# Table of contents

1. Diagram of the manufacturing process 3
2. Preparation of pulp 4
   2.1. Disintegration 4
   2.2. Deflaker 6
   2.3. Refining 6
   2.4. Mixture of additives 12
   2.5. Cleaning 15
3. Sheet formation 18
   3.1. Forming table 19
4. Wet pressing 20
   4.1. Pressing stages 22
   4.2. Pressing variables 23
   4.3. Types of presses 23
5. Drying 24
   5.1. Mechanisms of drying 26
   5.2. Steam 27
   5.3. Condensates 29
6. Coating of paper 30
   6.1. Elements involved in coating 32
   6.2. On-machine coating 34
   6.3. Off-machine coating 36
   6.4. Variables involved in the coating layer 39
   6.5. Most notable defects in the coating layer 40
7. Calendering 41
   7.1. Types of calendering 42
   7.2. Pressure of calendering 43
   7.3. Characteristics of calendered paper 43
   7.4. Defects produced in calendering 44
8. Winding process 45
   8.1. The winder 45
   8.2. Double-drum winder 45
8.3. Winder with individual winding process 46
8.4. Tests on the reel 48
8.5. Defects arising during the winding process 48

9. Cutting 49
9.1. Cutting machine 50
9.2. The unwinding process 51
9.3. Trimming 52
9.4. Final operations 54

Summary 56
The Spanish regulation UNE (57003) defines paper as a sheet mainly composed of cellulose fibres of natural origin, felted and interwoven. Above a certain substance (250 g/m²) and certain rigidity, the paper is known as cardboard.

1. Diagram of the manufacturing process

The manufacturing process of paper is divided into a series of operations which are set out below.

- **Preparation of the pulp:**
  - Disintegration.
  - Deflaker.
  - Refining.
  - Mixture of different additives.
  - Cleaning.

- **Formation of the sheet:** Forming table.

- **Wet pressing.**

- **Drying.**

- **Coating.**

- **Paper finish:**
  - Calendering.
  - Winding process.
  - Cutting.

In the following sections the basic concepts will be described regarding each of these operations that make up the paper manufacturing process and whose action can be seen in the following diagram:
Fig. 4: Diagram of the paper manufacturing process.

2. Preparation of the pulp

The preparation of the pulp is the first operation that has to be carried out in the manufacture of paper. In fact, the pulp has to be "put" in the right conditions to make it suitable for "making" paper.

Normally, when we speak about "pulp preparation" we are referring to the following operations that will be described in later sections:

- Disintegration.
- Deflaking.
- Refining.
- Mixing of different additives.
- Cleaning.

2.1. Disintegration

Paper mills can obtain the paper pulp themselves (in this case they are known as "integrated mills") or, alternatively, use the pulp that they receive from other mills (known in these cases as "non-integrated mills").
In a paper mill where the pulp is not made on the premises, the pulp is received in the form of pressed sheets which have to be broken down in water so that the pulp is suitable for use. Paper trimmings which are produced in all factories as a consequence of breakage, trimming or shreds, edges of reels, etc., are also reused or recycled in the process and they need to be broken down again in water. This operation is called disintegration.

When the mill itself has the facilities for producing the pulp this operation is not required, as the fibrous suspension (water and fibres) passes directly to the refining operation.

Disintegration is a mechanical operation by which pulp presented in the form of sheets or pressed boxes and which needs to be broken down is placed in a water suspension.

This operation of breaking down the bales of pulp, or cutting, to separate the fibres, is carried out in a machine known as a pulper. Subsequently, the fibres must be subjected to a series of operations which will alter them and thus provide the properties required for obtaining a certain type of paper.

The pulper

The pulper is a high performance machine in which the disintegration operation is carried out. It is made up of a cylinder shaped recipient, which has a propeller in the bottom part, which shakes up the sheets of pulp that are placed in it. By means of the continuous rubbing of the pulp against the propeller, the fibres which form the bundle of pulp are separated, leaving a suspension in the water with a consistency (percentage of dry material) of between 6% and 12%.

![Diagram of the pulper](image-url)
When the sheet is broken down, the pulper is emptied and the pulp passes through a grating which does not allow the passage of large fragments which have been insufficiently broken down. The pulp is deposited in a vat or drum for its subsequent use.

2.2. Deflaking

The pulper is not always the most suitable piece of equipment for carrying out the final stage of the disintegration process (stage in which total disintegration of the fibres is achieved) due to the excessive use of energy which this stage causes. To solve this problem more suitable machines, known as deflakers are used for total disintegration.

The deflaker is a machine composed of three discs (they can be perforated or grooved): two static external ones with barbs and projections, and the other central disc which revolves at great speed. During the movement of these discs the fibres are subjected to violent collisions and, having to pass through narrow pipes, they are broken up resulting in total individualization.

![Deflaker](image.jpg)

Fig. 6: Deflaker.

The fibres obtained originally from wood or other plants need refining to develop or improve certain properties necessary for the adequate formation of the sheet and its subsequent use. Each paper requires a particular refining process which improves specific characteristics. With this operation the pulp acquires specific qualities for the production of different types of paper: paper for printing, packaging, plant-based paper, etc.

2.3. Refining

The fibres obtained originally from wood or other plants need refining to develop or improve certain properties necessary for the adequate formation of the sheet and its
subsequent use. Each paper requires a particular refining process which improves specific characteristics. With this operation the pulp acquires specific qualities for the production of different types of paper: paper for printing, packaging, plant-based paper, etc.

**Refining is the operation in the preparation of the pulp in which, through the action of mechanical work and in the presence of an aqueous medium (water), the morphology of the fibres and their physical-chemical structure is changed.**

![Fig. 7: Principle of refining.](image)

The equipment used for carrying out the refining process is called the refiner (fig. 8), and is based on two elements; one static (stator) and the other rotational (rotor), between which the pulp is made to pass. These elements (rotor and stator) are equipped with metal bars or knives made of special alloys known as fittings, whose composition and tempering are studied in relation to the fibres to be treated and the paper which is to be obtained.

![Fig. 8: Diagram of a disc refiner.](image)
There are several different types of refiners, the most commonly used being the following:

- Hollander.
- Low-angle conical refiners.
- High-angle conical refiners.
- Disc refiners (these are generally the most commonly used).

The operation of refining requires high energy consumption. Nevertheless, most of this energy is used to make the machine move, and not for the operation of refining in itself, in which the cost is relatively low.

To understand the refining process it is necessary to remember what fibre is and what it is composed of. Therefore we will now briefly review each item.

**Composition of the fibre**

The fibres are composed of different chemical compounds. The most important are the following:

- **Carbohydrates (cellulose and hemicellulose):**
  - **Cellulose.** Constitutes approximately 40% of the total. It is a carbohydrate (carbon, oxygen and hydrogen), which essentially contains glucose. It forms a tridimensional crystalline network of which the external area is amorphous and hydrophilic. Three different crystalline states can be distinguished:
    - **α-cellulose,** long chains of glucose; hydrophobic and insoluble in soda.
    - **β-cellulose,** with shorter chains than α-cellulose. Formed by decomposition of α-cellulose in the cooking and whitening; soluble in soda and precipitates in acid. This is the amorphous fraction.
    - **γ-cellulose,** with short chains of glucose; soluble in soda and does not precipitate in acid. About 40% is also partly amorphous.

  Thus one part of cellulose is crystalline, which puts up resistance, while the other is amorphous and can be hydrated.

  - **Hemicellulose.** Contains up to five different sugars. In addition:
    - Structured in short hydrophilic ramified chains; it has an affinity for water and favours the swelling of the fibres and the union between these.
    - It is easily refined and gives the paper resistance.
About Paper
Paper Manufacturing

- **Lignin.** Is a dark coloured highly variable chemical compound, which causes ageing of the paper. In addition:
  - Does not allow hydration (absorption of water), so it serves no purpose in the manufacture of paper.
  - It is eliminated by means of cooking (it softens at temperatures of 130 to 160 °C).
  - It can be present in quantities up to 25%.
  - A small fraction may remain of the 3% of lignin bound up with cellulose, which cannot be eliminated.

