Brown Stock Washing

Objective of brown stock washing

Brown stock washing differs from digester washing. In a continuous digester zone, cooked chips not yet disintegrated into individual fibers are washed; whereas, in external washer, pulp is washed.

The objective of brown stock washing is to remove the maximum amount of black liquor dissolved solids from the pulp while using as little wash water as possible.

The dissolved solids left in the pulp after washing will interfere with later bleaching and papermaking and will increase costs for these processes. The loss of black liquor solids due to solids left in the pulp means that less heat can be recovered in the recovery furnace. Also, makeup chemicals must be added to the liquor system to account for lost sodium compounds.

It would be easy to achieve very high washing efficiencies if one could use unlimited amounts of wash water. As it is, one has to compromise between high washing efficiency and a low amount of added wash water.

The water added to the liquor during washing must be removed in the evaporators prior to burning the liquor in the recovery furnace. This is a costly process and often the bottleneck in pulp mill operations. Minimizing the use of wash water will therefore decrease the steam cost for evaporation.

Basic pulp washing mechanisms and operations

There are two separate mechanisms involved in any washing operation—washing and leaching.

Washing is simply bulk removal of the liquor surrounding the pulp fibers. This is done by removing the stronger liquor and replacing it with weaker liquor or water.

Leaching includes diffusion and desorption. Dissolved solids and chemicals in the interior of the pulp fibers must diffuse into the surrounding liquor before they can be removed. The diffusion rate of sodium is quite rapid while diffusion of larger molecules, such as dissolved lignin, is much slower.

Sodium and dissolved solids are also attached or bound to the pulp fiber surfaces to a certain degree. Desorption occurs when these attached compounds leave the fiber surface for the surrounding liquor. Desorption and diffusion are most significant in the final washing stages when the liquor surrounding the pulp fibers has a low concentration of dissolved solids and chemicals.

The two basic pulp washing operations are dilution/extraction and displacement washing.

In dilution/extraction washing, the pulp slurry is diluted and mixed with weak wash liquor or clean water. Then the liquor is extracted by thickening the pulp, either by filtering or by pressing. This procedure must be repeated many times in order to sufficiently wash the pulp. The efficiency of dilution/extraction washing depends primarily on the consistencies to which the pulp is diluted and thickened. (See Figure 6.9.)

Figure 6.9 Principle of dilution/extraction.

In displacement washing, the liquor in the pulp is displaced with weaker wash liquor or clean water. Ideally, no mixing takes place at the interface of the two liquors. In practice, however, it is impossible to avoid a certain degree of mixing. Some of the original liquor will remain with the pulp and some of the wash liquor will channel through the pulp mass. The efficiency of displacement washing then depends on this degree of mixing and also on the rate of desorption and diffusion of dissolved solids and chemicals from the pulp fibers. (See Figure 6.10.)
Figure 6.10 Principle of displacement washing.

All pulp washing equipment is based on one or both of these basic principles. Displacement washing is utilized in a digester washing zone. A rotary vacuum washer utilizes both dilution/extraction and displacement washing, while a series of wash presses utilizes dilution/extraction.

Most pulp washing systems consist of more than one washing stage. The highest washing efficiency would be achieved if fresh water were applied in each stage. However, this approach would require large quantities of water and is, therefore, not used.

Countercurrent washing is the generally-used system design. In countercurrent washing, the pulp in the final stage is washed with the cleanest available wash water or fresh water before leaving the system. The drained water from this stage is then sent backwards through each of the previous stages in a direction opposite to the pulp flow.

Terminology used in washing

Soda loss

Most pulp mills still express the efficiency of their washing systems in terms of "soda loss." Soda loss is defined as the sodium content of the pulp leaving the washing system, expressed as pounds of salt cake per ton of oven-dry pulp. "Salt cake" is another name for sodium sulfate.

Actually, very little of the sodium in the pulp is in the form of sodium sulfate. Soda loss was originally expressed in this manner because the sodium lost with the pulp was always replaced with salt cake added to the dissolving tank.

The ratio of sodium to organic compounds in the dissolved solids can vary widely and is dependent on factors such as wood species used and pulp product produced. This ratio also changes near the end of the washing operation.

