Fractionation of high Kappa number kraft pulps of the South African softwoods and sulfonating of coarse fibre enriched fraction for production of sack paper

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SUMMARY

The focus of this study was to investigate fractionation as a means to manufacture sack paper with uniform quality properties at increased refining energy efficiency compared to currently applied technologies. Kraft pulp produced at Kappa number approximately 85 was fractionated using a hydrocyclone and the coarse fibre enriched fraction was sulfonated. Sulfonation was carried out to enhance the refinability of the coarse fibre enriched fraction, evaluated using a PFI mill.

The results indicate that the best fractionation can be achieved using feedstock consistency of 0.25% at volumetric reject ratio of 30%. As expected, sulfonation resulted in the coarse fibre enriched fraction responding more favourably during the refining/PFI beating process. For effective sulfonation, sodium sulfite dosage of 10% at a treatment time of 20 minutes was required.

Measurement of the refining energy/PFI beating level required to achieve a target freeness of 550 ml CSF revealed that the sulfonated pulp can require 17% less beating energy compared to the unsulfonated pulp.

KEYWORDS

High Kappa number softwood kraft pulp, fractionation, Hydrocylone, sulfonation, coarse fibre enriched fraction, refining energy, strength properties, sack paper

INTRODUCTION

Due to fibre shortage in South African pulp and paper industry, there is an alarming rate of wood price increase. The recent approval of an increase in electricity tariffs by 26% combined with higher product quality demands have also put more pressure on the industry to re-think their operational strategies. It is imperative, if the industry is to survive in the current economical circumstances, that new strategies for improving the competitiveness are needed. The sustainability of wood resources, energy security and higher product quality should be of a key priority.

Improvements can be made to some extent by adopting technologies and/or process modifications that will provide substantial reduction in capital and production costs. A significant saving in refining energy and an improvement in product quality would lead to increased competitiveness of the South African high yield kraft pulping industry.

The heterogeneity in wood physical properties and pulp fibres has severe negative impact on product quality and refining energy efficiency. A most important way of offsetting these disadvantages is through fibre fractionation, i.e. separating the pulped fibres in the feed stock stream into two separate streams in which the pulp fibres have different morphological properties. Fibre fractionation can have a range of benefits depending on the scope of its application in pulp and paper industry. Improvements in refining energy efficiency, improving product quality and optimal utilisation of the costly and scarce wood resources have all been documented (*1-4*).

Fibre fractionation has in the past been dominated by the use of screens. However, fractionation using screens has limitations. Screens separate a fibre pulp stream predominantly based on the fibre length, i.e. into short and long fibre fractions (*4-5*). Thus, coarse fibres can be found in both short and long fibre enriched streams (*4*). On the other hand, hydrocyclones can separate a pulp stream into two distinctive fractions – one that is enriched with fine fibres, and one that is enriched with coarse fibres (2,4-6).

A paper sheet made using a fine fibre enriched fraction i.e. with predominantly thin-walled fibres, is characterised by high sheet density and good surface smoothness, while a paper sheet made from the coarse fibre enriched fraction i.e. with predominantly thick-walled fibres, is very bulky and porous. The latter forms an ideal pulp for manufacturing sack paper and was the focus of this study. Sack paper grades require relatively low air flow resistance (high porosity) and relatively high tensile strength properties e.g. tensile and TEA strengths, in their end-user applications (*7-9*).

Previous studies on South African grown softwood species i.e. *Pinus patula* and *P. elliottii* have shown extreme variation of fibre characteristics (*10*). Consequently, local South African sack kraft mills have been experiencing sack paper quality problems.

Using current technologies, the required tensile strength properties can normally be achieved; however this normally results in insufficient air permeability. This can usually be attributed to the high proportion of fine fibres present in the furnish made from softwood (*2,10*). Fine fibres collapse, consolidate and conform well in the paper sheet (*11,12*). This results in poor air permeability as there is limited number of open pores for air to pass through the paper sheet.