- **Other compounds.**
  - **Resins.** Substance of dough-like consistency which creates problems in the manufacturing circuits.
  - **Tannins.** Make bleaching difficult.
  - **Mineral material.** The content is low (0.2 - 1%).

**Fibre structure**

The fibre is made up of different layers (fig. 9), integrated in a primary and secondary wall (each composed of three different layers):

- **Primary wall.** This is very fine and contains few filaments, crossed between each other and lying almost perpendicular to the fibre shaft. It may contain up to 50% lignin and is that which disappears during bleaching and cooking in the production processes of the pulp.

- **Secondary wall.** This consists of three very different layers:
  - **External secondary wall** (also known as the transition sheet). This is made up of two layers of microfibrils which are aligned in opposing directions. It has little capacity for swelling. It contains lignin.
  - **Main secondary wall (or middle).** This is the widest. It is made up of microfibrils aligned almost parallel to the fibre shaft. It consists almost totally of cellulose. It has high swelling capacity and makes the paper rigid and strong. It is highly useful in paper manufacture. In refining it is easily fibrillated, increasing the specific surface and facilitating interfibrillar unions in the paper.
Secondary internal wall (or tertiary wall). This is very fine. There are many microfibrils and they are squeezed together. The main constituent is hemicellulose and it has great swelling capacity.

Effects of refining

During refining, the "primary" and "outer secondary" walls of the fibre break and are partially removed. The penetration of the water to the inside is therefore possible, causing "swelling". It also permits the release of internal fibrils which separate and produce a formation of finer microfibrils on the surface of the fibre.

Owing to all these effects, the fibre becomes more flexible and softer, at the same time increasing its surface and specific volume. All these effects can be grouped into three:
**About Paper**  
**Paper Manufacturing**

- **Hydration.** This occurs when, owing to beating or agitation of the fibres in the refiner, the water penetrates between the fibrils producing a hydration effect in the fibre. This is due to the fact that the water and the cellulose combine via a chemical reaction.

- **Fibrillation.** This is the releasing and separation of fibrils produced by the partial rupture of the walls during the rubbing of the refiner knives and the fibres against one another.

- **Trimming.** This is the effect caused by the action of the blades on the fibres, producing breakage (cuts) and therefore decreasing its length.

**Properties affected by refining**

The operation of refining influences differently the technical and mechanical properties of the manufactured paper, increasing some and reducing others. Some of these properties will now be given:

<table>
<thead>
<tr>
<th>Properties which increase</th>
<th>Properties which decrease</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Apparent density (g/cm³).</td>
<td>- Porosity.</td>
</tr>
<tr>
<td>- The traction index (N m/g)</td>
<td>- Opacity.</td>
</tr>
<tr>
<td>(increases the length of tear).</td>
<td>- The drainability of the pulp.</td>
</tr>
<tr>
<td>- Transparency.</td>
<td>- The volume index.</td>
</tr>
<tr>
<td>- Lengthening (%).</td>
<td></td>
</tr>
<tr>
<td>- Internal cohesion (Scott).</td>
<td></td>
</tr>
</tbody>
</table>

The operation of the refiner is verified by an apparatus known as SCHOPPER-RIEGLER, which is based on the drainability of the pulp; in other words, the speed with which the pulp allows the absorbed water to drain off. This measurement is expressed in "Schopper-Riegler degrees (°SR)".
2.4. Mixture of additives

In the manufacture of paper it is essential that the final result has a number of characteristics and properties suitable for each different use (writing paper, paper for magazines, toilet roll etc.) the paper is designed for, and which cannot be obtained with fibre alone.

In the pulp preparation process the characteristics of the raw material (fibres) are already conveniently modified through chemical-mechanical procedures, such as refining; but this alone is not enough. In addition, there are properties whose optimization conflicts with these processes, for example, resistance and opacity.

During paper production it is normally not sufficient to use different types or blends of plant fibres to create different products with the necessary conditions. Therefore, according to the type of paper being produced, a number of non-fibrous products must be added to the fibres which change their own properties as well as those of the paper obtained from them, and which we can divide into two groups:

- Additives.
- Auxiliaries.

Additives

These are products which are added in the manufacturing process in order to change the characteristics of the paper. The most commonly used are:

- **Loading and pigments.** These are additives which are inorganic by nature (of mineral origin). As their chemical composition is basically the same, the essential difference between them is that the pigments have a smaller particle size, and whilst the loading is applied to the mass, the pigments are applied on the surface.

  - **Loads** are white mineral particles, which are used as filler in the spaces between fibres, with the aim of improving certain properties of the paper, such as opacity and whiteness. They also increase the quality of the print by improving the surface. However, their use also has some disadvantages, as a decrease in the mechanical resistance of the paper is caused through the decrease in binding between fibres, resulting in limited formulations.

  - **Pigments** contribute to improving certain properties of the paper (especially whiteness, opacity and suitability for printing). Pigments are used especially on the "surface", using a process known as coating.
Colorants. Basically used to give the paper a specific colour, improving the tone of the paper at the same time.

Optical brightening agents (O.B.A.). These compounds have the special feature of providing the property of emitting a bluish luminosity to papers that contain the said compounds when they are in the presence of ultraviolet light, being optically whiter.

Resins to provide resistance in wet conditions. These are products (resins) which are added to help maintain the resistance of the paper when its use involves the need to resist the action of the water. These resins have this property thanks to the formation of chemical bonds between the resin and fibre that impede bonds between the fibre and water (the water cannot bind to the fibre as this is "coated" by the resin).

Binding agents. These products (a type of "adhesive") are added in the coating process to bind the pigments together and, in turn, become fixed to the surface of the paper (as the fibre is naturally an organic and fibrous component, and the pigments are naturally inorganic, in the form of particles, their union cannot be made without the inclusion of a binder).

Products sizing. Are those which are used for providing resistance to the penetration of liquids in the paper, that is, their purpose is to produce a paper that is more water impermeable.

Products to provide resistance in dry conditions. These are products used for improving the strength of the fibre to fibre unions individually thanks to the creation of supplementary hydrogen bridges between the fibres, without the need for excessive refining (refining increases dry resistance, but reduces drainage in the manufacturing wire, thus increasing energy consumption in drying).
Auxiliaries

These are products which do not change significantly the properties of the paper, their main purpose being to facilitate work and help in the manufacturing process. The most commonly used are:

- **Anti-foaming agents.** Their job is to remove or impede the formation of the foam that is usually produced in different points of the paper machine, as this foam reduces the quality of the paper and causes breakages and defects.

  The foam prevents the oxygenation of the water, and in closed circuits without a fresh water supply it can be a problem due to the growth of facultative anaerobic bacteria. Furthermore, the foam is an emulsion which may cause the agglutination of carbonate forming deposits on the surfaces of the conduction channels.

  An anti-foaming agent should be accompanied by well-designed facilities without water spouts or turbulence and with efficient "foam killing" sprinklers.

- **Microbicides.** These products are used to prevent the possible formation of colonies of bacteria or other microorganisms which adhere to the walls of vats or circuits, felts and other parts of the machine. Due to the moisture in this area, these microorganisms experience perfect breeding conditions and can cause soiling of the paper, breakage of the belt, infections, etc.

- **Retention agents.** Retention agents are added in the manufacture of the paper to improve the binding of different additives, crills (pieces of fibre) and loads, thus preventing these from going into the white water of the dewatering in the forming table, which would result in economic loss and problems in the circuits. Using retention agents components can be added to the paper little by little; otherwise, these components can cause deposit or pitch problems, by accumulating in the circuit of drained water which could result in holes and breaking.

---

**Non-fibrous products (additives or auxiliaries) can be applied in two ways:**

- **In the "mass":** when applied during the pulp preparation process.
- **On the "surface":** when the sheet is already formed. In this method a machine known as a "Speed Sizer" is often used.
2.5. Cleaning

During paper manufacturing it is essential to control the elements that are to become part of the sheet. During the pulp preparation process, this control is carried out using cleaning systems which separate the fibres, or products considered to be good, from all those undesired particles which harm the paper and can even cause problems during manufacturing.

