Efficiently Refining The Resources

Finlay John

ABSTRACT

The aim of this paper is to present currently employed methods of minimizing the refining energy requirement in the unit operation of stock preparation refining and thus increasing the efficiency of this operation.

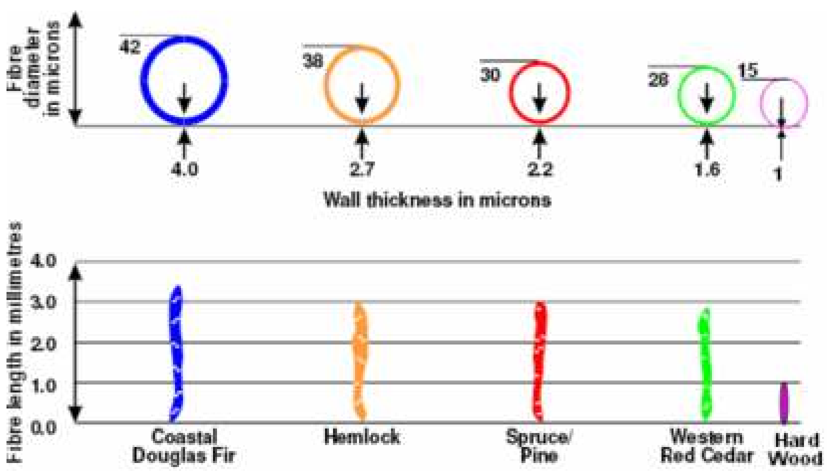
It will begin by presenting the dimensions of our resources and what we want to do with them in the refining process which is the largest consumer of energy as a unit operation in the whole papermaking process. It will then examine exactly what is the energy defined in the many refining theories as the net specific refining energy, comparing it to the energy actually required to break the various chemical bonds which occur during the refining process. The effect of the various refiner shapes disc and conical and their associated parameters on the energy consumption will be discussed along with the influence of plate patterns and material of construction. The most efficient way to operate a refining system will be addressed with a mill example.

Our Resources : What they look like

What is it that we are working on in the refining operation? What is it that is important in our resources to consider in the refining process?

The primary raw materials are cellulose fibres which can essential be thought of as hollow cylinders with specified length and diameter. The basic difference in fibres is between softwoods and hardwoods. The hollow cylinders can be considered as having a relatively thick cell wall which surrounds strands of smaller fibrils wound underneath this wall in various directions.

Softwood fibres are of the order of

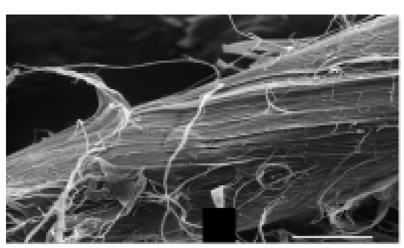


2.5mm long with a 40 micrometer diameter and hardwood typically 1.0mm or less and a diameter around 15 microns. In 1 gram of dry fibres there are some 1,000,000 softwood fibres and in hardwoods this can as high as 30,000,000. However these millions are still small because in the manufacture of paper we don't talk grams, we don't even talk kilograms we talk tons so there are lots and lots of fibres. This means that the refining process is statistical as not all fibres will receive some structural modification and even then the modifications will vary.

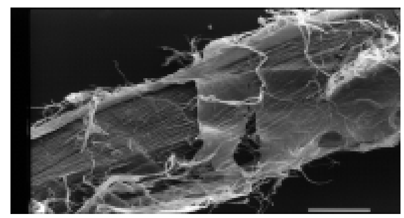
Parason Machinery(India) Pvt. Ltd.
28 Venkatesh Nagar,Opp. Jalna Road
Aurangabad - 431001

What we want them to look like

The structural modifications made to fibres in the refining process ALWAYS make an individual fibre weaker at the



Removal of Outer Cell wall



Exposure of Inner Layer(Fibrils)

expense of increasing bonding with other fibres and forming a stronger sheet of paper. A single unrefined unbleached softwood fibre can support a weight of around 2Kg. If you put just a small cut in the fibre wall it won't support 2g. The refining operation revolves around the question how far can I damage the fibre before it loses it's own integral strength.

The required structural modifications usually involve some attack on the outer cell wall and the exposure of the fibrils, and range from a cutting action on the fibres to a collapse of the internal structure where the fibre becomes more 2 dimensional than 3 and also more flexible. The bonding of water with cellulose is a very important feature in refining and it is this bonding that enables the fibre to undergo refining action. If another liquid such as methanol or ethanol is used to “transport” the fibres through the refining operation then the result simulates the manufacture of toothpaste.