A process/system that fractionates pulp fibres selectively according to the desired range of property values promises to give better control of the sack paper sheet quality variations. For example fractionation of the initial pulp fibre mix and refining of the coarse fibre enriched fraction might improve the sack paper quality (*7*). However, refining the coarse fibre enriched fraction to achieve the desired sack paper quality may require a huge refining energy (*12*). In addition, since the

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fibres of the coarse fraction are stiff and brittle, refining tends to generate more fines, an effect that counters the strengthening impact of refiner induced increased fibre flexibility (*12,13*).

Several methods for treating pulp to enhance refinability – make the pulp easier to refine - have been suggested, including sulfonating of stiff and brittle fibres (*14,15*). This procedure may potentially significantly reduce the refining energy required to refine a coarse fibre enriched fraction of the high Kappa number softwood kraft pulps.

In previous studies (*2,4,6,7*), promising results of fractionating softwood kraft pulps have been reported, however these studies focused on kraft pulp with lower lignin content (Kappa number 20 to 30). Thus, despite the promising potential of fibre fractionation using hydrocylones, little is known on the potential of fractionation of high Kappa number softwood kraft pulps (e.g. pulp at Kappa number of 85). In addition, the issue of minimising refining energy required for developing the strength properties of the coarse fibre enriched fraction has not yet been addressed.

This study therefore sought to investigate an alternative way of producing sack paper with improved critical quality properties, at the same time seeking to ensure the maximisation of the utilisation of wood resources and improved refining energy efficiency in sack paper manufacturing fibre lines. In order to achieve this objective, kraft pulp produced at Kappa number approximately to 85 was fractionated. Thereafter, the coarse fibre enriched fraction was sulfonated. Sulfonation was carried out to enhance the refinability of the coarse fibre enriched fraction, and the degree to which this was successful was evaluated through PFI refining/beating.

EXPERIMENTAL

Raw material

Industrial kraft pulp samples made from South African grown mixed *P. patula* and *pinus elliottii* were collected from mill A located in South Africa. The Kappa numbers of pulp samples was approximately 85. To minimize the negative effects of shives in the hydrocylone fractionation efficiency and operation, the pulp samples were sampled from the primary screen accept line. The primary screen removes shives and other bigger wood particles thus providing ideal pulp fibres for hydrocylone fractionation.

Fractionating high Kappa number kraft pulp samples

The potential of fractionation of the high Kappa number softwood kraft pulps using a hydrocylone was investigated. Trials were performed in CSIR laboratory at Forestry and Forest Products Research Centre (FFP). The influence of the hydrocylone operating parameters, feed stock consistency and volumetric accept/reject ratio were studied. The first set of fractionation experiments examined the influence of feed stock consistency on the hydrocylone efficiency. Three levels of feed stock consistency (0.25%, 0.5% and 1%) were tested at constant reject ratio of 20.

The second set of experiments examined the impact of the volumetric accept/reject ratio on the fractionation efficiency of the hydrocylone. The feedstock consistency of 0.25% was used for these trials. This optimal feed stock consistency level was initially determined in earlier experiments described above. The experiments were repeated for reject ratios - 30, 25, 16, 10, and 6. The influences of volumetric accept/reject ratio on freeness drop, fibre morphology and reject mass rate were studied.

The Noss Hydrocylone test canister rig was connected to the pilot plant low consistency refiner flow system which is provided with a mixing tank and positive displacement pump. For each trial, the pulp sample was mixed with water, in the refiner chest tank provided with an agitator, to the desired trial feedstock consistency. The sample was mixed at a high intensity for 15 minutes to ensure the pulp fibres were well dispersed and a homogeneous mixture produced. The mixture was subsequently pumped and recirculated through the hydrocylone at volumetric flow rate of 100 to108 L/min. The feed pressure was kept in the range of 2 to 2.3 bars. The feed stock flow rate and feed pressure range was set at the desired hydrocylone operating condition specifications.