The main objectives of cleaning are:

- To obtain clean paper, without stains.
- To prevent breakage and wear in manufacturing.

Cleaning is a process by which undesirable particles are removed during the manufacturing process or from the finished paper.

Cleaning can be carried out at different times during the paper manufacturing process: at the exit of the pulper, at the machine head, etc. Depending on the type of paper, a greater or lesser cleaning will be carried out (for example, an "Ink Jet" paper will require greater exigency in the cleaning process than a wrapping paper).

Origin and classification of impurities

Impurities can be classified as:

- Impurities in **weight** (heavy and light): sands, staples...
- Impurities in **size** (voluminous and slight): splinters, sticky substances...

The origin of these impurities can differ:
Impurities of the pulp itself: Splinters, resins, ash, etc.

Caused in transport and storage: Sand, wires, strings, metals, etc.

Caused in manufacture: Filings, splinters, sticky substances, oil, etc.

Cleaners

The apparatus where cleaning takes place is called a cleaner. There are two types of filtration systems depending on the working method:

- "Probabilistic" or "grooved and perforated" cleaners. This type of cleaner removes relatively large particles. This is based on the probabilities that a particle will cross a perforated mesh or sieve. Sieves or meshes with slots are usually used for pulps, and sieves with perforations (holes) are used in paper manufacturing.

  The cleaner consists of a sieve with slots or holes, depending on the case, that prevents bulky particles from passing through it, thereby separating them from the fibres. These are smaller and can pass through the slots or holes. There are two types of probabilistic cleaners: flat vibrating and pressure closed.

- "Dynamic" or "cyclonic" cleaners. This type of cleaner removes the heaviest particles. A cyclonic cleaner, known as a "cleaner", consists of a plastic or ceramic cone (more long-lasting but more expensive) depending on the treatment phase and the type of load added to the machine. It has an upper outlet for the acceptable pulp and a lower nozzle for the residue particles (fig. 12).

  The pulp is fed in at an input pressure which creates a kind of eddy and, through the effect of the centrifugal force of rotation of the pulp, the heaviest particles (impurities) go towards the wall, sliding towards the lower nozzle and producing what is known as "residue". The lighter particles remain in the central layers, finally leaving through the upper part at a different pressure to when they enter.
Both cleaning systems are complementary and necessary during paper manufacturing. This is due to the specific properties and aims of each.

**Secondary cleaning**

Secondary cleaning consists of repeating the cleaning of the residue that results from primary cleaning, to ensure that not much pulp is lost during this first phase. This process can be carried out up to three and four times to achieve a higher performance and lower efficacy. When the residue has an insignificant amount of fibres it can be emptied directly into the drainage system.

The pulp accepted during secondary cleaning is never taken as final, and is cleaned again.
The diagram below shows the journey taken by the pulp during cleaning before it passes to the manufacturing machine.

3. Sheet formation

Once the paper pulp has been provided with the necessary properties and the mixture of raw materials has been correctly prepared (fibres, additives, pigments, etc.) in the mixing box, the following stages in the paper manufacturing process will basically be the same as for any type of paper.

From this point the formation of the sheet will be carried out, which involves transforming a volume of the diluted pulp into a fine, wide and uniform laminate, with all the components perfectly distributed. This laminate forms that which later will be the sheet of paper.

In the paper industry, sheet formation is understood as the way in which the fibres interlink with one another (this can be seen by looking at the sheet in transparency). This sheet formation is carried out in two well-differentiated parts of the machine:

- **Head box.** The headbox is responsible for the output of pulp onto the forming table, in the form of a thin, wide and uniform sheet (the pulp arrives previously through round tubing).

- **Forming table.** The forming table is responsible for producing the sheet and reducing part of the water contained by the pulp.
There is a **critical area** in the paper machine which goes from the entrance of the box to the first few metres of the forming table. We could say that the sheet is virtually made in this critical area, where its main structure and characteristics are set:

- **Arrangement of the fibres**: This should be as uniform as possible.
- **Orientation of the fibres in a longitudinal direction** (running direction of the machine) or in a transverse direction.
- **Homogenous distribution of the loading and fines**.

### 3.1. Forming table

As we have seen, the forming table follows on from the head box, and its purpose is the **dehydration of the pulp** (eliminating a great quantity of the water it contains) and the **formation of the paper sheet**.

A forming table is made up of a series of components which permit, each in its own way, the process of sheet formation to be carried out conveniently. The pulp, sent via the lip of the head box, is deposited on a continuous "wire", which is responsible for transporting the fibres along the forming table. The sheet is consolidated during this journey, passing the different elements and carrying out the effect of dewatering (removal of water).

As the water is removed, the fibres are deposited on the surface of the wire, constituting what will be the sheet of paper. The dewatering on the forming table is carried out in two stages:

- **1st stage: dewatering by gravity**. On the first few metres of the table, the water is removed passing freely through the wire by the effect of its own weight (force of gravity) and by the slight depression created in some elements of the table ("foils", "dandy rolls"...). The fibres are retained in the upper part of the wire.
**2nd stage: vacuum dewatering.** When it is no longer possible to remove more water by using the force of gravity, vacuum elements are used which, by the effect of a suction force, remove the water that would have remained between the fibres. These elements are the "vacuum foils", the "suction boxes" and the "suction cylinders", with the strongest being placed at the end. Up to 20% dryness can be achieved.

**Classification of forming tables**

Paper forming tables can be classified as:

- **Conventional flat table.** With this type of table, the bottom side of the pulp laminate, known as the wire side, is held over the wire, while the top side, known as the felt side, is left free.

  The dewatering takes place in a single direction, that is, downwards. Due to this, the two sides of the paper tend to have a different configuration, and a sheet is usually rougher on the wire side than on the felt side.

- **Double wire table.** On this type of table, the two sides of the sheet are in contact with the wire. In this case it is possible to direct the dewatering upwards as well as downwards with the help of suction boxes. In this way a more symmetrical sheet where the two sides are more equal is obtained.

**4. Wet pressing**

In the paper production table, with the help of a series of dewatering elements, it is possible to eliminate a part of the water contained in the sheet. Subsequently, on its route until its finished formation, the paper needs to eliminate the rest of the water it contains.

The drying procedure that is used immediately after the forming table, is known as wet pressing, and can therefore be considered as a continuation of the water elimination process which started on the forming table.

On leaving the forming table and entering the pressing section, the sheet of paper has an approximate 20% consistency, that is, it contains approximately 80% water. At the end of the pressing operation it will be left with approximately 60% water. In this process, the sheet is transported along rolls that put pressure on the paper and manage to extract up to 20% more of the water, while at the same time, they give the paper certain surface and resistance qualities that are favourable for its subsequent use.

In the pressing section, the sheet is transported along a series of presses where a large part of the water is eliminated and the sheet is consolidated (the fibres are forced into close contact) for subsequently facilitating the drying operation. Wet pressing is carried out by passing the sheet between the rolls (Fig. 16), in contact with the felt.
A type of pressing process was carried out many years ago, when housewives passed their washed clothes through rolls, using a crank. Using this system, they managed to eliminate the vast majority of the water and, at the same time, stretch the fabric.

The felt is a fabric which turns around the rolls of the presses and which is responsible for transporting the sheet and absorbing the water, thanks to its great capacity of absorption. Throughout its journey, it is washed and dried, for each new contact with the paper.

The rolls are responsible for applying pressure to the paper, which then releases the water to be absorbed by the felt, in order to then be evacuated.

The principle functions of the pressing process are:

- The extraction of the maximum amount of water possible, uniformly along the width of the machine.
- High levels of efficiency and machinability, providing the sheet with greater resistance in the pressing zone or damp part.
- Energy saving in the process which takes place after drying.
- To maximize the quality of the sheet, giving it surface smoothness, without reducing its thickness in excess, and assuring that both sides are the same.
4.1. Pressing stages

On of the main objectives of the pressing is the dewatering of the paper, which will depend on different parameters (pressure, grammage of the paper, speed, water content, etc.). The paper pressing process can be divided into four stages, which are differentiated according to the action of the various parts (fig. 17).