It is the action of the bars on the fibres, and the fibres on other fibres, that generate the structural changes that occur to the fibres, when the fibres are compressed in the gap between opposing rotor and stator bars. The fibres are trapped in groups or flocs on

the edges of the stator bars and are dragged across the edges and stator bar surfaces by the edges of the rotor bars when they pass over. This mechanism has been confirmed by high speed photography taken inside an industrial refiner at the Innventia laboratory in Sweden.

The photography also confirms the presence of fibres travelling from the outside of the stator refiner zone back in towards the centre. There is a large amount of internal recirculation taking place within a refiner and therefore the residence time of fibres within the refiners will always be a distribution due to the mixed reactor environment. Some fibres will spend a relatively short, the majority a mean or average time and some fibres will be in there for a long time.

Refining Gap Dimensions

The most important variable in the refining operation is the gap between an opposing rotor and stator bar. It is first this gap, in combination with the speed of movement of the rotor bar, and how the fibres are being suitably positioned and held on the stator bar edges, that will determine the structural changes and modifications that can be made to the fibres. This gap is of the order of 0.1mm but has been measured to be usually around 0.2 to 0.3mm. It is very small in relation to the size of the equipment that has to work at these small dimensions. Typically the bar and groove width on a refiner filling is a magnitude 10 times that of the gap and the diameter of these fillings can be of magnitude 1000 times that of the gap.

Refining Energy

The energy required to break the chemical bonds that are broken during the structural modifications to the fibres can be calculated from known values in organic chemistry. For a good fibrillation of any pulp it amounts to less than 1 kWh/t of pulp fibres. The same changes in an industrial refiner would require around 200 kWh/t. Where is all the energy going to?

Simplifying a Refiner

To understand exactly what is the energy that is talked about in the refining operation it is necessary to simplify the refiner and ignore what it is primarily being used for although even it's primary use may be somewhat misunderstood. The writer specialised in refining while studying for a Chemical Engineering degree oil refining and had all the necessary vacation training in this area, so when entering the pulp and paper industry in 1988 knew nothing about the papermaking process and even less about stock prep refining. He clearly remembers seeing a refiner for the first time a 46" diameter Beloit series 4000 with the door opened and asking the man who was standing with a hammer and anvil knocking stones, wire and other foreign material out of the grooves on the plates what this piece of equipment was responsible for in the papermaking process. He was informed that this is the machine that removes the stones and the wire from the pulp. Refiners still perform this function but the primary aim is to structurally modify fibres to meet the property requirements in the various grades of paper.

To better understand what we call the refining energy it is necessary to simplify the refiner to a machine comprising a shaft onto which is fitted a rotating element disc or conical which rotates inside a casing full of a slurry of water and fibres and under pressure. The shaft is connected to a motor which is usually rotating at a fixed speed of rotation. In order to accomplish this rotation, the shaft and rotating element draw torque from the accompanying motor. Torque is power. As we change the gap between the rotating and stationary elements the fibre slurry increases the resistance on the rotating element and this draws more torque to maintain the speed of rotation. It is this torque which our refining theories refer to as the gross or total refining energy.

However as mentioned this amount of energy far exceeds the amount required to do the structural modifications during refining. A percentage of the energy is what is termed the no-load but the majority of this energy is going into heating up the pulp slurry by just a few degrees. This can be easily shown when calculating this amount of heat using the specific heat capacity of water as an approximation for a low consistency pulp slurry in the basic thermodynamics equation.

No-load Power

However to rotate anything in a water slurry under pressure there is a certain amount of torque required just to overcome the resistances to the movement without, in the case of a refiner, doing any structural modifications to the fibre. This amount of power has been used in the refining theories, is specified as a papermaking standard with TAPPI and SCAN, and referred to as the no-load power. The net refining power is therefore defined as the gross (or total refining power) less the no-load power.

The no-load power has been found to be primarily a function of the diameter of the rotating element and its speed or rotation. It is not a function of the mass of the rotating element. Remember F = ma, to have a force the mass must be accelerating. A refiner generally rotates at constant speed which means no acceleration. However the no-load is proportional to the speed to the power of 3 and to the diameter to the power of 5. Everything else that effects the no=load is minimal.

The efficiency of a refiner was typically evaluated using the total power used as a function of the no-load power. This meant that the larger disc refiners, where the no-load power was a smaller percentage of the total power, and the short wide angle conical refiners were the most efficient.

Diameter of the Rotating Element

The diameter of the rotating element determined the area over which the bars can operate. The disc refiners, in comparison to the concial (single and double cone) refiners have the largest diameters for equivalent area and therefore consume the most no-load power. The difference in no-load power between double disc and Conical is about 30%. The refining result is obtainable in both refiners for roughly the same net energy as reported by the manufacturers so the gross refining energy, the energy you pay for, is lowest with the conical refiners. The refining energy accounts for over 90% of the cost of refining so in choosing a new refiner it would appear to be a clear decision which type of refiner to choose.