Sodium diffuses out from the cell wall more easily than the bigger lignin fragments and so a higher proportion of sodium is removed from the pulp than organic material.

An alternate method of reporting washing efficiency would, therefore, be to determine and report the loss of total dissolved solids per unit of pulp, then convert to sodium equivalents. Each mill would need to determine a set of correlations between sodium loss and dissolved solids loss specific for the different conditions encountered at that mill.

When reporting washing efficiency in relation to salt cake loss, it is important to indicate whether it is total soda loss or washable soda loss that is reported. The sodium in the pulp consists of two fractions, washable sodium, which is water soluble and can be removed to 100% by thorough washing, and sorbed sodium, which consists of sodium bound to the acidic groups in the kraft pulp. The level of sorbed sodium varies with kappa number and pH. (See Figure 6.11.)

Figure 6.11 Effect of pH on sorbed sodium.

The total soda loss, therefore, will not tell one very much about the actual washing efficiency. It is an important factor in determining the amount of makeup chemical required, however.

Dilution factor

The quantity of water used for washing pulp is normally expressed as dilution factor. It can be calculated for a single washing stage or for a whole system and is adaptable to all types of washing. Dilution factor is defined as the weight of wash water introduced into the black liquor per unit weight of oven-dry pulp being washed. The wash water added to the black liquor is the difference between wash water applied to the washing unit and the water remaining in the pulp after washing. A negative dilution factor means that less wash water is added than remains with the pulp after washing.
Diffusion washers

Diffusion washers are pure displacement washers. There are two types: one stage or multistage ring diffusion washers, and pressure diffusion washers.

The ring diffusion washer unit consists of a series of screen rings, one inside another. (See Figure 6.18.) Each ring is hollow and has perforations on both sides so liquor can be drained through it. Each ring is connected to a radial drainage arm through which the drained liquor is removed. The whole ring assembly is mounted to a set of hydraulic cylinders and can be moved up and down. Figure 6.19 shows a close-up of one ring.

The pulp enters the diffusion washer at the bottom and moves upward through the annular spaces between the screen rings. The wash liquor is introduced into the pulp through a set of nozzles, mounted on a rotating radial arm. Each nozzle is located at the mid-point between two screen rings. As the nozzle arm rotates, it leaves a string of wash liquor behind. This wash liquor then moves radially through the pulp in both directions toward the screen rings, thus replacing the liquor entering with the pulp. The displaced liquor is removed through the drainage arm and flows to a storage tank.

Figure 6.16 Principle of a pressure washer.

Figure 6.17 Flowsheet for a two-stage pressure washer system.

Figure 6.18 Ring diffusion washer.
**Figure 6.19** Flows in a ring diffusion washer.

The screen rings move upward with the same velocity as the upward flowing pulp. When the screen ring assembly has reached its top position, it is moved rapidly downward in order to keep the screens clean and prevent them from plugging.

In a multistage diffusion washer the units are mounted on top of each other. They work in countercurrent fashion; that is, displaced liquor from one stage is used as wash liquor in the preceding stage. A multistage ring diffusion washer is shown in Figure 6.20.

Typical retention times for one stage in a ring diffusion washer is eight to ten minutes. This gives plenty of time for diffusion of liquor from the interior of the fibers.

The pressure diffusion washer is built to operate at digester pressure and is connected to the blow-line of a continuous digester. The washer consists of a pressure vessel with a central body through which the wash liquor is introduced. A moving cylindrical screen is located at the periphery of the vessel. Figure 6.21 shows a pressure diffusion washer.

The pulp is introduced at the bottom of the washer and flows upwards in the annular space between the screen and the outer shell. Wash liquor is injected into the pulp from nozzles located in the outer shell. It flows radially through the pulp bed, displacing the liquor surrounding the pulp. The displaced liquor is extracted through the screen and is collected in the central collection chamber. The cylindrical screen moves upward with the pulp. A periodic fast downstroke keeps the screen clean.

