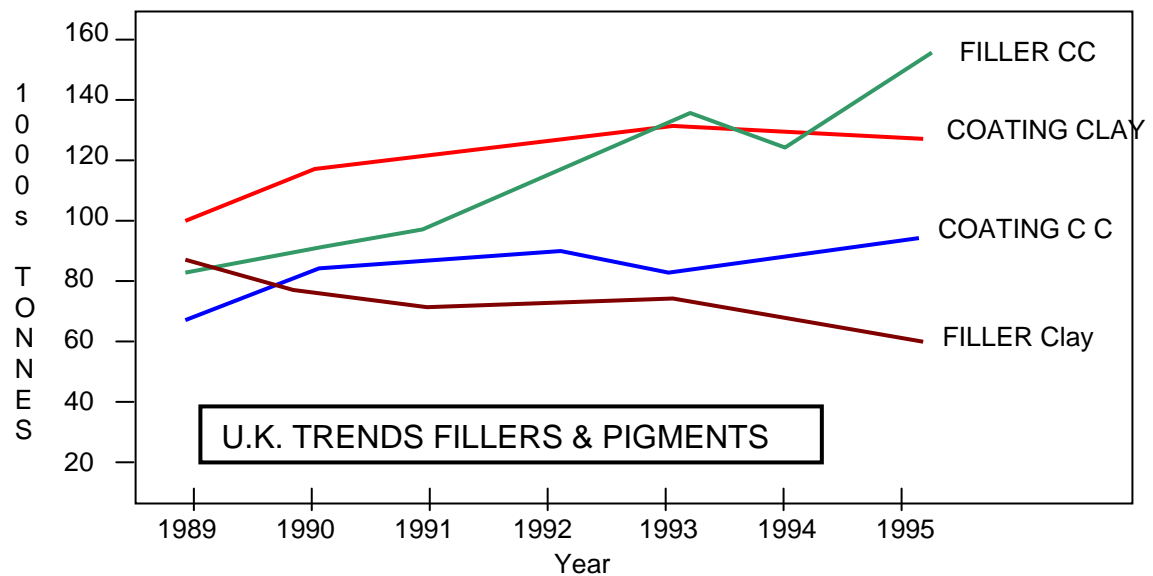
WORLD PIGMENT COATED PAPER CONSUMPTION MILLION TONNES				
	1980	1985	1990	% GROWTH
WORLD	11.1	13.8	17.5	4.7
NORTH AMERICA	4.6	5.6	6.9	4.1
WESTERN EUROPE	3.8	4.5	5.7	4.1
JAPAN	1.4	1.9	2.6	6.4
OTHER	1.3	1.8	2.5	6.8



3.21 Trends

The graph shows that while the consumption of both pigments and fillers are increasing, total starch usage is declining.

A closer examination of the filler and pigment statistics is given in the graph below.



For fillers, it can clearly be seen that while the trend in the use of clay is declining, the use of calcium carbonate is increasing. Since the rate of increase is greater than the rate of decrease, then in addition to winning business from clay, carbonate must be gaining new business.

For pigments, the story is different. Both minerals are increasing. High levels of coating gloss can only be achieved from clays, and not from carbonates, hence they are not competing. Market forces, (the demand for glossier sheets), is the dominant force.

The function of pigments.

The purpose of a pigment is to enhance the printability of the coated surface. It does this by providing absorbency, smoothness, opacity and brightness.

A single large crystal of most coating pigments would be clear and colourless, however when broken down into tiny fragments, it becomes white and opaque.

This is because light travels slower in solids than it does in gasses. As light travels from one medium to another, it bends and becomes scattered at each interface, and it is this repeated scattering, which produces the whiteness and opacity.

The ratio of the speed of light in air, to the speed of light in a solid is known as the refractive index of that solid. This defines the angle through which the light is bent.

Opacity and brightness

The repeated scattering of light from the particle surface gives the opacity and brightness. The higher the refractive index of the material the better. If the pigment is coloured, it will absorb light, this will enhance its opacifying power, but detract from its brightness.

Smoothness and gloss

Generally, the smaller the particle size, the better smoothness, and hence the better gloss.

If the surface is calendered, then the particle shape also has an influence.

Absorption

The pigment provides uniform absorption, and the deft use of binder levels is used to control the rate of absorption.

The Ideal Pigment

- Freely available
- Cheap
- Easily Dispersed
- Good Rheology
- High refractive index
- High Brightness
- Low solubility
- Low Binder Demand

Properties of Pigments

Summary of the properties of paper fillers and coating pigments

Name	Index of refraction	Brightness 457nm	Specific gravity	Particle size μm^1	Remarks
Clay-filler	1.56	82	2.58	0.5-10	Abrasive, very cheap
Clay No1 coating	1.56	86-92	2.58	80-82%	Most common type used
Clay No2 coating	1.56	86-92	2.58	92%	Better gloss and opacity
PCC	1.65	97-98	2.56	0.1-2.5	Cheap, bright pH> 7
Ground CaCO ₃	1.65	94-97	2.56	0.1-0.4	Cheap, bright pH> 7
Anatase TiO ₂	2.55	97-98	3.9	0.15-0.3	Excellent opacity bright
Rutile TiO ₂	2.7	97-98	4.2	0.15-0.3	Excellent opacity bright
Talc	1.57	96	2.7	0.5-5	Used in Europe
Cell wall material	1.53		1.5	10x1000	

Summary of Pigments

Kaolin: Stacks of irregular, charged, hexagonal platelets. Major European use in wood-free and LWC sectors, where acid Papermaking excludes the use of CaCO₃. Also in gravure grades. Good natural water retention.

Calcium Carbonate: Deposited as chalk, limestone or marble. Most commonly used crystal structure is the calcite structure. This particular conformation is bi-refrangent.

Talc: Hydrous magnesium silicate, from France or Finland. Main use gravure printing. Have both hydrophilic and hydrophobic sites.

Satin White: Calcium alumino sulphite, pH 12'ish

Gypsum: Calcium sulphate, by-product of sulphuric acid production. Limited use.

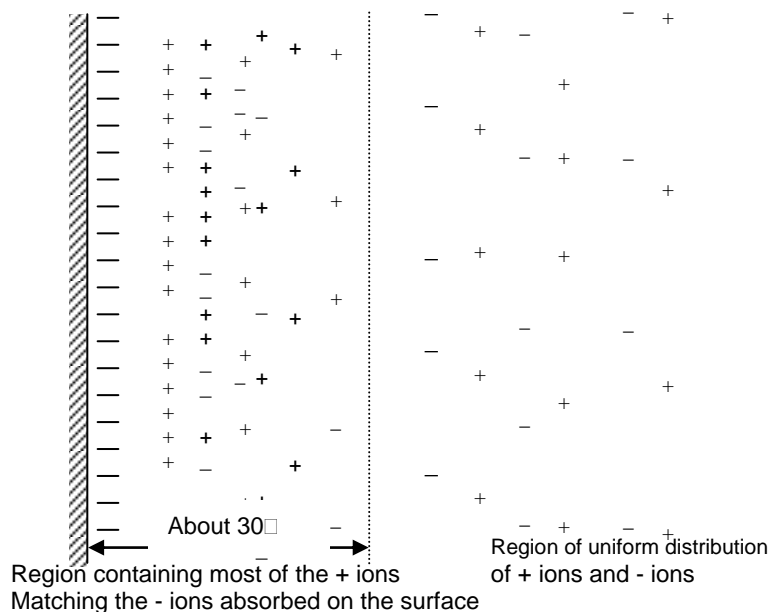
Titanium Dioxide: Highest refractive index. Anatase, 2.55, Rutile 2.7. High UV absorption reducing effectiveness of OBA's

Plastic pigments: Hollow, polystyrene based spheres.