Speed of Rotation

The other great contributor to the no-load power is the speed of rotation. The speed of rotation is usually chosen so as to give an outer diameter bar crossing speed of between 20 and 30 m/s. The speed of rotation also affects the hydraulic capacity of the refiner. It is generally fixed but there are many pilot plants and some industrial applications where a frequency converter is used on the main drive motor to vary the speed of rotation. This can certainly be an energy saving method by always rotating at the lowest speed to meet the primary refining requirement. It also gives control of a very important refining variable but it comes with a high initial cost. Frequency converters for motors the size used by refiners are typically as costly as the motor itself which is similarly priced to the size of the refiner.

The speed of rotation has a big effect on the type of structural modifications that take place. A lower speed will promote fibre shortening while a high speed protects the length and promotes fibre to fibre bonding thus significantly improving the strength (tear and tensile) of the resulting sheet of paper. However there is a price for this improved strength and that is the higher energy requirement and associated cost which provides the upper limit on the speed of rotation.

Refiner Filling Patterns

The refiner filling patterns should be chosen primarily to meet the refining requirement but they are often a compromise due to other factors such as the hydraulic capacity of the refiners or even the manufacturing methods themselves. They can have a significant effect on the energy consumption. Generally finer fillings, that is, narrower bar and groove widths, will require more energy to reach a given drainage/filtration rate of the pulp but usually result in producing stronger sheets of paper. This is essentially because more bars mean more resistance to the rotation of the rotor at a fixed speed.

Refining intensity and refining power are the most important variables to control to develop fibers suitable for papermaking. Refining intensity is the refining energy applied to the intersecting bar edges of the refiner. Refining power is the net energy applied per ton of pulp.

Refining action in stock-preparation refiners takes place at the intersecting edges of the refiner bars. For this reason, it is important to determine the total number of bar crossings, which is defined as Cutting Edge Length (Km/rev). This factor can be calculated by multiplying the total length of the refiner bars in the rotor by the total length of the refiner bars in the stator by refiner speed (rpm).

The average magnitude of fiber deformation referred to as **'Refining Intensity'** or **'Specific Edge Load' (SEL)** is directly related to the applied power divided by the product of rotating speed and cutting edge length, typically expressed in units of **Watt-seconds per meter (Ws/m).**

A refiner with a high **CEL** usually has a low SEL and does more brushing and splitting than cutting. A refiner with low **CEL** usually has a high SEL and does more cutting than brushing or splitting.

To increase CEL, more bar length is required and therefore finer bar and narrower grooves are necessary.

Low intensity can Improve strength, Maintain fiber length, Reduce fines, Improve tear, Improve Ring Crush, Improve tensile, Reduce freeness to kW response, Savings in refining energy.

Parallel Bar Fillings

The conventional Parallel bar fillings for refiners have comprised a combination of bars and grooves where the bars have been straight lines in the radial direction and inclined at an angle. Different widths and angles have been employed. Some filling manufacturers made fillings 30 years ago where the bars were curved like vanes on a pump impellor instead of the conventional straight lines but they were never adopted by the industry and made commercially available. However since 2002 curved bar patterns have been widely employed in the industry.

Curved Bar fillings

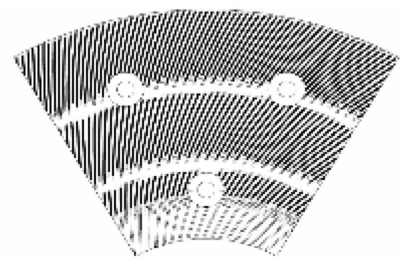
The initial motivation for the use of curved bars was to remove the variable bar crossing angle that was generated by the conventional straight bar patterns where the bars were most often split up into sectors with all the bars in one sector being parallel to one another. This effectively meant that each bar was at a slightly different radial angle to the next bar resulting in all the bar crossing angles within a sector being different. Many researches had shown this crossing angle to be important in determining the structural changes that took place. Small crossing angles around 5 degrees resulted in required pulp drainage rates being achieved for little energy input but no strength in the paper sheet whereas angles of the order of 60 degrees produced strong sheets but took 5 times the energy to get to the same drainage rates. The pattern of crossing angles in parallel bar design is illustrated below:-

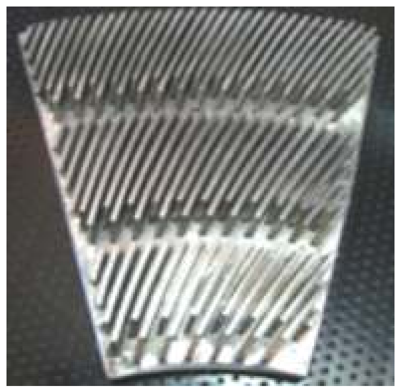
As shown below the curved bar patterns enabled the crossing angles to be kept constant.