The four pressing stages are:

- **Compression and saturation of the sheet (stage I).** This involves the entrance of the sheet into the pressing zone through to the moment in which it reaches saturation point. During this stage, due to the compression, the air leaves the sheet via the pores in the paper, which are full of water. The water fills the sheet to the point where it becomes saturated; or, in other words, it contains the greatest possible amount of water. During this stage, there is no increase in water pressure and the water does not yet pass from the sheet to the felt.

- **Compression and saturation of the felt (stage II).** This involves the moment during which the sheet is saturated with water through to the moment of maximum water pressure (more or less half way through the pressing zone), where the felt reaches saturation point. Once at this stage, the sheet is already saturated, and the increase in hydraulic pressure provokes the movement of the water contained in the paper towards the felt; in other words, it produces a process of dewatering in the paper. The felt starts to absorb water, until the point where it becomes saturated.

- **Expansion of the felt (stage III).** This involves the moment in which the hydraulic pressure (water pressure) is at a maximum, through to the moment when the sheet is at a point of maximum dryness. During this stage, the pressing zone expands to the point where the pressure of the fluid contained in the paper
is null and void. The felt expands at a faster rate than the sheet, and for this reason it sucks up the water. The dewatering of the paper continues until the point where the sheet has eliminated the maximum quantity of water possible.

- **Expansion of the sheet (stage IV).** This involves the moment in which the sheet is at a point of maximum dryness, through to the moment wherein it is separated from the felt. During this stage, the paper and the felt become decompressed and the paper is no longer saturated. The hydraulic pressure is converted into "negative"; in other words, a vacuum is produced in the paper, in a more accentuated way, and this produces a return flow of water from the felt to the sheet. This last action of the return of water towards the paper must be avoided and therefore the following must be observed:
  - A narrow contact zone, used to reduce water return time.
  - A rapid separation of the paper and the felt.

### 4.2. Pressing variables

The main variables which affect the features and working order of the presses are summarised below:

- **Type of presses and their configuration.**

- **Speed of the machine:** at low speeds, low pressures should be used in the operation, while at high speeds, high pressures should be employed.

- **Pressure in the pressing area:** As the machines become faster, the pressures become greater.

- **Wetness of the sheet as it enters the press:** a dryer paper can withstand greater pressure while a very wet paper will break up.

- **Wetness of the felt:** the dryer the felt, the longer it will take to become saturated and the more water it is capable of draining.

- **Types of felt and conservation:** using the most suitable felt and keeping it in good condition will greatly favour the dryness of the paper.

- **Properties of the paper (composition, degree of refining, compressibility, grammage, temperature, etc.).**

### 4.3. Types of presses

The most important thing when designing a press is to design it in such a way that it makes sheet dewatering easier. For this reason, it is very important to provide the water which leaves the pressing zone with the shortest possible route for its eventual evacuation.
Theoretically, the shortest distance for dewatering coincides with the thickness of the felt and, for this reason, the main flow of water must be perpendicular to it and as vertical as possible. In accordance with the way to make dewatering easier, the following classification of presses can be made:

- Nip rolls.
- Vacuum cylinder paper making presses.
- Shoe presses.
- Transverse presses:
  - Fabric press.
  - Vented nip press.
  - Blind drilled press.

### 5. Drying

When the paper comes out of the press section, its water content is usually about 60%. From this point it is not possible to eliminate more water by physical means; this can only be done through the application of heat. This is carried out in the drying operation, whereby the moisture of the paper will be reduced to 5% water, which is the content that it must have at the end of the manufacturing process.

The drying operation is carried out in an area known as the drying section, in which the heat causes the water in the paper to evaporate leaving it dry. At the end of this operation, the paper will have eliminated practically all the water it contained, leaving a slight dampness (approximately 5%) which is necessary in its final composition to maintain elasticity.

The drying operation is the most costly part of the paper manufacturing process. For this reason, special care is required during the development of the operation to reduce costs as much as possible.

The water found in the paper before being eliminated can be one of three types, as shown in the following table:

<table>
<thead>
<tr>
<th>Types of Water in the Paper Before Drying</th>
</tr>
</thead>
<tbody>
<tr>
<td>Absorbed water</td>
</tr>
<tr>
<td>- That which fills the hollows in the paper.</td>
</tr>
<tr>
<td>- Found in 20%-30%.</td>
</tr>
<tr>
<td>- Easy to eliminate.</td>
</tr>
</tbody>
</table>
The drying of the paper consists in applying a great amount of heat to the sheet, through the appropriate method, with the aim of raising its temperature until evaporation of the water is achieved. It is a chemical process, as it causes a change of state, from liquid to vapour.

The drying operation produces the following:

1. An **energy transfer** (heat is applied to the sheet).
2. A **mass transfer** (water in the form of steam that must be eliminated rapidly out into the atmosphere).

However, the effectiveness in the water evaporation depends on:

- The temperature.
- The quality of the ambient air.
- The circulation of the air in the dryer section.

**The aim of the drying operation is to obtain:**

- A homogeneous formation of the sheet.
- A homogeneous drying profile.
- A regular distribution of temperature to the sheet.
- An effective and balanced ventilation.
5.1. Drying mechanisms

The heat transfer used to heat the sheet in the drying operation is produced mainly in two ways:

- **By Conduction.** Carried out through the body (from molecule to molecule).
- **By Convection.** The way of spreading heat within fluids (liquids and gases). When fluids are heated they have less density than when they are cold, therefore they tend to rise.

If we take hold of a metal bar and heat the other end, the heat progresses along the bar until we can feel the heat in the end we are holding. In this case, the heat is transferred by “conduction”.

When we turn on the central heating at home, the air heats up and rises to the highest parts of the room displacing the cold air and sending it downwards. The cold air starts to heat up in the same way until all the air in the room is at the same temperature. What we are experiencing is heat transfer by "convection".

Based on the various methods of heat transfer, there is a wide variety of drying systems in the manufacture of paper:

- **Drying by through-air.** By means of the passage of hot air through the porous structure of the paper. Used in production of tissue paper, paper towels, filter paper...

- **Drying with Yankee cylinder.** Through contact of the paper over a huge steam heated cylinder. Used in the production of carbon paper, glassine paper, paper for wrapping bread...

- **Drying by air jet.** By means of a jet of hot air hitting the surface of the paper. Used for drying the coatings on many types of paper.

- **Infrared drying.** Used for drying coatings and for pre-drying the sheet. Widely used in coated papers.

- **Drying with heated cylinders (multi-cylindrical dryer section).** This is the method generally used for drying any type of paper. It consists of a series of steam heated cylinders varying in diameter. The paper stays in contact with the top cylinders on one sheet side and with the bottom cylinders on the other, enabling drying on both sheet sides. In this drying method felts are used (except in the manufacture of cardboard) to keep the sheet in contact with the cylinders.
5.2. Steam

Steam is a great transporter of energy which has the following advantages:

- Water is used for its production (there are large amounts, it is economical and easy to obtain).
- It is easy to control (at each temperature there is a specific corresponding energy and specific volume).
- It transports large quantities of energy per unit of mass and is easily distributed.

### TYPES OF STEAM ACCORDING TO THEIR QUALITY

<table>
<thead>
<tr>
<th>Type of Steam</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Saturated steam</td>
<td>This is a steam that is completely produced by evaporated water, that is, it contains no water droplets.</td>
</tr>
<tr>
<td>Wet steam</td>
<td>This steam contains water droplets in suspension. This steam increases erosion in the pipes and reduces heat transfer.</td>
</tr>
<tr>
<td>Reheated steam</td>
<td>This steam is found at higher temperatures than that of saturated steam, thus guaranteeing that it contains no water droplets.</td>
</tr>
</tbody>
</table>
It is important that the steam contains no impurities (remains of solids from the water itself, corrosion of the pipes, solder remains, etc.). To eliminate these impurities filters are installed in the pipes. Neither must it carry water droplets (they produce corrosion in the pipes) nor air (negative effect in heat transfer). Purgers are installed for the elimination of both.