The pulp samples from each stream (feed, accept and reject) were thickened and kept in a fridge at 4 ºC for fibre morphology and strength properties evaluation. Portion of reject stream - the coarse fibre enriched fraction pulp samples were used in the subsequent sulfonation stage.

Sulfonating the coarse fibre enriched fraction pulp samples

The experiments focused on evaluating the potential of improving the bonding ability of the coarse fibre enriched fraction at reduced refining energy. Coarse fibre enriched fraction pulp samples were sulfonated prior to refining/beating. The influence of the main sulfonation process parameters, reaction time and sodium sulfite dosage were investigated.

The weighed portion of pulp fibre (200 g oven dry) from the coarse fibre enriched fraction pulp sample was placed in a polyethylene bag. The required volume of distilled water (calculated to make a desired pulp slurry consistency of 10%) was used to dissolve sodium sulfite powder (97% purity) at percentages of: 4, 6 and 10% relative to oven dried mass of pulp. Thereafter, the resulting solution was added to the polyethylene bag containing the raw pulp.

After a thorough mixing of the pulp slurry by hand in polyethylene bag, a portion of the slurry (approximately 10 g) was taken for pH analysis. This was to ensure that the pH was such that sulfonation would take place with limited hydrolysis, by restricting the pH within the range 9 to 10 (*15*). After confirming the pH, the contents of the polyethylene bag was then transferred into the rotating digester. The digester was closed and the heating programme was started up. The ramping time to the maximum temperature of 90ºC was 50 minutes. The reaction time at maximum temperature at each sodium sulfite dosage was varied between 10 and 20 minutes.

Sack paper quality for unsulfonated (control) and selected sulfonated sample were evaluated at target freeness of 550 ml CSF. This freeness value is used in industry for the feedstock used in manufacturing sack paper sheets (*7,9*). The amount of refining energy/PFI beating level required to reach the target freeness for sulfonated and unsulfonated pulp samples were noted.

Evaluation of pulp quality

The Canadian Standard Freeness (CSF) measurement was performed according to TAPPI test method T227 om-94. Hand sheets were prepared according to T205 sp-95. The prepared hand sheets were left in a conditioned room 23 °C ± 0.5 °C and relative humidity 50% ± 1 for 24 hours prior to testing. TAPPI or ISO test standard methods were used for all physical tests that were performed on the hand sheets. The fibre morphology analysis tests were performed using the Techpap MorFi fibre analyzer according to instructions supplied by the manufacturer.

RESULTS AND DISCUSSION

Fractionating the high Kappa number kraft softwood pulps

Effect of stock consistency on fractionation efficiency

The results for the effect of the feed stock consistency on fractionation efficiency are shown in Table 1. The data indicate that in order to achieve best fractionation efficiency, the lower feed stock consistency (0.25%) is required. When comparing the fine fibre enriched fraction (accepts) with the control (hydrocyclone feed), the difference in freeness decreased with increasing feed stock consistency. The highest freeness drop (61 units) was observed at the lowest feed stock consistency (0.25%). At the higher feedstock consistency of 1% the freeness drop was only 16 units.

For the coarse fibre enriched fractions (rejects) the freeness increased, showing an increase in water drainage rate due to poor collapsibility of the coarse fibres. Again an increase in freeness was more pronounced at a lower feed stock consistency (0.25%), indicating strong fractionation. Compared to control, an increase of 45 units could be observed at feed stock consistency of 0.25%, while the increase in freeness was insignificant at feed stock consistencies of 0.5 and 1%.