	ADVANTAGES	DISADVANTAGES
Calcium carbonate	Rheology, brightness, low binder demand, higher solids content	Gloss and opacity (hiding power)
Clays	Gloss, smoothness	Brightness, rheology
Calcined clays	Brightness, opacity	Rheology, price
Satin white	Gloss, smoothness, brightness, opacity	Low solids content, rheology, high binder demand
Titanium dioxide	Opacity brightness	Price, availability, binder demand
Plastic pigments	Gloss, volume, opacity	price
Talc	Rotogravure: gloss, smoothness	difficult to disperse, rheology
P C C	Brightness, ink absorption, opacity	difficult to disperse, high binder demand, rheology.

Dispersion of Pigments

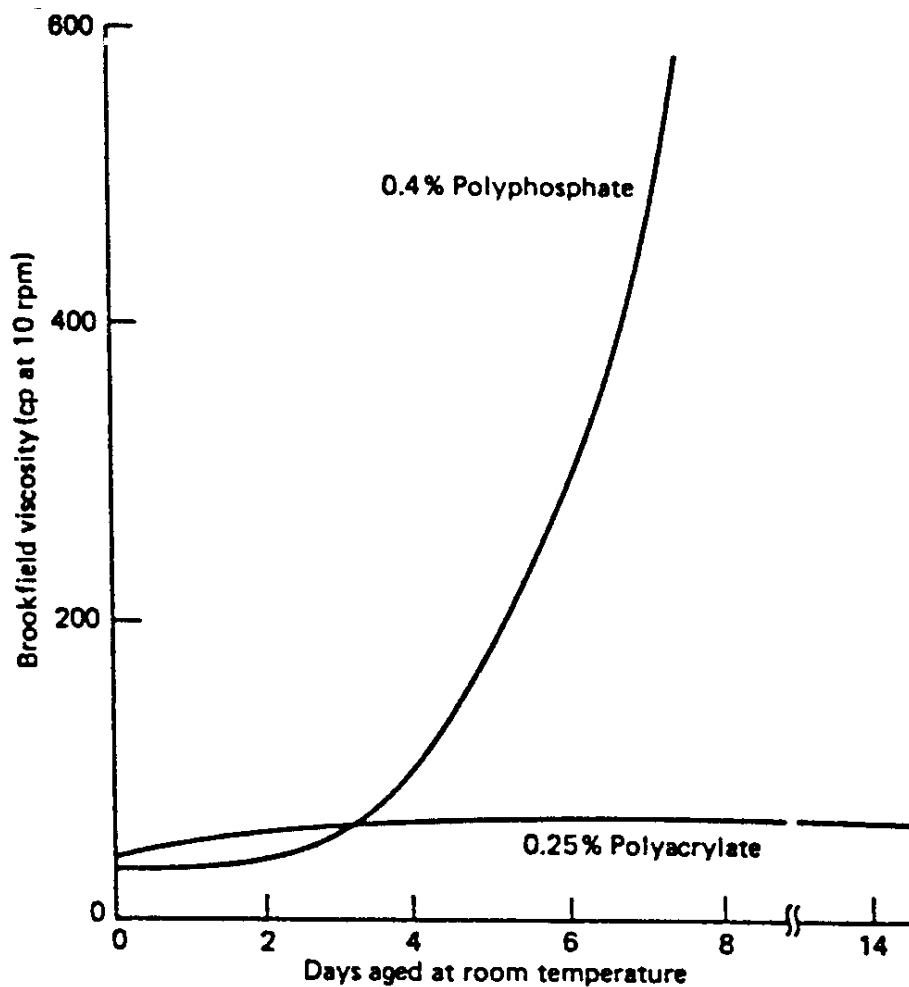
Optimum dispersion is achieved when the viscosity is at a minimum. Dispersion is usually brought about by the use of dispersants such as poly phosphates, or poly acrylamides, to form an electrical double layer at the surface of a pigment, as shown in the diagram below.



Of the pigment

The surface of the particle is negatively charged, and would repel similar surfaces. The positive charges of the dispersant 'mask' the charges to the maximum when at the optimum concentration.

Some dispersants are more suited to particular pigments than others. For example, polyphosphates are not suitable for calcium carbonate. Slowly, over a period of time, the calcium reacts with the phosphate, to form an insoluble deposit of calcium phosphate. This will result in a depletion of the double layer, and a viscosity increase will occur. There are no phosphate ions in the acrylate system, so no instability, as demonstrated in the graph below.



Care should be taken when mixing two pigments that have different dispersion systems.

Binders

Binders fall into two groups,

Natural

Starch

Casein

Soy Polymer

Synthetic.

Latex

CMC

PV-OH

Acrylic Thickeners

Natural

Natural binders come from a variety of sources, both animal and vegetable, either grown specifically for the job, or as a by product.

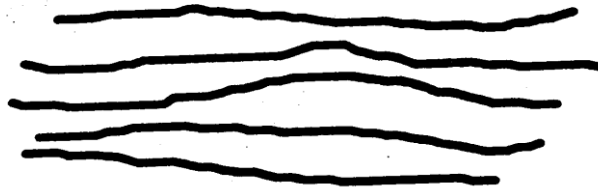
Casein

This is derived from excess milk production, and is by far the best of all the binders, when the quality is good. Unfortunately, quality is very variable, and so is availability. It follows that price is also variable. In the old coating systems, the casein binder was insolubilised by passing the coated paper over a water box containing zinc sulphate, just before the calender stack.

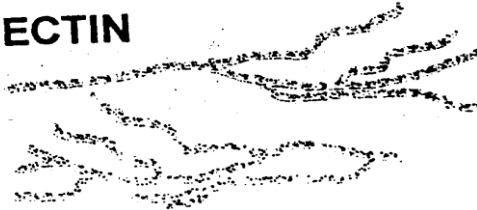
Starch

Starch is the most important of the binders, as it is still the most widely used. It exists in two structurally dissimilar forms, amylose, and amylopectin. Each type of starch can be chemically modified, or physically modified, or both.

AMYLOSE



AMYLOPECTIN



Chemical modifications include

- Etherification
- Esterification
- Ehtylation
- Propylation
- Oxidation
- Cationisation

Physical modification is really reduction in molecular weight. Lower molecular weight means lower viscosity

Chemical modification provides for greater stability, better film forming, and enhanced affinity for fibres.

Starch exists in two structural forms, straight chains, (amylose), and branched chains, (amylopectin), and both forms exist in almost all starch containing plants. Wheat contains a higher proportion of amylose than does potato, and this leads to some interesting differences. Amylose is the lower molecular weight material, and so is easier to disperse.

One big problem with cooked starch is set back, or retrogradation. This is the tendency of the dispersed starch chains to re-agglomerate, either as a gel or as a precipitate.

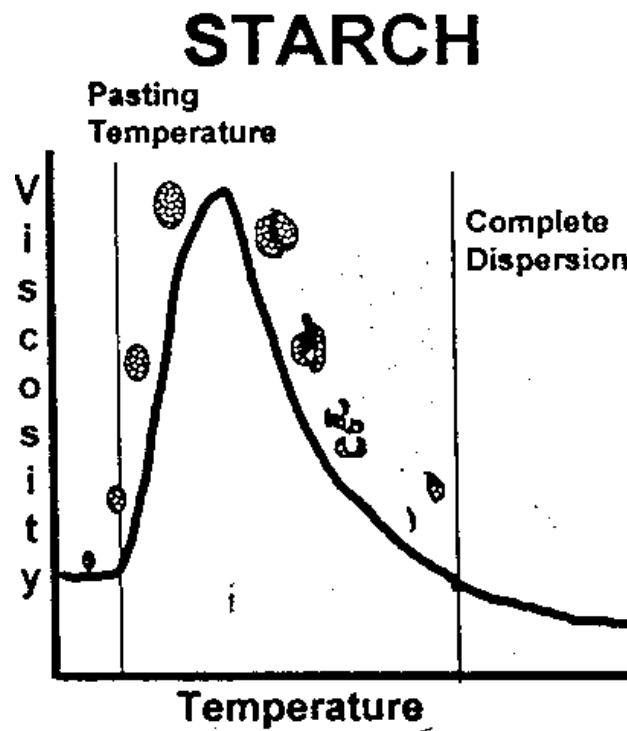
The linear nature of the amylose allows the starch chains to pack closely together, hydrogen bonding can play its part, and retrogradation happens easily.