As we have seen, the evaporation of the water from the paper is performed by heating the latter as it comes into contact with the hot metal of the drying rolls. These rollers, in turn, are heated by the introduction of steam. This steam comes from a boiler and is conducted through a pipe until it reaches the cylinder entrance, through which it is introduced by means of a "steam box", which joins the dryer with the pipe.

Reheated steam is used to avoid condensation in the pipes during the conduction of the steam to the drying cylinders.

**SATURATED STEAM AND REHEATED STEAM**

When water is heated to a determined pressure, its temperature rises until it reaches boiling point or saturation temperature, which is when it starts to boil. The heat required for carrying out this temperature increase is known as sensitive heat. Once the water has reached boiling point, all the heat applied after this point will be used to carry out the change in state from liquid to vapour. This is heat is called latent heat.

The steam from pure water is an invisible gas, but when the water boils, miniscule water droplets are swept up by the steam, making it visible. In this case it is said that the steam is humid. When air, at a determined temperature, absorbs steam from water until it can no longer admit any more water, the steam is said to be saturated, that is, it has reached the degree of saturation.

Saturated steam is that which is found at saturation temperature. If this steam is heated further (without varying the pressure and without producing any change in state), to above saturation temperature, the result will be reheated steam.

When the reheated steam enters the dryers and comes into contact with the walls of the cylinders it transfers heat through them, decreasing its temperature until it reaches that of saturation. At this temperature the steam is condensed (water droplets appear), recovering the heat (latent) that it had previously acquired in the boiler.
APPLICATION OF STEAM

<table>
<thead>
<tr>
<th>IN THE BOILER</th>
<th>IN THE DRYERS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water + Heat → Steam</td>
<td>Steam → Water + Heat</td>
</tr>
<tr>
<td></td>
<td>(condensates)</td>
</tr>
<tr>
<td></td>
<td>(heats the dryers)</td>
</tr>
</tbody>
</table>

Ventilation of the drying section

During drying, the steam formed from the evaporation of the water contained in the sheet of paper is mixed with the air that surrounds the dryer section. As the air temperature rises, this in turn increases the capacity to admit steam (raising its saturation temperature), thus improving the drying speed.

However, as this air absorbs the water it tends to become saturated, reaching a point at which it can no longer receive more steam from the evaporation of water from the paper and consequently the drying is slowed down. This is why the air surrounding the dryer section must be kept hot and dry. This is done by extracting the steam saturated air.

5.3. Condensates

We have seen that steam gives heat to the paper through the drying cylinders and that, as it loses heat, the steam starts to condense in drops of water that are deposited inside the cylinder. These water drops are known as "condensates".

The behaviour of the condensates depends on the speed of the machine and can be divided into three types as set out in the following table:
### ARRANGEMENT OF THE CONDENSATES

<table>
<thead>
<tr>
<th>Pattern</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pool pattern</td>
<td>Occurs when the speed of rotation of the dryer is slow. Condensates accumulate at the bottom of the dryer through the effect of gravity.</td>
</tr>
<tr>
<td>Cascade pattern</td>
<td>As the speed increases, the condensates start to rise adhering to the dryer wall, although later they fall back down again due to their own weight, as the rotation speed is not high enough.</td>
</tr>
<tr>
<td>Ring pattern</td>
<td>At sufficiently higher rotation speeds, the condensates adhere to the wall through centrifugal force, forming a layer of uniform thickness in the form of a ring around the inner wall of the dryer. To deal with such cases there are turbulence bars, consisting of a series of bars mounted inside the drying cylinder that break the condensate ring, increasing condensate evacuation and improving the heat transfer profile.</td>
</tr>
</tbody>
</table>

Condensates can affect the operation of the dryers causing:

- **An increase in the weight of the rollers**, slowing down the running and requiring greater energy consumption.

- **A reduction in the effectiveness of heat transmission**, especially in the lower cylinders, as the paper comes into contact with them at the point where the condensates tend to be deposited (in the tank and cascade systems).

The condensed water must be extracted from inside the dryers to avoid problems during drying.

### 6. Coating of paper

When the paper has been formed, its surface is not entirely suitable for ink printing. To improve its surface quality so that inks can be applied easily and successfully, a very important operation is carried out, known as coating, which consists in applying a kind of paint that gives the sheet the smoothness and shine necessary for the ink to adapt well to the paper.
The paper has a porous structure due to the fibres. For this reason, when the paper comes into contact with the printing ink, the latter tends to spread in all directions. To avoid this, it is important to achieve a **smooth** and **even** surface.

With the aim of eliminating or covering the cavities of the paper (macropores) a series of additives are applied that improve the surface, making it smoother, with a view to optimum results in printing, reducing the cavities to a very small size (micropores) although large enough for the ink to impregnate the paper. At the same time, this gives the paper properties such as gloss, opacity, smoothness and whiteness. This operation is called coating, and is carried out exclusively on papers destined for printing or writing.

**Coating can be defined as the operation that consists in covering the surface of a paper or cardboard with a material in liquid form providing the sheet with a series of properties suitable for printing.**

The coating operation principally achieves a series of **advantages** in comparison with a non-coated paper, such as:

- Greater clarity in printed images.
- A paper that is more opaque.
- Reduced ink consumption.
- Sharper outlines.

Fig. 19: Structure of coated paper and that of non-coated paper.

**Coated paper acquires many properties, such as:**

- High water resistance.
- Low absorbency, resulting in lower ink consumption in printing.
- Very fine surfaces.
- pH alkaline, which provides greater ease in drying ink.
6.1. Elements involved in coating

Coating consists in applying a kind of paint, known as the coating mixture or 'sauce', over the surface of the paper. This operation could not be carried out without the involvement of the following three essential elements:

- The medium (paper).
- The coating mixture or 'sauce'.
- The coater.

Below is a brief explanation of each of these elements. In subsequent sections we will cover them in greater detail.

Medium

When we talk about a medium in the coating operation we are referring to the paper the operation is being carried out on. This is presented as a porous body, composed of fibres and fillers, with varying amounts of empty spaces.

The medium must be:

- Homogeneous.
- Resistant.
- Even thickness.
- Opaque.
- Clean.
- Both sides the same.

In order for the treatment to be effective, the surface of the paper must be well formed, without any defects (fig. 20).
The coating mixture is the material or compound that is applied over the surface of the paper, and is made up of:

- Pigments.
- Binders.
- Auxiliary additives.

At the moment the coating is applied, it is in a liquid state, more or less viscous, and should spread easily. Finally it is dried through evaporation of the water leaving a solid layer of coating. The coating layer is prepared in a section known as the coating kitchen.

Using a coater, the 'sauce' or coating mixture, which is previously produced in the coating kitchen, is applied over the surface of the paper. It consists of:

- A tray where the continuously renewed mixture is deposited.
- A filter system.
- A mechanism for applying and measuring out the coating (Backing-Roll).
- A mechanism for evening out the applied layer (blade, roll, air-knife, etc.).
- A drying system.

The mixture can be applied using different systems, which can be carried out in the paper machine itself or separately. Each one of these methods presents a series of advantages in relation to another. Further on we will look at the different 'on-machine' and 'off-machine' systems used and the advantages of each.
Depending on where the operation is carried out, two ways of coating can be distinguished:

- "On-machine" coating: the coater is located inside the paper machine.
- "Off-machine" coating: the coater is located outside of the paper machine.

### 6.2. On-machine coating

The method of machine coating is characterized by the fact that the coater is installed inside the paper machine itself and is used when a high quality finish is not required.

With these machines a gloss or matt finish is obtained, although normally a matt finish paper is obtained. If greater gloss is required this can be achieved later through calendering, in which the paper surface is smoothed, giving it greater gloss. This type of finish is used for text books, brochures, instruction manuals, etc.

The advantages and disadvantages of this type of coating are set out in the following table.

<table>
<thead>
<tr>
<th>MACHINE COATING</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Advantages</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Disadvantages</strong></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

There are various systems of machine coating, among which the following should be mentioned:

- Size-press.
- Speed Sizer.
**Size-press**

The Size-press is a simple treatment which consists in applying a thin layer of coating on the surface of the paper. It is performed by making the paper pass along rolls that exert pressure. At the same time, these rolls form a coating mixture bath, provided by means of a shower rose on each side of the paper.