Constant crossing angles provide uniform refining action shows marked improvement on the pulp quality. The curved bar plates required less energy to reach the same strength properties and usually at faster drainage rates. This reduction in energy was of the order of 10 to 15 percent. It is probably due to the improved transport of the pulp between the refiner fillings which reduces the resistance on the rotor drawing less torque and therefore by definition requiring less refining

Changing Crossing Angles in Parallel Bar design

Constant Crossing Angles in Curved Bar design





Curved Bar Plates

Table - 1

SN	Particulars	Unit	Inlet	110 Kwh/t		140 kwh/t		170 kwh/t	
1	Plate Pattern			Parallel	Curved	Parallel	Curved	Parallel	Curved
2	CEL/rev	Km/rev		42.73	52.93	42.73	52.93	42.73	52.93
3	Flowrate	L/min		1402	1377	1403	1387	1389	1387
4	Net Specific Energy	Kwh/t		111	102	130	134	169	162
5	Intensity	J/m		0.47	0.38	0.59	0.50	0.72	0.58
6	°SR	0	25	31.5	33.5	32	35	39.5	41.5
7	Bulk	dm³/kg	1.89	1.88	1.74	1.76	1.73	1.63	1.65
8	Porosity	Ml/min	>1000	>1000	>1000	>1000	755	890	457
9	Tensile index	Nm/g	31.39	43.87	49.83	49.03	53.46	52.11	54.59
10	Tear index	nMm²/g	6.32	6.4	11.06	6.7	12.1	7.80	11.07
11	Stiffness	kNm/g	4.94	5.55	6.53	5.91	6.76	6.20	6.21
12	Scott Bond	J/m²	120	160	260	210	280	320	360
13	Opacity	%	83.0	81.6	80.3	82.5	80.3	82.2	79.6
14	Formation		2.31	3.80	3.57	3.37	4.26	3.87	3.89

energy. The fact that a constant crossing angle should result in a more uniform treatment of the fibres may also be reflected in the strength improvement as when these strength tests are carried out the reported values are at the point of rupture which is always the weakest part of the test strip of paper. A strength improvement would therefore result if more of the fibres were treated in the same way.

The curved bar plates also resulted in another advantage for the papermaking process in that in double disc refiners, where the rotor was free to move without any resistance, then the rotor immediately moved towards one of the stator plates at a distance such that refining took place even without any disc adjustment. This meant less unrefined pulp going forward to the papermachine and better runnability.

Mill data of 34" Beloit refiner from Portugal of Bleached Eucalyptus Pulp with casted Parallel bar and casted Curved Bar refiner disc pattern are tabulated in Table- 1 below at different kwh/t:-

As can be seen from the table at same Net specific Engery there is improvement in overall strength properties of Pulp .

Materials of Construction

Most conventional refiner fillings are made from alloys of iron and steel and will need to be replaced either due to wear or breakage. It is not possible to obtain both resistance to wear and breakage in one alloy so the choice is always a compromise to maximize the cost/life economics. The choice of alloy can have a significant effect on the required energy due to the ability of the alloy to maintain a sharp edge and thus trap the fibre on the edge while the rotor bar passes over it thus treating it but also increasing the resistance on the rotor and thus drawing more torque.

The condition of the bar edge and its ability to trap fibres is important as shown by the use of refiner fillings made from ceramic material which were employed in an industrial disc refiner. The discs were closed to the point of disc to disc contact occurring but there was no increase in the amount of power drawn. This was because the edge of the ceramic bar is too smooth, it's co-efficient of friction too low, to trap the fibre and as a result the fibres just slid over the bar edge not restricting the movement of the rotor and hence no increase in the required torque.

There is some good research into the effects of the material of construction, and the use of a global co-efficient of friction, but alternative methods of construction are providing alternative bar edge conditions which are more favourable to the refining operation.

Milled Refiner Plates

Methods of Filling Construction

The majority of refiner fillings are supplied as cast segments. This method of construction has its limitations on the exact bar/groove pattern configurations that are available and on the properties of the alloy such as hardness which usually has to be achieved with a heat treatment process. The new manufacturing method for refiner fillings is fabrication or welding where the properties of the bar material can be enhanced by using such methods as cold re-rolling and cutting the bar against the lie of the grains within the material. This enables the bar edge to be kept in the rough condition which reduces energy consumption. It also enables narrower bars while maintaining good volume in the grooves for hydraulic capacity. It also permits higher bars which can increase the lifetime of a set of fillings.

Welded Refiner Plates

Conclusion

There are a number of ways to more efficiently refine our resources that revolve around reducing the large proportion of power that goes into just heating up the pulp. Fine bar design in casted plates, Welded plates, Milled plates and more recently developed Curved bar Refiner plates are commercially available but they have not been adopted wholeheartedly by the paper industry. Refiner filling suppliers have a future.