**Figure 6.20** Multistage ring diffusion washer.

Diffusion washers have some advantages compared to rotary vacuum washers:
- Diffusion washing takes place in a submerged environment, which excludes the possibility of air entrainment and foaming.
- There is no release of odorous gases.
- They take up less space.
- They are easy to operate and require little process control instrumentation.
The dilution factor can be expressed mathematically as:

\[
DF = \frac{F - 100 - C}{P - C}
\]

\(F\) = wash water flow to the stage (tons/hr)

\(P\) = pulp throughput (tons/hr)

\(C\) = consistency of pulp leaving stage (%)

A higher dilution factor means more wash water added to the system, which results in a higher washing efficiency. The economical benefits of an increased washing efficiency must be balanced against the increased costs of evaporation, however. Dilution factors are normally in the range of 2.0 to 3.0.

**Displacement Ratio**

Displacement Ratio (DR) is a term that expresses the effectiveness of a single displacement washing stage in removing solids from the pulp. It is defined as the ratio of the actual reduction in solids content in the stage compared to the maximum possible reduction.

\[
\text{Displacement Ratio} = \frac{C_v - C_s}{C_v - C_w}
\]

\(C_v\) = concentration of dissolved solids in the liquor entering the stage with the pulp. (For rotary vacuum washers: \(C_v\) = concentration of dissolved solids in the washer vat.)

\(C_s\) = concentration of dissolved solids in the liquor leaving the stage with the pulp.

\(C_w\) = concentration of dissolved solids in the wash water added to the stage.

In the ideal case, the liquor in the pulp leaving the washer would have the same concentration of dissolved solids as the wash water added, i.e., DR = 1.0. In reality, however, displacement ratios for rotary vacuum washers are in the range of 0.60 to 0.90.

**Norden Efficiency Factor**

The Norden method is a way of comparing the efficiency of different kinds of washing equipment independently of dilution factor. The method assumes that a washing stage can be likened to a number of countercurrent mixing stages connected in series. Pulp slurry, which enters one stage, is mixed with liquor from the next stage. The stock is then rethickened to the original consistency, and the separated pulp and liquor pass on to the next stages.

The original method of calculating was slightly modified. The modified Norden Efficiency factor, \(N\), is now defined as the number of mixing stages that will give the same results as the washing equipment under consideration when operated at a standard consistency and at the same dilution factor as the equipment in question. (See Figure 6.12.)

![Figure 6.12 Modified Norden Efficiency Factors.](image)

**Washing equipment**

There is a large variety of pulp washing equipment available these days. The rotary vacuum washer is still by far the most widely used washer equipment, but other methods of washing have been developed and are becoming more common. Among these are rotary pressure washers, diffusion washers, horizontal belt filters and wash presses.

**Rotary vacuum washers**

The rotary vacuum washer consists of a wire- or cloth-covered cylinder that rotates in a vat containing the pulp slurry. A schematic of a rotary vacuum washer is shown in Figure 6.13. Vacuum is applied from the inside of the cylinder and a pulp mat is formed on the surface of the cylinder when in the vat. As the cylinder continues to rotate, the pulp mat emerges from the vat, and wash water is applied with showers. The mat is continuously dewatered by the vacuum applied.

Finally, the vacuum is cut off, and the washed pulp mat is removed from the cylinder. In a multistage system, the washed pulp mat is diluted with new wash liquor and is transported to the next washer vat. From there, the whole washing process is repeated. Consistency in the washer vat is normally around one percent, while consistency of the pulp mat leaving the washer is between 9% to 18%.
**Horizontal belt washers**

The belt washer is a new kind of pulp washing equipment that resembles the fourdrinier section on a paper machine. (See Figure 6.22.) Pulp slurry at a consistency of up to 3.5% is distributed across a traveling wire from a headbox. The pulp is dewatered, forming a mat of about 8% to 12% consistency. This pulp mat is then washed in a series of displacement stages as it moves from the headbox to the couch roll. The mat's consistency remains relatively constant at 8% to 12% during these washing stages.

The cleanest wash water is added in the final shower ahead of the couch roll. It is drained through the mat with a suction box, then sent to the previous shower. The filtrate from the first shower is finally sent to the evaporators, while the filtrate drained ahead of the first shower is used for dilution of the headbox furnish.

**Figure 6.22** Horizontal belt washer.

Belt washers, thus, use one dilution/extraction stage, followed by several displacement stages. Theoretically, a large number of displacement stages can be fit along the wire. Belt washers are supposed to give high overall washing efficiencies at comparatively low dilution factors.