![Fig. 21: Arrangement of the rolls in the Size-Press.](image)

The Size-press is normally positioned between the first and second drying section, and it can be said that it is really a **precoating**. The most important properties provided by a size-press are:

- Internal cohesion.
- Greater uniformity in absorption.
- Greater smoothness.

**Speed Sizer**

The roll system is similar to that of the Size-press, but the coating bath does not form a pool in the NIP, decreasing considerably the tension that the sheet is subjected to. This is achieved by applying a film of mixture over the surface of each press, which will be transferred to the medium sheet as this comes into contact with the presses.
6.3. Off-machine coating

The coating is carried out in a machine known as the coater, which is separate from the paper machine.

Here the coating consists in the application of an excessive amount of coating mixture over the paper medium, using an applicator system and the subsequent adjustment of the quantity of layer required by means of a dosing system (crossbar-blade).
Applicator system

There are different application systems; the following can be mentioned as representative examples:

- **Roll applicator.** A roll applicator turns semi-submerged in a tray, to which the coating mixture will be transported, and as the applicator turns it transfers the mixture to the surface of the paper.

  ![Fig. 24: Roll applicator system.](image)

- **Roll applicator. Vector system.** Differs from the conventional doser system in that there is a middle support roll. In this way, the effect of centrifugal force on the coating mixture deposited on the surface of the paper is prevented due to the passage being linear from the exit of the applicator to the doser system.

  ![Fig. 25: Jagenberg vector head.](image)
Jet type applicator system. The coating mixture is applied directly on to the sheet of paper medium, projecting a jet of coating mixture in laminate form from a nozzle. This system, besides distributing the coating mixture to achieve uniform distribution right across the sheet, requires a process of deaeration of the coating mixture to avoid the presence of air bubbles that break the homogeneity of the jet.

Dosing system

The dosing system consists of:

- **Backing roll**, which is a roll with a rubber coating that serves as a support to the blade.

- **Crossbar**, on which the following can be distinguished:
  - Blade fixing crossbar.
  - Support bar for adjusting the profile of the transverse layer.
6.4. Variables involved in the coating layer

At the stage of applying the coating mixture over the paper, the resulting layer will be conditioned by a series of factors that must be controlled:

- **Angle adjustment mechanism**, which enables the crossbar to pivot taking the point of the blade as its pivot point.

Fig. 27: Crossbar Combiblade.

Fig. 28: Angle of the blade.
Viscosity of the coating mixture. This variable depends on the following factors:

- The temperature.
- Type of binder.
- Percentage of solid material.
- Shearing speed.
- Thickeners.

Blade characteristics. In the use of the blade, which is usually made of steel, the following elements can have an influence:

- Surface.
- Thickness.
- Length.
- Elasticity (a flexible blade enables the application of a greater amount of coating layer).
- Application angle (contact angle on the applicator roll).
- Pressure applied to the coating layer.
- Available height.

The support roll. Regarding the roll, the following can be said to have an influence:

- Hardness of the material.
- Smoothness of its surface (the smoother the roll, the greater the smoothness achieved on the paper).
- Deformities it may suffer.
- The type of covering.

6.5. Most notable coating defects

The end of a coating operation is often accompanied by the appearance of a series of visible defects which, thanks to experience and technological advance, can be corrected and even eliminated completely.
The most commonly occurring defects are set out below:

### MOST FREQUENT COATING DEFECTS

<table>
<thead>
<tr>
<th>Dirt or specks on the surface.</th>
<th>Foam craters (too much antifoam).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coating layer spread incorrectly.</td>
<td>Dye and grease stains.</td>
</tr>
<tr>
<td>Fibre marks.</td>
<td>Cuts along the edges.</td>
</tr>
<tr>
<td>Roll marks.</td>
<td>Tearing and holes.</td>
</tr>
<tr>
<td>Sticky blobs or foreign bodies (splashing).</td>
<td>Bad pigment dispersion (fisheye).</td>
</tr>
<tr>
<td>Dark strips (rolls that do not turn).</td>
<td>Latex badly dispersed (orange peel).</td>
</tr>
<tr>
<td>Sticking (splicing).</td>
<td>Strange odours.</td>
</tr>
<tr>
<td>Rough surface.</td>
<td>Uneven coating layer.</td>
</tr>
</tbody>
</table>

7. **Calendering**

There are papers which, as they come out of the paper machine and after passing through a coating process, are already suitable for use in ink printing processes. However, there are many others, especially those which require a high surface finish, which have to pass through an operation known as calendering.

The main purpose of the calendering operation is to improve the **gloss** and **printing properties** of the paper. In the following diagram a general view can be seen of the machine that carries out this process; known as the calender.
Fig. 29: General view of the calender.

The calender has a series of rolls (normally 12) positioned one on top of the other, which rotate making the sheet of paper pass between them. Normally one roll made of a hard material (steel) is alternated with another of a soft material (fibrous material), being the metal rolls that give the paper its gloss.

7.1. Types of calendering

Logically, the finish of the paper is not always the same. It is the client who determines the type of finish that is required depending on what its eventual use will be.

The fundamental objectives of calendering are homogenizing the thickness and making the paper surface uniform in order to achieve correct absorption of inks; however, increasing the gloss is not always essential or desirable, as by increasing this gloss other characteristics of the paper are diminished, such as whiteness and opacity. Furthermore, depending on the type of product, gloss on printed paper can make it difficult to read.

According to the types of finish obtained with the calendering, three types of calendering can be distinguished:

- **Semi-matt calandering.** This refers to any calendering technique used for producing a smooth surface (make the surface and thickness uniform) with a minimum increase in gloss. Uses a calender with less rolls (normally four).

- **Gloss calandering.** In this case, the paper passes through a series of pressing areas made up of one relatively soft roll and a roll that is very smooth, made in rectified steel, at a high temperature.

- **High gloss calandering.**
7.2. Pressure of calendering

As we have already seen, during the calendering process the paper passes across a series of rolls positioned vertically that exert pressure on the paper at the contact point. This pressure is achieved through the effect of two factors:

- The **weight of the cylinders** themselves.
- An **additional load** upon the upper cylinder, produced by a hydraulic cylinder.

Thus, by regulating the pressure upon the hydraulic cylinder, the pressure of the rolls upon the paper is also controlled whenever necessary (fig. 30).

![Fig. 30: Pressure produced by the rolls on the paper.](image)

The pressure acts by **compressing the paper** between the rolls, creating a uniform smoothness and density right across the paper.

7.3. Characteristics of calendering paper

In this section we will look at a series of characteristics which involve calendering and which affect subsequent uses given to the paper:

- **Smoothness.** Is a very important aspect when it comes to printing on paper and one of the main purposes of calendering. The greater the smoothness the greater the gloss and subsequent absorption of inks.

- **Thickness.** Calendering reduces the thickness of the paper at the same time as it gives the sheet an overall uniformity. The thickness is measured with high precision gauges or micrometers.

- **Optical characteristics.** These are a number of characteristics which are seen according to the light the paper is placed under. We will look at four of these:
About Paper

Colour. When light is reflected on the paper we receive radiations (colours). If the paper only reflects radiation of a certain colour (it absorbs the rest), we will see the paper in that same colour.

Whiteness. When the paper reflects all the radiations (colours) in the same proportion we can see it as white. Pigments and additives enhance the whiteness.

Opacity. This depends on the quantity of light that crosses the paper. A paper that only allows a small amount of light to pass through is said to have high opacity.

Gloss. Gloss depends on the quantity of light reflected by the paper. The greater the amount of reflected light (in the case of a smooth surface), the greater the surface gloss will be.

7.4. Defects produced in calendering

Paper is made with the logical aim of producing a quality product. The same applies to the process of calendering. To achieve this, it must be taken into account that certain faults and defects can occur during the operation. In order to tackle these defects it is necessary to know their origin (reason), detect them and correct them.