Similar findings on the limitation of fractionation at consistency >0.25% has been reported elsewhere. When Paavilainen (*2*) increased feedstock consistency above 0.3% for fractionating Scandinavian softwood pulp (Kappa number 33), a high tendency to form fibre networks (solid body like rotating) was observed. It was presumed that fibre network formation is responsible for the limitation of the free movements of the fibres. It has been reported that fibre fractionation takes place when there is relative movement of fibres to each other (*16*). In this regards, fractionation with hydrocyclone is limited by the feedstock consistency. The highest feed stock consistency successfully used has been 1%, and this was with short fibres viz. thermal mechanical pulp (TMP) fibres (*16*).

Table 1
Effect of feed stock consistency on freeness at constant reject ratio of 20

Feed stock consistency (%)	Freeness (ml CSF) Accept	Freeness (ml CSF) Reject
0.25	594±12	700±15
0.5	613±10	660±12
1.0	639±9	656±13
Control – unfractionated	655±12	

Table 2
Mass reject rate at different reject ratios setting

Reject ratios	Mass reject rate (%)	Thickening factor
6	24±0.4	6.0
10	44±1.4	4.4
16	63±3.4	3.9
20	58±3.2	2.9
25	73±3.8	2.9
30	56±1.3	2.8

Table 3
Fibre morphology results at selected reject ratios

Reject ratios		30		20		6	
Fibre morphology properties	Control	Accept	Reject	Accept	Reject	Accept	Reject
Fibre length (mm)	2.23	2.00	2.31	2.15	2.18	2.18	2.30
Fibre width (microns)	36.6	30.4	39.1	33.1	39.1	35.5	40.2
Fines % total Area	3.81	7.61	2.52	7.06	2.14	4.54	2.04
Fibre per gram(10e^6/g)	3.05	4.79	2.13	3.13	2.35	3.10	1.72

Note: due to error in fibre cell wall and coarseness data, the data are not reported here.

Effect of volumetric accept/reject ratios on fractionation efficiency

The reject ratio effects data are detailed in Figure 1. The fractionation efficiency was evaluated in terms of freeness values of accept and reject relative to feed. Operating the hydrocylone at reject ratio of 6, 10 and 16 gave poor fractionation efficiency. The accept samples attained freenesses which were 6, 7 and 16 units lower than the feed (control) respectively, and accept and reject freeness values were almost equal to feed freeness indicating that only limited fractionation occurred.

Presumably, reduced reject valve opening imposes restriction on the free movement of pulp fibre flow resulting in a high pulp fibre thickening in the reject stream line. It is worthwhile also to note that at reject ratio of 6, reject stream line started to clog.

Better fractionation can be achieved by using reject ratio of 20, 25 and 30. When compared to control pulp samples, the respective accept samples attained freenesses which were 61, 71 and 88 units lower than the control respectively. Normally, operation of the hydrocylone should be limited to lower volumetric reject ratios (*5*). However, the volumetric

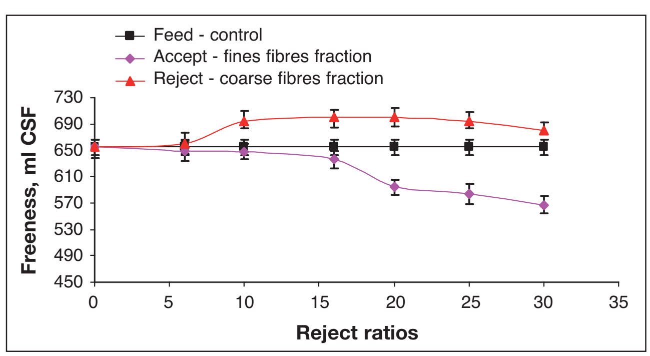


Fig. 1 Comparison on the effect of reject ratios on freeness drop between feed - control, accept and reject pulp samples

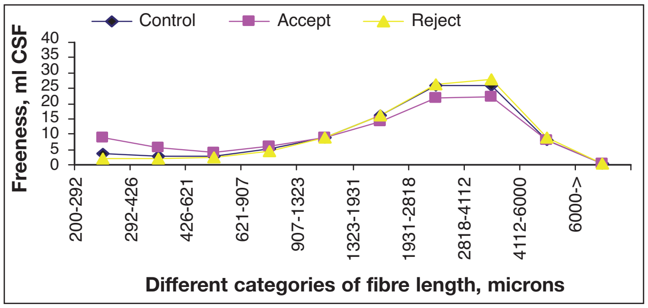


Fig. 2 Fibre length distribution at reject ratio of 30.