Amylopectin chains, because they are so branched, cannot pack closely together, and so retrogradation is a lot more difficult to achieve.

High levels of amylopectin can also be disadvantageous, because the viscosities of the solutions are higher.

Starch Preparation

The preparation of starch is summarised in the graph on next page



The starch powder is dispersed in cold water, to around 25%, and heated. As the heating process continues, the starch granule takes in water and swells. As the granules get bigger and the free water between them gets less, the viscosity increases. Eventually, the granule bursts, the starch chains are released, and the viscosity falls.

Synthetic

It is not surprising that synthetic binders were introduced. Natural binders are subject to variable quality, performance, and availability, due to the variability in their growing conditions.

The main feature of these synthetic binders is their long chain like structures.

A single unit within the chain is known as a monomer, and the large chain, a polymer. Where two different units are used, it is referred to as a co-polymer

Just as starch, a natural polymer, is composed of chains of hundreds of anhydrous-glucose units, the synthetic polymers are also composed of chains of individual units, repeating themselves.

Latex

The advantage of synthetic polymers was that the manufacturers were able to change the types of repeating units, to give the products different properties.

The first synthetic polymers were introduced into the paper & board industry in 1946. The driving force for their production was the need to produce a synthetic rubber for the war.

It was not until the early 1960's that synthetic products started to make an impact on the industry. Their great value was in giving water resistance to coatings.

Most of these type of products used in the industry are co-polymers.

Typical starting monomers are,

- Styrene
- Butadiene
- Acrylates
- Ethylene
- Vinyl acetate

and from these, a variety of different polymers can be produced.

- Styrene-Butadiene SBR
- Styrene-Acrylate STAC
- Ethyl-Vinyl Acetate EVA

SBR latices are by far the most common, but do have their drawbacks.

Latex production

There are three stages in polymerisation reactions

- Initiation
- Propagation

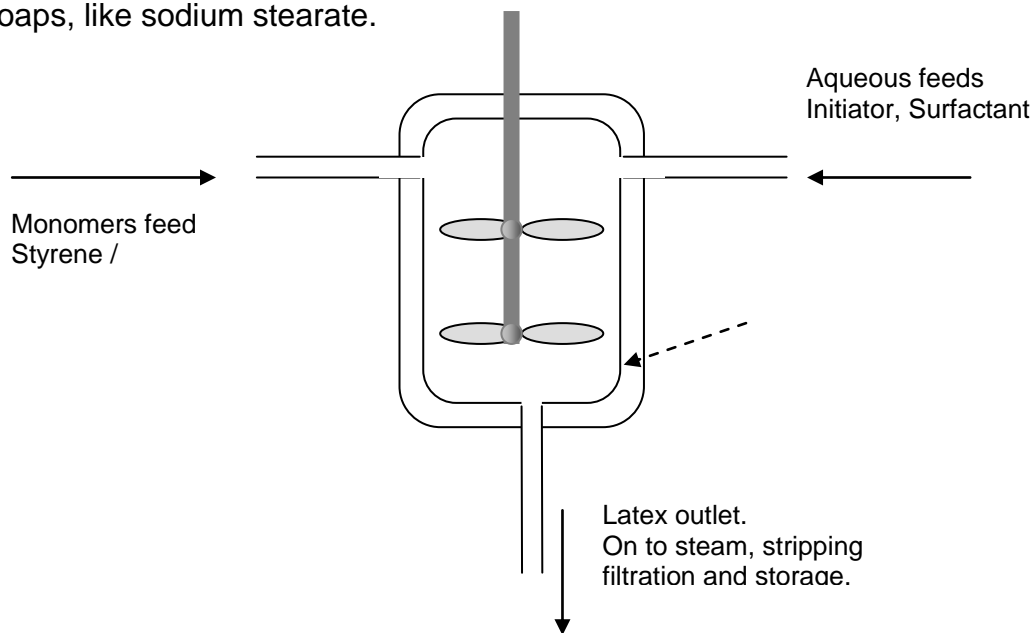
- Termination

An initiator chemical, such as ammonium persulphate, produces free radicals.

These free radicals collide with the monomers, which in turn collide with other monomers, to make longer and longer chains.

Ultimately, we need a terminator.

The reactions are carried out as an aqueous emulsion, and to keep the particles apart, and in suspension, surfactants are added. These are usually soaps, like sodium stearate.

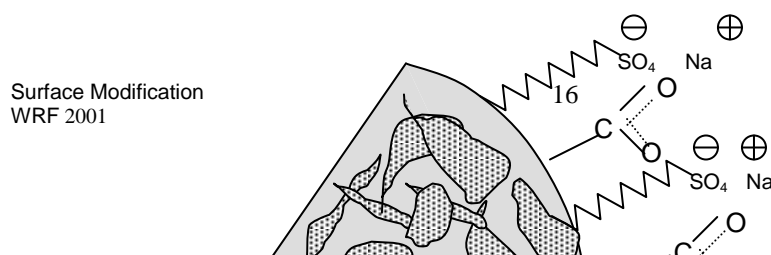


For a typical SBR latex, the reaction will take up to 6 hours to reach 99% conversion.

Carboxylic acids can be added to the to the polymerisation mix. The acid will be incorporated into the polymer particle and the acidic groups will help stabilise the particles.

The surfactants, which also stabilise the particles, are only loosely attached. They can be detached easily, by mechanical means, or even chemical. They may be redistributed onto other latex particles , or even pigment particles. This can lead to instability.

The diagram below shows a section of a latex particle, with both the carboxyl groups, and the surfactants.



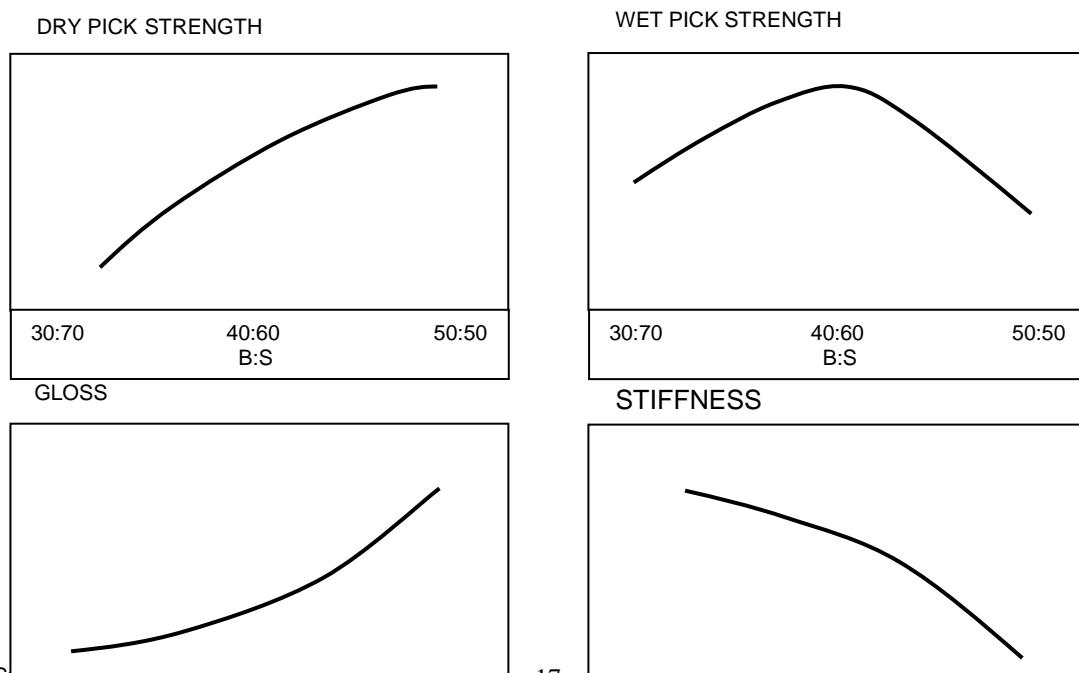
When the reaction is finished, there is still unreacted monomer present. This needs to be removed by steam stripping. Finally the product is filtered to remove oversize material, pH adjusted, and bactericides added.