Some of the most common defects that occur in this operation are set out in the following table:

<table>
<thead>
<tr>
<th>MOST FREQUENT DEFECTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Areas of the paper with greater thickness (ridges).</td>
</tr>
<tr>
<td>Areas with greater moisture content (bands).</td>
</tr>
<tr>
<td>Wrinkles in the paper (accumulation of the paper in specific points due to inadequate tension).</td>
</tr>
<tr>
<td>Breakage (weak points in the paper).</td>
</tr>
<tr>
<td>Loss of characteristics on the rolls with covering (dimensions, elasticity, homogeneity, deformities due to hard particles or wrinkles...).</td>
</tr>
<tr>
<td>Oxidation and marks on the metallic rolls.</td>
</tr>
</tbody>
</table>
8. Winding process

Paper users need the paper to get to them in a form that is appropriate to their needs. For example, in printing presses reels of paper are used of sizes and diameters that are suitable for the machines. The same thing happens with cutting machines.

The paper that comes out of either the paper machine or the calendar, in the case of the paper being calendered, is rolled up in the form of reels to facilitate its transport and use in other operations. Each of these reels, known as jumbo rolls, is then stored while awaiting the following operation, which is the winding process.

A reel is a roll of paper having particular characteristics and dimensions (in terms of the diameter, width and length of the paper).

The purpose of the winding process is to cut and rewind the reel produced by the paper machine (i.e., the "jumbo roll", with a large diameter) into reels with a smaller diameter and width ("final reels"). This process is carried out in a machine known as a winder, or winding machine.

8.1. The winder

The winder is the machine in which the winding process takes place. It is based on a mechanical device which transforms the "jumbo roll" into several smaller reels of the appropriate diameter, size and hardness.

These characteristics will be determined by the customer's requirements or in view of the operations to be carried out subsequently (storage, transport, reuse, etc.).

There are basically two types of winder. They are:

- The double-drum winder.
- The winder with an individual winding process (with a single central drum).

8.2. Double-drum winder

This was the most commonly found type of winder until the appearance of the winder with an individual winding process.
Variables which affect the winding process (in the case of a winder with a double drum)

The parameters that indicate the progress of the winding process are modified as it proceeds. These modifications can be implemented in two ways: manually (by operating the controls) or automatically (by means of control systems).

In order to correct the (undesired) shape of reel which the double-drum winder naturally tends to produce, a series of factors are controlled. There are three basic factors involved:

- Tension.
- Load.
- Differential torque.

8.3. Winder with individual winding

This is the type of winder which is gaining ground over double-drum winders. An example can be seen in the following image.
Variables which affect the winding process (in the case of a winder with a central drum)

For winding machines with a central drum the variables which have an effect on the winding process are:

- **Tension.** In this case the same procedure is followed as for winders with double drums.

- **Pressure at the "nip".** This is the pressure that exists at the point of contact between the drum and the reel. At the beginning of the winding process, the pressure which the winding device exerts against the central drum is greater, but reduces gradually as the diameter of the reel increases.

The advantage of this type of winder is that the force of the paper's weight (and we should remember that weight has a negative effect on the quality of the reels as their diameter increases) is counter-balanced by the force exerted by the winding device on the central drum, and consequently the quality of the reels is higher using a winder with a central drum.

<table>
<thead>
<tr>
<th>MAIN ADVANTAGES OF THE WINDER WITH INDIVIDUAL WINDING PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>It gives separate individual rewinding for each final reel, avoiding the risk that two consecutive reels could get stuck together (or &quot;mixed up&quot;).</td>
</tr>
<tr>
<td>The final reels' own weight (as their diameter increases) has practically no effect on the hardness of the winding process, so that the defects present in the jumbo roll will be better concealed.</td>
</tr>
<tr>
<td>It makes it possible to obtain reels with a larger diameter.</td>
</tr>
<tr>
<td>The degree of hardness produced in the final reel depends on the linear pressure, which is electronically controlled and is in constant relation to the diameter at all times.</td>
</tr>
<tr>
<td>The winding process is carried out without axes; guide headers or probes of different diameters are used, which makes it possible to obtain reels with cores of different diameters.</td>
</tr>
</tbody>
</table>
8.4. Tests on the reel

Once completed, the reel needs to be able to withstand the treatment and forces it is going to be subjected to: storage, transport, etc. The quality of its composition depends on two factors: the base paper (i.e., the original reel) and the evolution of the winding process.

Once the reel has been completed, a series of tests are carried out which indicate the final quality of the reel. These tests are as follows:

- Hardness.
- Diameter.
- Density.
- The level of friction between layers.

8.5. Defects arising during the winding process

A certain number of production defects can be found in reels. The most common ones are included in the following table:

<table>
<thead>
<tr>
<th>POSSIBLE DEFECTS DURING THE WINDING PROCESS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Defects in the winding process</td>
</tr>
<tr>
<td>□ Reel is soft at start of winding process.</td>
</tr>
<tr>
<td>□ Creases from the winding machine.</td>
</tr>
<tr>
<td>□ Base is irregular.</td>
</tr>
<tr>
<td>□ Paper is loose.</td>
</tr>
<tr>
<td>□ Tears in the edge.</td>
</tr>
<tr>
<td>Cutting defects</td>
</tr>
<tr>
<td>□ Inaccurate cutting.</td>
</tr>
<tr>
<td>□ Paper creased or turned up.</td>
</tr>
<tr>
<td>Defective joins</td>
</tr>
<tr>
<td>□ Overlapping join.</td>
</tr>
<tr>
<td>□ Adhesive join.</td>
</tr>
<tr>
<td>Patchy reel</td>
</tr>
<tr>
<td>□ Soft edges.</td>
</tr>
<tr>
<td>□ Loose strands.</td>
</tr>
</tbody>
</table>
### Defects in the core
- Core sticking out.
- Core sunk in.
- Core in defective condition.

### Other
- Core flattened.
- Reel turned outwards.
- Reel shattered to pieces.

#### 9. Cutting

The paper emerging from the paper-making machine is produced in the form of reels, and before reaching the customer may be subjected to different processes to give it the properties and dimensions that the customer requires.

The customer, according to the use he or she is going to make of the paper, may require it in either of two forms:

- **In reels.** These are produced directly by the winding-machine with specific dimensions (in terms of the diameter and width of the reel and the length of the web). The purchaser orders the paper in kilograms.

![Diagram of a reel with dimensions labeled](image)

**Fig. 33: Reel of paper and method of printing.**

- **In formats or sheets.** These are produced from the paper reels, by cutting them into rectangular pieces the dimensions of which (in terms of width and length) can be standardized or not, according to the customer's requirements. The most usual form in which to order is in reams.

![Diagram of paper sheets](image)
Fig. 34: Sheet of paper and method of printing.

Therefore, before the paper can reach the customer in the form of formats or sheets, it must be subjected to a cutting process in which the reel is converted into sheets of paper with the measurements that the customer requires for use in other machines.

It must be borne in mind that paper with a format of "70 x 100" is not the same as paper with a format of "100 x 70". If both formats are handled in the same way, in one of the two cases the orientation of the fibre changes and thus the performance of the sheet during printing is different.

9.1. The Cutter

The Cutter is the machine in which the reels of paper are converted, by cutting, into a series of formats or sheets of a precise length and width (although there is a system of standardization of formats, customers may request formats of very different types, which may or may not be standardized).

The quantity of sheets obtained will depend on the original size of the reel and the dimensions required for each sheet.

Although the cutting process is carried out automatically, the machine operator is responsible for adjusting the various factors, checking that the machine is working correctly, and keeping the installations clean and in order.
There will need to be a good distribution of the different phases of the process inside the factory to ensure that the cutting process is completed successfully. The phases into which the process is divided are:

- The unwinding process.
- The cutting process (in two phases).
- Detection of defects.
- The conveyor belts.
- Stacking.
- The counting process.

9.2. Unwinding

In order to insert the paper from the reels into the cutter it is necessary to undertake the unwinding of the reels at a suitable speed. This unwinding must take place in a continuous and uninterrupted fashion, since the cutter needs to operate at a constant rate. In other words, when the reels being used are finished it is necessary to insert new ones immediately in order not to interrupt the process.