The wire on the belt washer can be one of three basic designs. It can be a grooved rubber belt, a woven plastic filament belt, or made of a thin sheet of solid stainless steel, which has been perforated and welded to become a continuous belt.

**Wash presses**

Basically, wash presses are dilution/extraction washers, although some wash presses also have a displacement stage. Wash presses are frequently used for pulps that are difficult to permeate.

In order to reach sufficient efficiencies, a press must be able to reach a very high discharge consistency up to 40% or 50%. A wash press system consists of a number of presses arranged in a series with an agitated tank for dilution between them. (See Figure 6.23.) A system's efficiency mainly depends on two factors: the degree of equilibrium reached in the agitation tank and the degree of extraction in the presses.

**Figure 6.23** Wash press system.
system is flexible and can operate at specific loadings much higher than what they were designed for, but the overall washing efficiency will decrease correspondingly.

The vat consistency must not be too high in order for a well-formed, easily-drained pulp mat to form on the drum. It is also more difficult to achieve proper mixing with the dilution water when working at higher consistencies.

An adequate shower flow distribution is important to achieve a high displacement ratio and avoid mixing and channeling. The temperature of incoming wash water should be in the range of 50°C to 80°C. Washing is poor at cool temperatures and at hot water temperatures above 80°C.

Drum speed is a variable that depends on vat consistency and/or pulp throughput. A high drum speed combined with a low-vat consistency results in a thinner pulp mat and gives better washing results than a low drum speed combined with a high-vat consistency, resulting in a thick, unevenly formed pulp mat. An optimum speed-consistency relationship results in a high-vat consistency improving the displacement ratio.

Air in the stock has an adverse effect on pulp washing, since it lowers the drainage rate of the pulp mat, thus lowering capacity. Therefore, it is important to separate air entrained in the washer filtrate before it is used again.

The type of stock has a big impact on obtainable overall washing efficiency. Hardwood pulps are, for example, easier to wash than softwood pulps due to the greater foaming tendency of softwood liquor. Pulps of high kappa numbers are more difficult to wash. They contain fiber bundles holding black liquor solids that will not have enough time to fully diffuse into the surrounding liquor during the washing process.

**Rotary pressure washers**

A rotary pressure washer is very similar to a rotary vacuum washer. The main difference is that an external pressure is used for mat formation and dewatering instead of an internal vacuum. A pressure washer is shown in Figure 6.16. The cylinder and vat are fully enclosed in a washer hood in order to be able to raise the pressure in the air space surrounding the drum.

The main difference in drum construction is the absence of channels on the inside. The interior of the washer drum can, therefore, be utilized for a more sophisticated liquor collection system. The washer can be operated with two or three displacement stages by having separate draining systems for each set of showers. The cleanest filtrate, collected under the last stage of showers, is led back to the previous set of showers on the same washer. The most concentrated filtrate is used for dilution of the pulp before the washer and for the cleanest showers on the preceding washer, (see Figure 6.17), a typical countercurrent operation.

Pressure washers offer a few advantages compared to vacuum washers in addition to having up to three displacement stages. The higher pressure reduces foaming and allows higher temperature wash liquor to be used. The closed vapor circulation system makes it possible to collect and treat odorous vapors released during washing.
There are a number of different press designs. Figure 6.24 shows a screw press and Figure 6.25 shows a twin-roll press.

Figure 6.24 Screw press.

Figure 6.25 Twin-roll press unit.

Washing in continuous digesters

As was seen in Chapter 5, the washing that takes place in a continuous digester’s washing zone is called diffusion washing. It is pure countercurrent displacement washing. The cooked chips flow downward, while the wash liquor, introduced at the bottom of the digester, flows upward and is finally extracted along with the mother liquor through the extraction screens.

The retention time of the chips in the washing zone is normally from 1.5 to 4 hours, depending on what washing efficiency the digester was designed to achieve. A long retention time is required in order for the dissolved solids entrained inside the chips to have enough time to diffuse into the surrounding liquor. The washing efficiency is a function of retention time and dilution factor as can be seen in Figure 6.26.

Figure 6.26 Washing efficiency in digester washing zone.