The major variables are:-

- Monomer ratio
- Particle size
- Chain length

Generally, as the particle size decreases, the binding power increases.

There is an optimum. for molecular weight, and this is related to its binding ability. Manufacturers will produce a latex on the lower, safer side. Monomer ratio has the most dramatic effect on paper properties, as shown in the graphs below.



30:70	40:60 B:S	50:50
-------	--------------	-------

30:70	40:60	50:50
-------	-------	-------

Additives

The biggest proportion of a dried coating mix is the pigment, up to 90%. The next biggest component is the binder, up to 20%, The total of the remaining components, all together, is usually well under 5%, and are generally termed additives.

Typical additives in a coating mix are:

Dispersants

These materials are used right at the beginning of the process, when the pigments are dispersed. The two most common go by the trade names Calgon and Dispex

Calgon is an inorganic material, fairly inexpensive but does tend to go off after a while.

Dispex is much more stable. It is a synthetic organic material but much more expensive. It is quite common for the two to be used together.

Alkalis

Foam Control Agents

There is a difference between an antifoam and defoamer. A defoamer gets rid of foam, while antifoam is there to stop it forming in the first place.

Air is the enemy of the papermaker and coater. Where there is a bubble of air there is no longer fibre or filler or binder, therefore there is a weakness.

Antifoams are based on silicones, oils or alcohol, and are usually added early in the process. Since oils and silicone are water repellent, if too much is added or the mixing is incorrect then the agent can gather into a single drop and cause a fault commonly known as fish eyes

Lubricants

Lubricants are usually composed of stearates, wax emulsions, or polyethylene derivatives, and can be used to lubricate either the wet coating or the dry.

Biocides

Biocides are essential for many papermaking and coating situations.

The most important thing to note about these types of products is their toxicity. H&S regulations must be strictly followed and it is **certainly not true that if some is good then more must be better**.

Regulations controlling these substances vary from country to country so it is important to check. The regulations are also reviewed regularly. What is OK today is not necessarily OK next week. Keep Checking.

Biocides have to be used with natural products such as starch and casein but are also used with synthetic products like latex.

Biological attack of coatings can lead to a variety of problems

- Odour
- Mix instability
- Viscosity increases
- Poor runability

Optical Brightening Agents, (OBA's),

These also known as Fluorescent Whitening Agents, (FWA's) are molecules that take in ultra violet light and emit it at blue-white light. This fools the human eye into thinking the item is whiter and brighter.

Cross Linkers

Also known as insolubiliser resin, or hardener. Their purpose is to make the coating resistant to the water in the printing process.

Traditional materials have been Glyoxal, Melamine-Formaldehyde and Urea formaldehyde resins. Glyoxal is the best type of crosslinker for starches but works best in acid conditions. With the ever-increasing quantities of chalk, this acid environment is less and less common. The health risk associated with formaldehyde has contributed to the decline in the use MF and UF resins.

Urea-glyoxal condensates, and zirconium-based materials are increasing in popularity.

Flow modifiers

The general principal of most coating processes is to put on too much coating and then take off the excess. For a few moments, between these two operations, there is the opportunity for the water in the coating to soak into the substrate. If this happens the coating which is scraped off and returned to the bulk mix will have a higher solids content than the original mix. As this happens repeatedly the overall solids will increase and so the viscosity will increase. Eventually it will reach a point when the coating will not run.

To avoid this situation 'thickeners' or Water Retention Aids are added. These are materials that produce very high viscosities at very low concentrations. Starches can be used although the usual materials are Carboxy Methyl Cellulose, (CMC), polyvinyl alcohol, (PVOH or PVA), or soy protein

COATING METHODS

There are twelve different types of coating methods, only some of which we will look at in detail.

Brush coating

Size press coating

Dip coating

Rod coating

Air Knife coating

Kiss coating

Spray coating

Blade coating

Transfer roll coating

Reverse roll coating

Cast coating

Curtain Coating

In many, but not all cases, the coating process consists of presenting to the surface of the paper or board, more coating than it needs, then taking off the excess.

The methods we will look at in detail are highlighted

Size Press Coating

The main function of the size press is to apply non-pigmented, film forming coatings to the surface of a sheet, thereby improving surface strength and limiting penetration. It is still the most common of all the coating methods.

It is not unusual, particularly in Scandinavia, for mills to work themselves up through the grades after starting with a size press.

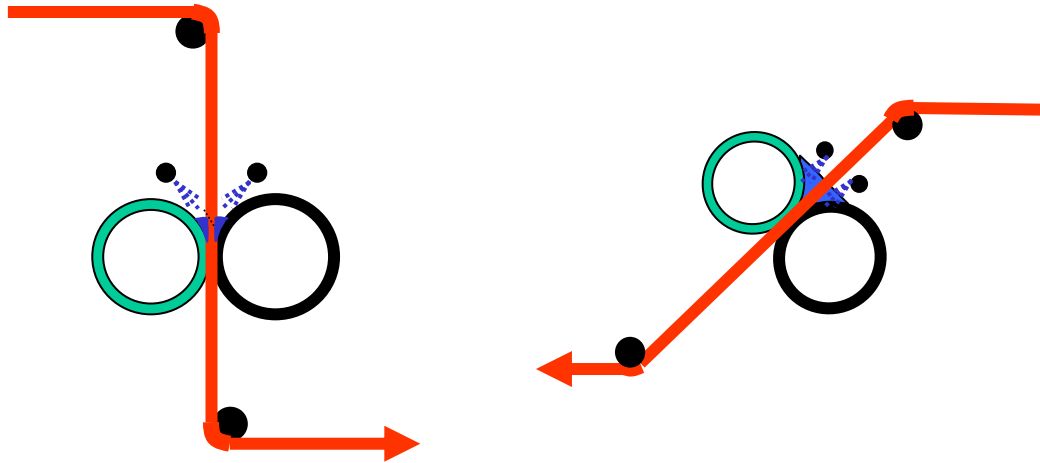
They start off with simple printings and writings, then they start to use the size press to apply pigmented coatings. After a few years, they decide to put a blade coating station on the machine, or go for an off-machine coater.

There are three main types of the traditional size press.

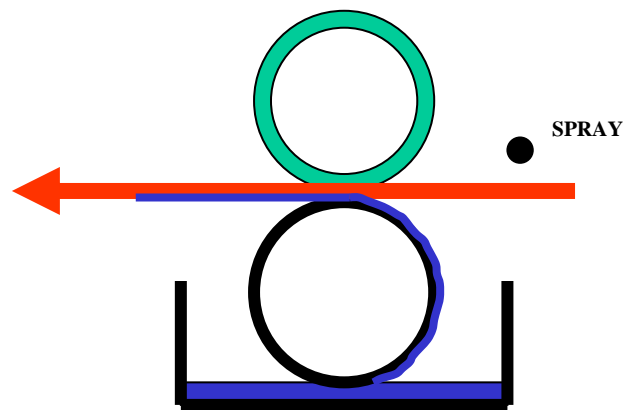
Types of size press

The vertical size press is so named because the rolls are aligned vertically. Starch, (usually), is picked up from a tray with the bottom roller, and applied to the bottom of the sheet, but is sprayed onto the top of the sheet. This led to a very two-sided sheet and to the development of the horizontal size press.

The inclined size press was developed to have all the benefits of the horizontal size press, but to take up less room.



By changing the run of the web, the horizontal size press can be used to treat just one side of the sheet.