In order to ensure that there is no interruption of the unwinding process, a mechanism is used which makes it possible to have a series of reels unwinding simultaneously, and sees to it that at the precise moment when these reels are finished, new ones which had been kept in waiting up to this moment are duly inserted, either by means of a rotating platform or through a movement to one side (fig. 36).
9.3. Trimming

As the unwinding of the paper proceeds, it passes through the cutters to be converted into sheets with the required dimensions.

There are two different types of cutting process, which nowadays are both carried out in the same machine.

- **Lengthwise cuts**: these are the first to be carried out, and determine the width of the sheets.

- **Transverse cuts**: these are carried out after the lengthwise cuts and determine the length of the sheets.

We will now see how each of these types of cut are carried out and which factors affect each operation.

**Lengthwise cut**

Lengthwise cuts are carried out by pairs of rotary blades, which cut the paper into narrower strips, giving the sheet the final width required for the order. They also carry out trimming, or removing of the outside edges of the paper. Each pair of blades is formed by an upper and a lower blade, which are perfectly parallel and at a slight distance apart (fig. 37), so that the cutting effect is similar to that produced when we cut paper with scissors.
Transverse cut

Once the paper web has been cut into lengthwise strips (corresponding to the width of the sheet), the latter are then cut transversely to convert them into sheets of a specific length.

The transverse cuts are effected using rotary blades with a synchronized cutting action, which determine the length of the sheet. This is done by passing the paper web through knife-bearing drums -one higher and one lower drum, both rotary- which are adjusted before use (fig. 38). The blades are mounted in the drums and fixed in place using screws, which have to be adjusted as accurately as possible so that during the cutting action the lower blades do not clash with the upper ones.

The length of the sheet is determined by the speed of the rotary blades, since a drum will have to make a complete rotation in the same time that the paper covers the required length before being cut. In this way, each time a drum makes a complete rotation, the blade will make a cut in the paper that will determine the length of each
sheet. During the process, the cut is carried out in the paper when the two knife-bearing drums (i.e., the upper one and the lower one) rotate in unison.

![Angle of inclination of the blades in the blade-carrying drums.](image)

Fig. 39: Angle of inclination of the blades in the blade-carrying drums.

9.4. Final operations

Once the sheet has been cut the final operations are carried out, which as we have mentioned previously consist of the detection of possible defects, the transport, the stacking and counting.

Detection of defects

During the cutting process defects can appear at any time, and for this reason it is necessary to detect the defective sheets and eliminate them, since if they were present in the final product, the customer would have problems when using them for printing. Two types of defect can be found:

- **Defects already present in the reel.** These are defects that are already present in the paper before it enters the cutting machine: stains, incorrect weight or thickness, etc.

- **Defects produced in the cutting machine.** These are defects that are detected after the paper has passed through the cutter: incorrect size, wrinkles, folds, tears, etc.

Although manual detection systems exist (in which the machine operator detects defects visually), the modern practice is to use **automatic checking** equipment installed inside cutting machines, which reduces the need for manual sorting.

Transport

Once the web of paper has been cut and converted into formats with pre-determined measurements, it is sent to the stacking section by means of **conveyor belts** operating on rollers.
Stacking

Once the sheets have passed through the defect detecting device, and defective sheets have been eliminated, the sheets that do not have defects are taken on the conveyor belt to the stacking unit, where they are stacked together, in perfect alignment, before being subsequently packaged and dispatched to the customer.

Counting

Once the paper has been cut, each packet has to be marked with the number of sheets it contains. For this purpose, before the sheets reach the stacking unit, counting is carried out automatically, making it possible to know the number of sheets produced in the final phase of the papermaking process.
## Summary

### Preparation of pulp

The preparation of different pulps in a non-integrated mill (that which does not produce the pulp itself but rather, receives it in the form of sheets) is composed in the following operations:

- **Disintegration**: the sheets of pulp are put into an aqueous suspension inside a pulper with the aim of breaking them down.

- **Deflaking**: using a machine known as a deflaker the pulp is totally broken down, thus avoiding an excessive consumption of energy in the pulper.

- **Refining**: the pulp is subjected certain treatments which modify the morphology and structure of the fibres to make it suitable for the future quality of the paper. This is carried out in a machine known as a refiner.

- **Mixture of additives**: with the aim of modifying the properties of the pulp, products are added that are classified as additives (loads and pigments, colorings, binding agents, sizing products, etc.) and auxiliaries (anti-foam, microbicides, retention).

- **Cleaning**: aimed at eliminating particles that are undesirable in the formation of the paper. Normally flat vibrating cleaners or pressure closed cleaners are used.

### Paper machine

The paper machine is where the sheet is formed from paper pulp. This machine is divided into two parts:

- **Head box**: this is responsible for letting out the pulp in the form a fine, wide and homogeneous sheet.

- **Forming table**: on which dewatering and formation of the sheet are carried out.

### Pressing

Pressing is a process in which the sheet of paper is made to pass between two rolls while in contact with a felt to eliminate part of the water and strengthen the sheet. This process is carried out in four stages:

- Compression and saturation of the sheet.
About Paper

Paper Manufacturing

- Compression and saturation of the felt.
- Expansion of the felt.
- Expansion of the sheet.

The machines used for carrying out the pressing process are called the presses, and according to their dewatering capacity and characteristics can be classified as follows: nip rolls, vacuum presses, shoe presses, transverse presses ("fabric" press, vented nip press, blind drilled press).

### Drying

Drying is the operation whereby the paper reduces its water content until it is left with approximately 5% humidity. There is a wide variety of methods to carry out the drying process: drying by through-air, drying using a Yankee cylinder, drying by air jet, infrared drying and drying with heated cylinders (multi-cylinder drying section).

The multi-cylinder drying section is the method generally used in the drying of any kind of paper. This involves the use of reheated steam inside the cylinders, and during the process condensates are produced that must be extracted in order to avoid problems in the operation.

### Coating

Coating is the operation which consists in covering the surface of the paper or card with a mixture of components in a liquid state to give the sheet the required properties for ink printing. There are three elements involved in paper coating:

- **The medium**: paper on which the coating is carried out.
- **The coating mixture**: material or compound (pigments, binding agents and additives) which are applied on the surface of the paper or medium.
- **The coater**: machine used for carrying out the operation. According to its location, the operation can be one of two types: on-machine coating and off-machine coating.

The quality of the coating layer depends on a series of factors, such as the viscosity of the coating mixture, the characteristics of the blade used for evening out the coating layer and the support roll.

### Calendering

Calendering is an operation that is carried out on papers that require a high surface finish, and whose essential aims are to even out the surface and the thickness of the paper, and improve its...
gloss. In calendering there are three distinct types of finish: semi-matte, gloss and high gloss.

The machine used to carry out this operation is known as the calender, which consists of a series of rolls, positioned one on top of the other so that the paper passes through them while being subjected to pressure at the point of contact.

The calendering operation affects a series of characteristics such as smoothness, thickness and optical characteristics (colour, whiteness, opacity and gloss).

### Winding process

Winding is the operation whereby the "jumbo reel" is unwound and cut with the aim of obtaining, after its winding, new smaller reels with a specific diameter and width. The machine used for the winding is known as the winder and generally there are two types:

- **Double-drum winder.**
- **Winder with individual winding process (with a single central drum).** This is the type which is currently most frequently used.

In order to check the final quality of the reel a series of tests are conducted: hardness, diameter measurement, density of the reel and strength of friction between layers.

### Cutting

The cutting process converts a reel into a series of formats or sheets with the precise measurements required by a customer. The phases into which the process is divided are:

- **Unwinding process:** the reel is unwound so that the paper can be entered into the cutter.
- **Cutting in two stages:** two cuts are made; one lengthwise (which determines the final width) and the other; crosswise (which determines the length).
- **Detection of defects:** for which photoelectric cells are used.
- **Conveyor belts:** using conveyor belts the sheets are sent to the stacking unit.
- **Stacking:** the sheets are stacked up for their packaging and subsequent dispatch.
Counting operation: the sheets are counted.