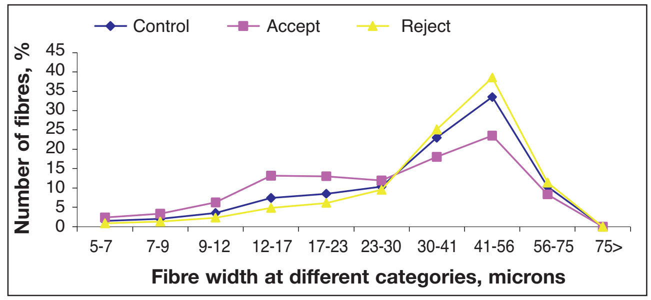


Fig. 3 Fibre width distribution at reject ratio of 30.

reject ratio required depends on the hydrodynamic characteristics of the pulp being fractionated. For the fractionation of softwood kraft pulp at Kappa number 85, a reject ratio of 30 produced the most pronounced fractionation effect.

Effect of volumetric accept/reject ratio on mass reject rate

Mass reject rate plays a vital role in deciding on whether to use fractionation in industry. The pulp mass split at the fractionation unit will generally be required to match with the pulp mass balance required in the mill. In this context, the mass reject rate at different reject ratios settings was evaluated. The results are illustrated in Table 2. At the preferred reject ratio of 30 a mass reject rate of 56% of the total feed was achievable. The reject thickening factor at this reject ratio setting was 2.8, indicating also better fractionation (*3*).

Effect of volumetric accept/reject ratio on fibre morphology properties

Fractionation resulted in pulp with different morphological properties. Using the preferred reject ratio of 30, a high proportion of fine fibres: fines, small fibre width and short fibres was observed in the accept pulp samples. This result supports the freeness trend explained in the previous section i.e. the fine fibre enriched fraction exhibited lower freeness values while coarse fibre enriched fraction exhibited higher freeness.

As expected, no clear distinction between unfractionated (control), accept and reject fibre length distribution was observed (Figure 2) because hydrocyclones fractionate according to density/cell wall thickness and not based on fibre length (*1-6*). On the other hand, Figure 3 shows that the reject pulp contains a high proportion of fibres with a larger fibre width compared to the control and the fractionated accept pulp.

Unrefined fractionated pulp samples - Strength properties

As discussed in the previous section, a reject ratio of 30 achieved superior fibre fractionation efficiency. The pulp samples obtained using this setting were then used to study the effect of fractionation on pulp strength properties. The strength properties for the unrefined samples of the unfractionated (control), accept and reject pulp samples are shown in Table 4. When compared to control, accept pulp samples showed improvements in all pulp strength properties except tear strength: Tensile index (54%), TEA index (104%), Burst index (65%) and sheet density (23%). A tear index decrease (30%) could be attributed to a high proportion of short and fine fibres in the accept stream.

The reject stream gave pulp samples with inferior strength properties with exception of tear strength. This may be due to high proportion of coarse fibres which have limited fibre collapsibility. Poor fibre collapsibility leads to a limited fibre bonding ability and thus resulting in inferior hand sheet strength properties. Compared to the control, an average 15% decrease in strength (i.e. Tensile, TEA, Burst and Apparent density) was observed.

The data tend to suggest that accept pulp samples may require less refining/beating compared to control and reject pulp samples to reach a given freeness. In addition, reject pulp samples could be used for sack paper provided that tensile strengths could be developed without negatively affecting the air permeability. This is discussed in the next section.