There are limitations to the size press. Only low coat weights can be applied, up to about 20 gsm, it is often therefore used for pre-coats. This limitation is because it is difficult to achieve coating solids above 40%. The coating solids in turn, are limited by the maximum runnable viscosity, which is around 300 mPa.s

The variables that can affect pick up are:

- Nip pressure
- Roll hardness
- Web absorbency
- Machine speed
- Mix rheology - temperature, solids
- Web moisture content

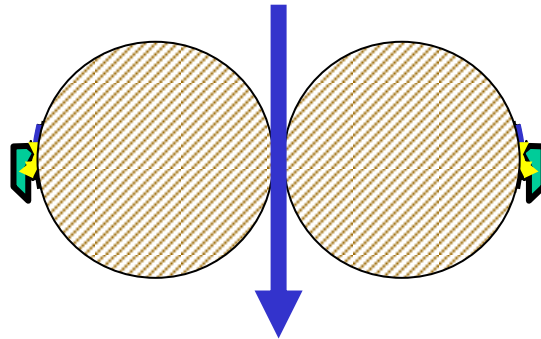
Moisture content can be critical, too high, and the web will break, too low and the sheet can become water repellent. Between 3 and 7% is considered the optimum.

Not all the coating mix will transfer from the roll to the web. So the mix splits itself between the two surfaces, which is usually called film split. This can lead to patterning on the coated surface, and is known as the orange peel effect.

The size press follows and accentuates the profile of the sheet, hence a good sheet is important.

The Metered size press

This type of device is also known as the HSM, the speed sizer, Film Press and the sym sizer. It is probably the most significant advance in the industry in recent times.

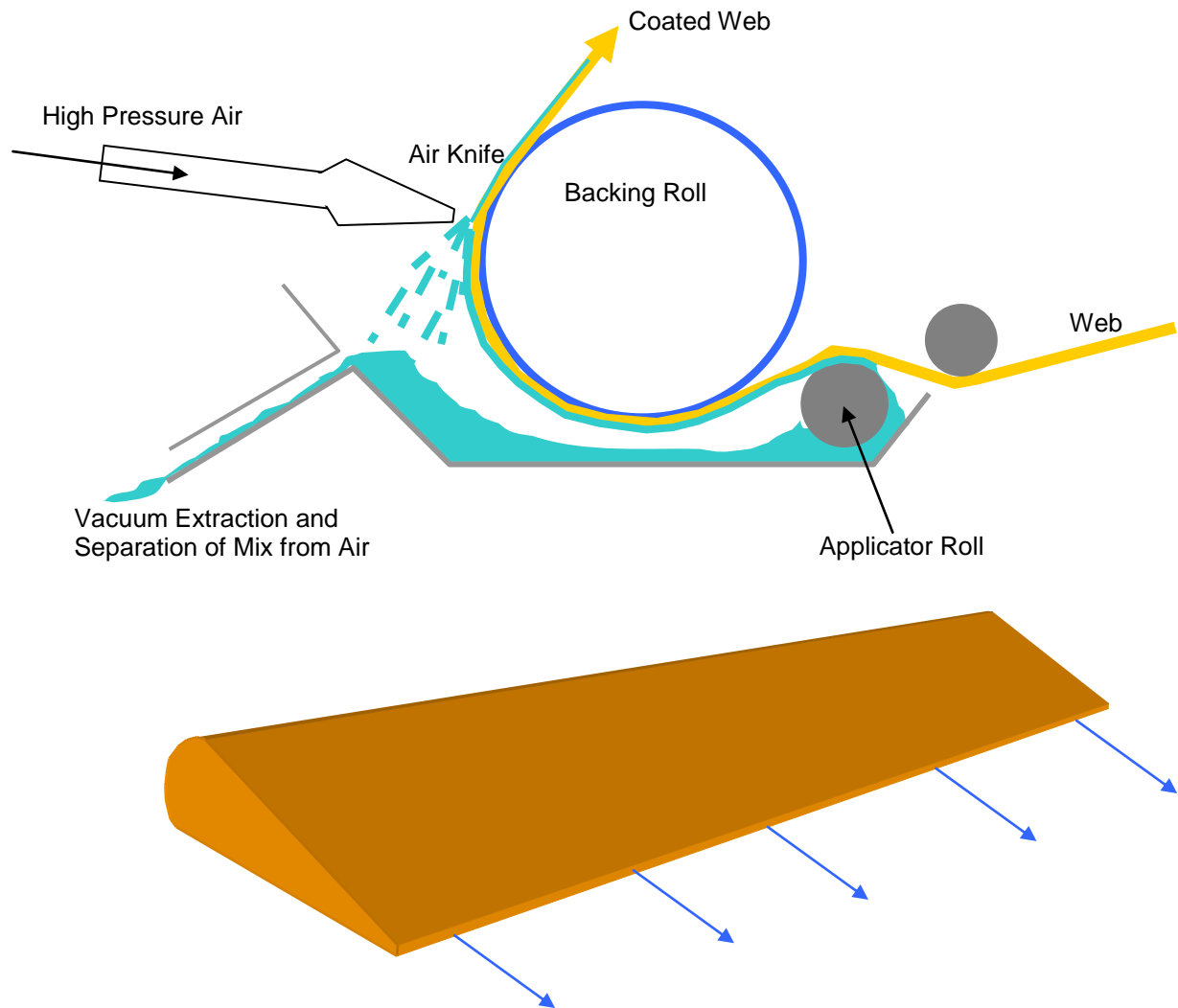


Coating mix is metered onto the rolls, (blade or bar), excess is returned to the mix tank, and the material on the roll is transferred to the web. By avoiding the flooded nip, air entrainment is reduced, and higher viscosities are achievable because there is less chance of the orange peel effect.

With the Film Press, machine speeds of up to 1500m per minute have been achieved, and coat weights of up to 28 gsm. This is due to achievable viscosity levels of up to 3000 mPa.s, at a solids level of 50-60%.

Unlike the conventional size press, the absorbency of the base sheet does not affect the coat weight. Since the absorbency is affected by the moisture content, it follows that you do not have to dry the sheet before it enters the press, thus saving energy.

Air Knife Coating



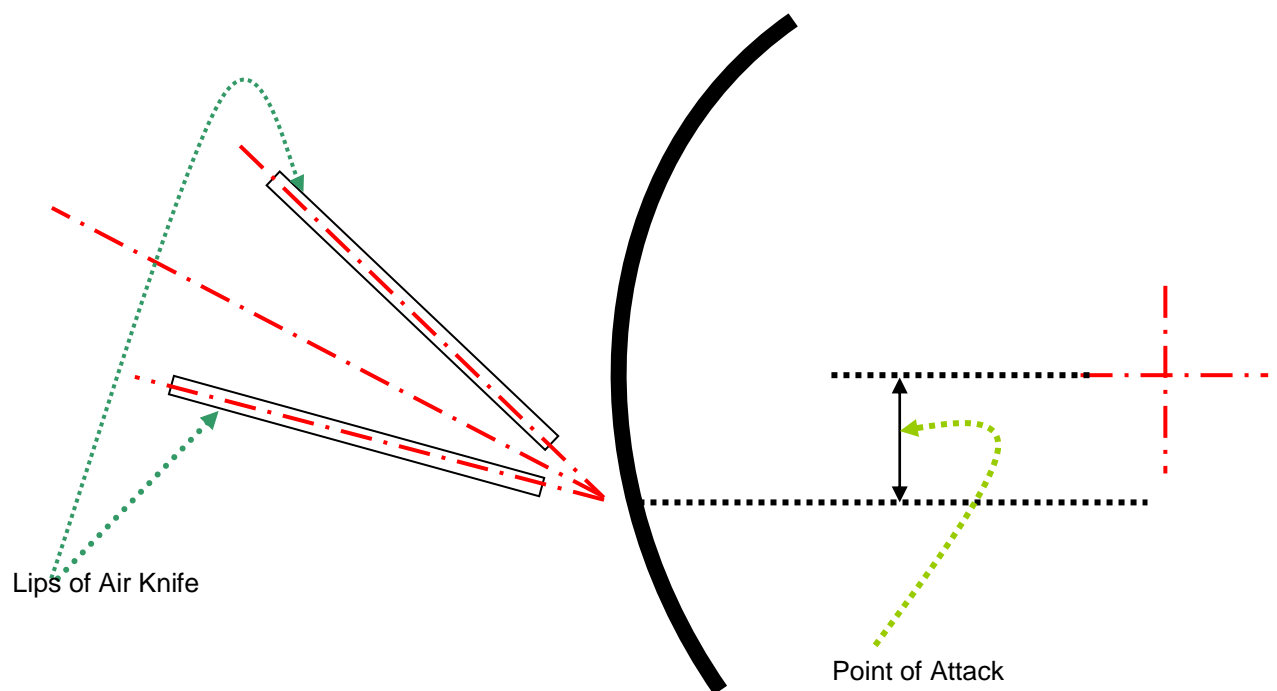
The air knife was introduced in the 1930's, and the basic principle is to apply too much coating to the web, and then take off the excess. The main advantages of the air knife are its versatility, and its ability to apply pressure sensitive coatings. Its main disadvantages are that it is slow (500 m/m), and can be dirty.

The following factors will affect the efficiency of the process:

- The energy of the air jet
- The angle of the jet
- The path length of the jet
- Machine speed
- Solids content of the mix

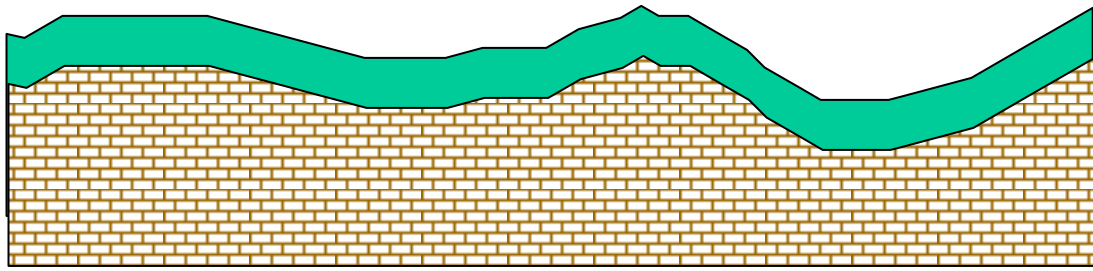
The energy of the jet, or in practice its velocity, is the best method of coat weight control.

The angle at which the air impinges on the wet coating is critical. The point of impingement in relation to the backing roll is also important, as shown below.

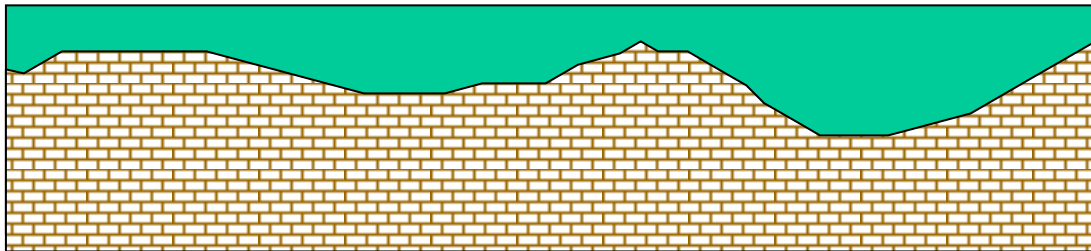


The air knife coater can operate in three ways;

- To brush or smooth out the coating layer
- To act as a barrier, and prevent excess mix going past a certain point.
- As a combination of both the above



The air knife is a contour coater, and therefore does not fill in the valleys of a rough sheet. Because of this, it often follows some other type of coater such as a blade.



One of the problems associated with the recycling of the coating colour is the entrained air. Where the machine speed is very fast, or the air velocity is high, then considerable amounts of air can be incorporated in the returning mix, and needs to be removed before it can be reused.

Blade Coating

The blade was introduced in the mid 1940's, and the basic principle again, is to apply too much coating to the web, and then take off the excess, but this time to scrape it off rather than blow it off.. The main advantages of blade coating are that the web can be run faster, high solids mixes can be used and a level surface is achieved. Its main disadvantages are that pressure sensitive coatings cannot be applied, and the smoother the base sheet, the lower the coat weight that can be achieved.

There are many variations of blade coating, the general principals of which are outlined below.

There are three phases to consider for blade coating.

- How the coating is applied
- How long it stays there
- How it is taken off

The Pond, or **Short Dwell Time Applicator**

Here a flooded nip is employed, and the coating is only in contact with the web for a short time. Very high shear rates are employed, with the shear rates being in excess of 2000m/min.

The Roll, or Long Dwell

These are the most common type of applicators to be found. It consists of a dip roll, rotating in the same direction as the web, but at a slower speed. This gives a flooded nip between the roll and the web.

The Fountain Jet

As the name implies, a fountain of coating mix is applied to the lowest part of the web run.

Having applied the coating, and allowing it to sit on the web for a short or long time, it must be metered off with a blade, for which there are two configurations.

The BENT blade

In this mode, as the blade load is increased the coat weight applied will also increase. This is thought to be because the contact angle grows faster than the blade pressure.

The STIFF Blade

In this mode, as the blade pressure is increased, the coat weight decreases.

The bent blade is the most common configuration, as it gives higher coat weights, and less streaking.

Depending on the type of coating being applied, blades have only a short lifespan, and the degree of wear is very important.

Coating	Standard Blade	Ceramic Blade
Reactive Clay	2-4	8-24
Pigmented pre coat	6-8	30-50
Pigmented top coat	6-8	30-50
Starch	16-24	40-60

Blade loading must be even all across the web to ensure an even coating

The blade angle is also critical. Positioning of the blade angle must not affect the pressure.

Cast Coating

This is the quality end of the coatings. Traditionally, casein was used as the binder, but today synthetic products are used.

Unlike all other coating systems, here, the wet coating is brought into contact with a surface, before it is dry.

Another difference between cast coated, and traditional processes, is that the coating mix is deliberately destabilised, just prior to being applied to the substrate. The wet coating colour is pressed against a hot, highly polished cylinder, and the surface of the coating, as it dries, takes on the contour of the surface, and becomes highly reflective also.

The final coating, is smooth, bulky, has good ink receptivity, and excellent gloss.

Because of the nature of the process, it is slow, and therefore expensive.

One trend, is to produce traditional coatings, print on them, and then use an overprint varnish to obtain a similar mirror like finish

Summary of Coating Process Variables

	Size Press	Metered Size Press	Air Knife	Bill Blade	Roll Applicator	S.D.T.A
Speed (m/min)	400	1500	500	800	1400	1500
Viscosity (mPa.s)	300	500	50-400	1000	300-2000	200-2000
Solids (%)	10-35	50	45	56-60	45-70	45-67
Coat Wt. (gsm)	5-10	15	25	12	25	12

Drying

Drying is an important part of the coating process, especially if it is considered more generally, as water removal, or dewatering.

By this definition, dewatering starts the moment the coating mix hits the web, and well before the driers, or even whatever device is used to take off the excess.

As soon as the coating colour hits the web there is some migration of the water away from the mix, and into the web. The power of the mix to retain the water is known as its water retention value.

For air knife coating, the extent of dewatering influences the coat weight. For other coating methods rheology changes can manifest themselves in problems such as scratch marks, or orange peel effects.

To inhibit the uncontrolled dewatering, flow modifiers, or co-binders are often added to formulations, for example,

- Acrylic thickeners
- CMC
- PVOH
- Alginates
- Guar Gum
- Protein

As well as water moving down through the coating, by capillary action, some of the binder can move with it. This is especially true of water soluble binders like starch.

This can give a binder rich layer in the surface of the web. If there is a binder rich layer, then the binder must have come from somewhere; therefore another part of the coating layer will be binder deficient. This can at best lead to ink receptivity problems, or at worst pick problems due to the weakness of the coating.

Different types of binder can migrate into the web at different rates, starch and latex for example. This can lead to concentrations and deficiencies of a particular binder type in different areas of the sheet. When it comes to printing on this coating, these areas will interact differently with ink and water. This can lead to mottle problems.

High solids, and high viscosity reduce the opportunity for binder migration

Dryer types

Drying may be with or without forced air, and with or without contact with a heated surface.

Infrared Dryers

Without forced air, these have limited use in high-speed paper coating. Their main purpose is to provide additional heat in a limited area. Without the benefit of good airflow, IR drying is not very effective for medium and high-speed coating.

With forced air, some workers believe that it offers higher drying rates than any other drying method, whilst avoiding binder migration.

Typical dryers operate at temperatures in the range 980-1090 C, with a medium velocity airflow. IR dryers may be gas or electric, and the differences between the two have been the subject of many conference papers.

The flow does not just take away moist air, but serves other useful purposes, as detailed below.

The airflow: -

- Moderates the temperature of the web.
- Increases the rate of water removal
- Conserves energy
- Provides cooling for the emitter
- Keeps the paper from contacting the emitter in the case of a break.

Drum Dryers

These are often found immediately after a size press or transfer roll coater. They are usually run between 70-76C to avoid the coating sticking to the drum surface. The drums must be doctored, to prevent debris build up, and to prevent drum wrap in the case of a break.

The disadvantage of this type of dryer is that it is slow in the early stages of drying. It can be used to great effect at the end of the dryer run, to even out the moisture profile, and to produce a flat sheet free from wrinkles and cockles.

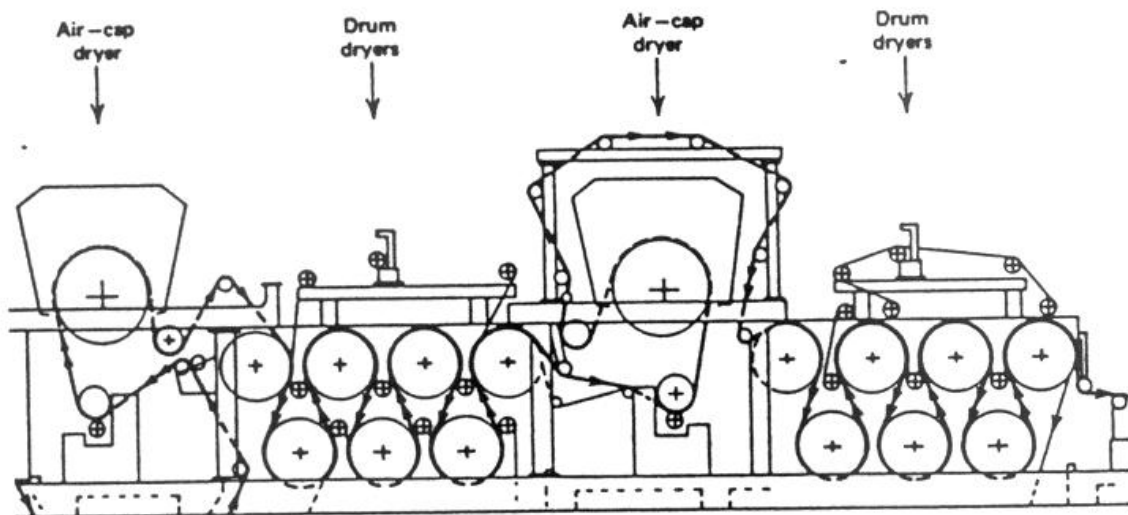
Air Cap Driers

With the development of blade coating, there was a need for drying systems that had higher evaporation rates. This resulted in the development of the high velocity air cap dryer. It involves the use of hot air at high velocity striking a coating, which is simultaneously being heated on the reverse side by a drum dryer.

There are many different designs, but the essential features are the same.

- Air velocity 3000 - 6000 m/min
- Temperature 150-450 C
- 80-90 % air recycle
- Discharge distance 1.3 cm

Combinations of different types of drying systems are common. Below is an example of drum plus air cap.



Air Float Dryers

The high drying rates of the air cap dryer did cause quality problems due to binder migration problems, and two sidedness. This led to the development of the air float dryer. It is particularly suitable for on machine drying.

- ❖ Advantages of the air float system are claimed to be:-
- ❖ Improved drying rate
- ❖ Drying from both sides
- ❖ Non-contact drying
- ❖ Wide web tension range
- ❖ Good web stability
- ❖ Versatile - non/extensible webs
- ❖ Easy access
- ❖ Low energy usage

Most of the air float dryers make use of the coanda effect.

CALENDERING

Calendars may be on or off machine, and may be either HARD or SOFT nip. The main purpose of the calendering operation is to produce a smoother surface for printing on, an additional benefit, is that the calender can also be used to improve gloss.

The consequent reduction in calliper can be an advantage, but is usually a disadvantage

Hard nip calendars utilise chilled iron rolls, and soft nip calendars use resilient rolls.

Paper and board properties can also be affected by the number of nips, the load, the roll diameter, the speed, temperature, and moisture content of the web.

The table below summarises the changes.

Calender operating properties

Paper properties	Increase number of nips	Increase load on Calender	Increase roll diameter	Increase speed of calender	Increase temperature of rolls	Increase web moisture
Calliper	↓	↓	↑	↑	↓	↓
Smoothness	↑	↑	↓	↓	↑	↑
Gloss	↑	↑	↓	↓	↑	↑
Tensile MD	↓	↓	↓	N C	↑	N C
Tensile CD	↓	↓	↓	N C	↑	N C
Tear MD	↓	↓	↓	N C	↑	N C
Tear CD	↓	↓	↓	N C	↑	N C
Stretch MD	↓	↓	↓	N C	↑	N C
Stretch CD	↑	↑	↑	N C	↑	N C
Burst	↓	↓	↓	N C	↑	N C

↓ Properties decrease

↑ Properties increase

N C No Change

Note. Smoothness and gloss need not replicate together; it will depend on furnish, filler, coating etc. It is possible to have a dull (matt) sheet with a high smoothness.

Calenders can be broadly categorised into two groups, on machine and off machine. These two groups can then be subdivided into hard nip calendars and soft nip calendars.

In addition to the traditional calenders, there are brush calenders, super calenders, and the intermediate calender, or breaker stack.

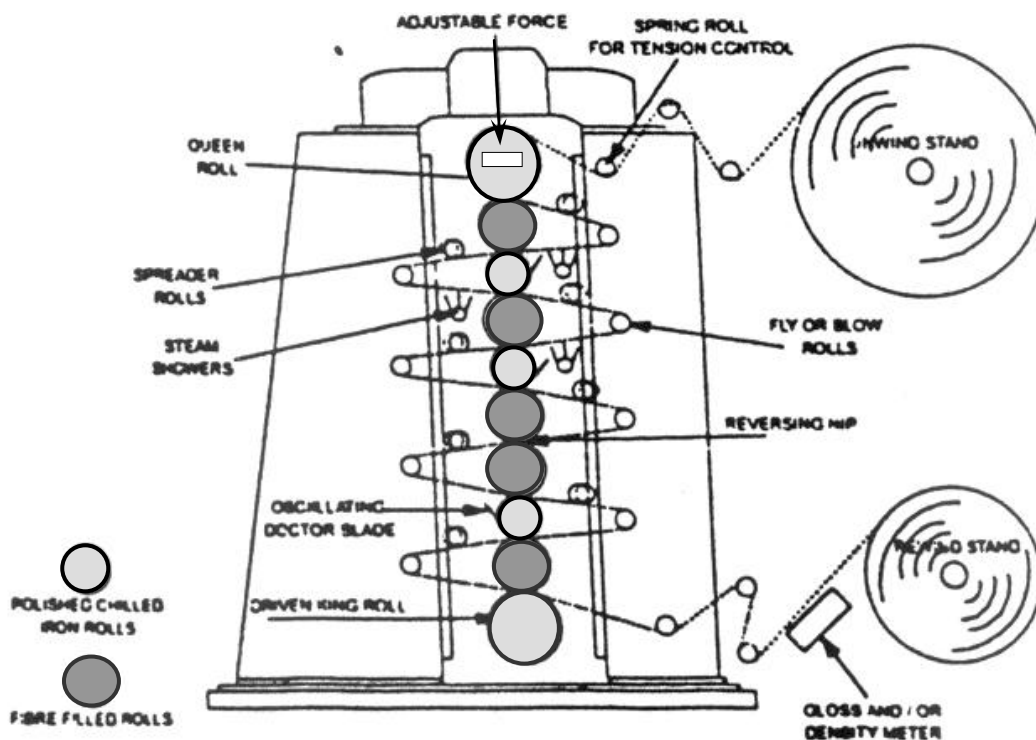
The main objective of coating a paper or board is to produce a smooth finish to enhance print definition. For the high volume market the addition of coating to the surface with a light rolling by the machine calender stack may be sufficient e.g. publishing grades, food board. Other selective grades require not only a smooth surface finish but also a gloss finish eg: glossy brochures and magazines, posters.

SUPERCALENDERING

The supercalender (SC), is an off machine process, and has been used for over 100 years. The sheet passes between a series (5-15 rolls or bowls) of hard and soft material. The hard rolls are made from chilled iron and have a highly polished surface. The soft rolls are constructed from discs of natural fibre compressed together. Different fibre mixtures produce rolls of different harnesses.

The rolls are positioned alternately down the stack and as the paper passes through the nips it is passed around fly rolls, which hold the sheet away from the bowls thus preventing air entrapment that could cause creasing.

The metal rolls may be heated with steam or hot water and moistening sprays may be used prior to the sheet entering certain nips. When both sides of the sheet require treatment two fibre filled bowls are placed next to each other between half way and two-thirds way down the stack.



A super calender arrangement

The table below shows a typical variation in the make up of the fibre bowls of a supercalender for different papers and finishes.

Fibre	Typical Application	Line Loading KN/m	Speed m/min	Hardness ° Shore D
Raw Cotton	Art & High quality papers	215	350	72-81
Long Fibre Cotton	Coated papers	235	450	84
White cotton paper	Coated papers/magazines	350	1000	88-90
Woollen paper	Coated papers Fine papers Newsprint	300	800	85-87
Blue Denim	Newsprint, Magazine	400	900	90

Whereas on machine calenders can be used to reduce problems in the base sheet, the supercalender cannot. The supercalender can only make existing faults worse, as well as creating new ones.

There are usually two heating circuits for the SC to enable the top and bottom sections to be controlled separately.

The maximum surface temperature is around 80-90⁰ C, with the front -back temperature being controlled to within 3⁰ C.

BRUSH CALENDERING

In this particular process the coated surface of the sheet is brushed by rapidly rotating brushes to obtain the desired degree of finish. The coating formulation is tailored with high levels of binder, as it is mainly the binder that produces the gloss, the pigment is not affected by the brushing action and is not dislodged from the base. There are two methods of brush calendering, line brushing and area brushing.

LINE BRUSHING

Line brushing machines, consist of a series of rapidly rotating brushes positioned around a backing drum. The coated paper passes between the brushes and the drum. Control of finish is possible by varying the number of brushes, pressure applied, speed of operation, and direction of rotation. This is usually an off-machine process.

AREA BRUSHING

In the area brushing process the sheet is wrapped partially round a series of brushes and rolls. The finish is again controlled by machine speed, direction of brush rotation and number of brushes with the pressure being controlled by the degree of sheet wrap around the brushes.

Whereas in line brushing, the sheet is rigidly held, in area brushing it is not. The brushes contact the surface in the intermediate draws, and therefore only the tips of the bristles are in contact, and they do not bend.

Brush diameters are round about 500-600 mm and operate at up to 1200 rpm.

The brushing tends to close the surface and reduce ink absorbency but care must be taken in formulating the coating mix to produce a satisfactory result.

HARD NIP CALENDERS

Machine finished (MF) products, are usually processed through a single nip calender, although 3 and 4 rolls are quite common. Up to 8 rolls used to be common, when it was believed that more low-pressure nips was better than a few high pressure ones. This was before the advent of moisture controllers.

In addition to imparting smoothness and low gloss levels, the hard nip calender can be manipulated to correct poor profiles coming from the making/coating machine. Calliper variations in the un-calenderer sheet that cannot be completely corrected in the hard, straight (uniform) nip can be addressed by deforming the nip at the appropriate position to alter the specific nip pressure. Wide variations can often be controlled by zone-controlled crown compensating rolls. The more usual way to address localised calliper variations is to deform the nip at the offending area by increasing/decreasing the roll diameter at this point. A number of specialised components are marketed to do this, all of which can be linked into on-line scanners, which continuously monitor all the variables. Calliper control units alter the roll diameter by either microscopically increasing the roll diameter by heat (hot air or induction heating) or by reducing the roll diameter in the same proportions by cooling (cold air). Some units use a combination of hot and cold air. In this way the calliper of the product can be controlled continuously within very fine tolerances (in microns). This method of control does increase the density of the product in localised areas, as mentioned previously.

Board products are invariable processed through a multi-nip calender. Often the calender processing board is fitted with water boxes that are mounted in such a way that the rotation of the roll picks up a film of water.

The addition of water has the effect of plasticising the fibres resulting in an increased smoothness to the finished product. Other solutions such as starch, wax emulsions, and alginate solutions are employed to improve oil, water and scuff resistance, for example, which could be important in the end use of the board. This method of application is surprisingly versatile. It is quite normal for

a calender fitted with water boxes (wet stack) to be followed by another calender without water boxes (dry stack) for imparting a final finish. It is most important that such installations are kept under strict control otherwise the rigidity of the board can suffer.

SOFT NIP CALENDERS (SCC)

As today's most widely accepted procedure for finishing coated papers is by using a supercalender it became inevitable that ways and means would be developed to transfer this type of technology directly to the paper/board machine and coating machine. The idea of putting a supercalender on the end of a paper machine is not new and many attempts have been made. Their failure has been the ease with which the soft bowls would mark especially when feeding through; the bowls were not resilient and all marks would persist. Quite obviously the speed of the calender is linked to the speed of the machine and it was not possible to feed the stack on crawl as is the practice for an off machine unit. Neither was it practical to run the stack without paper for a period of time to "run out" any marks.

The earliest of examples of the soft nip or soft compact calender (SCC) can probably be traced back to the early 1960s with the appearance of the gloss calender. These calenders were used almost exclusively on board grades and used softer covered resilient rolls at much slower speeds than present day SCCs. Even today an SCC on board grades will normally operate with a softer cover than an SCC for paper grades.

In an SCC the nip is formed by a metal, temperature-controlled roll (TCR) and a crown compensated roll with a soft cover. The number of rolls, the temperature of the metal roll, the nip pressure and the type of resilient cover are determined by the required paper/board properties. That side of the sheet requiring surface treatment runs in contact with the metal roll, therefore, if both sides of the sheet need to be treated then 2 nips are required

Dull (matt) grades are calendered with low temperature in the metal roll with the specific nip pressure (line pressure) imparting the necessary smoothness. For more glossy products the temperature of the heated roll is much higher (up to 200 C) to achieve the highest gloss levels. The higher temperature of the heated roll also has a marked improvement on the smoothness, but primarily supports the development of gloss. It follows therefore that high temperature supporting the development of smoothness and gloss with reduced line pressure can influence bulk also.

The types of covers differ in their physical characteristics of hardness, elasticity, thermal and mechanical stability as well as resistance to marking. The harder covers with higher elastic modulus are used for calendaring paper, whereas softer covers are used for finishing board, especially when the consideration is saving both bulk and rigidity. The softest covers can achieve high gloss but smoothness is distinctly reduced.

During operation, the temperature of the soft cover is usually some degrees lower than the ingoing sheet temperature, due to the short dwell time in the nip. More important is the temperature of the heated metal roll that can be many degrees higher than the product. Depending on the type of roll cover, maximum surface temperatures of between 80 -130°C can be allowed. Equally, if not more important is the temperature difference between the cover inside and outside the edges of the web that has to be kept within very close limits to avoid thermal stressing. On low grammage papers, because of the deformation of the cover due to nip pressure, contact between the heated roll and cover can occur. This can result in an undesirable increase in the cover temperature outside the paper width. Special arrangements have to be made to apply auxiliary cooling devices to the cover in these exposed areas. Usually infra red sensors are used to monitor the cover temperature and control the cooling devices to prevent the cover becoming overheated and thus susceptible to failure.