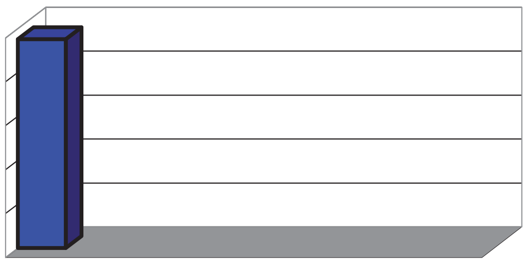
The effect of sulfonation conditions on freeness drop of coarse fibre enriched fraction

Development of tensile strength properties i.e. Tensile and TEA with limited fibre collapsibility produces ideal pulp for manufacturing sack (*7*). Sulfonation may assist this so to evaluate this concept, the reject pulp samples were sulfonated at different combinations of sodium sulfite dosage and reaction time. Thereafter, all pulp samples were subjected to PFI beating at 5000 rpm. The best sulfonation effect was achieved at sodium sulfite dosage of 10%, compared to 4% and 6% dosages, at any given reaction time investigated. For achieving standard freeness of 550 ml CSF required for sack paper stock furnish sodium sulfite dosage of 10% at reaction time of 20 minutes is required (Figure 4).

It is important to highlight that at this sulfonation conditions, the pulp yield preserved varied between 100 and 99%, indicating that the pulp yield loss is insignificant. As removal of lignin would have led to losses, the effects of sulfonation on pulp yield suggest that sulfonation modifies the lignin rather than removing it. Kingstad and Olausson reported similar effects in studying sulfonation of unfractionated North American softwood kraft pulp (*15*).

Table 4
Strength properties for unfractionated (control), accept and reject samples after fractionating at reject ratio of 30 (unrefined pulp samples)

	Control	Accept	Reject
TEA Index (kJ/g)	0.50	1.02	0.43
Tensile Index (kNm/g)	33.00	51.00	28.00
Burst Index (kPa.m^2/g)	2.80	4.60	2.40
Tear Index (mN.m^2/g)	16.00	11.00	17.00
Apparent density (g/cm^3)	0.78	0.96	0.80
Air flow resistance (Gurley s/100ml)	0.25	2.00	0.30



Comparison between unsulfonated and sulfonated coarse fibre enriched fraction pulp samples on refining energy requirements

In order to determine the influence of sulfonation on coarse fractions pulp samples collected in the reject stream, the pulp samples sulfonated using sodium sulfite dosage of 10% at reaction time of 20 minutes were further compared to unsulfonated pulp samples. The influence of sulfonation was more pronounced at PFI beating level >3000 rpm (Figure 5). The data also indicate that sulfonated pulps are softer and easier to refiner. It can be seen that to achieve the target freeness of 550 ml CSF, sulfonated pulp samples required 17% less refining/PFI beating energy than the unsulfonated pulp samples i.e. 5000 rpm instead of 6000 rpm.

The strength properties were also measured on the pulp samples after refining to the target freeness (550 ml CSF). The data (Table 5) tends to suggest that at this freeness, sulfonated pulp can attain similar tensile strengths to the unsulfonated pulp even though requiring 17% less PFI beating. However, the air permeability for the unsulfonated pulp samples is negatively affected (decreases by 36%). This may be contributed to high fibre collapsibility and fines generation inherited at higher PFI beating levels of coarse fibres (*12,13*).

The lower porosity (high air flow resistance) of the unsulfonated sample suggests that in practice, refining at lower intensity may be required. For industrial application this means that more refiners in series is required. This will result in additional operational costs.

According to Scott-Kerr (*12*), the air permeability of the good sack paper should be in the range of 1000 ml/min (equivalent to Gurley air resistance of 6s/100 ml) or slightly higher. Therefore, the sulfonated coarse fibre enriched pulp appears to give both satisfactory tensile strength properties and air permeability. However, since PFI mill refining favours lower intensity refining which has minimal effect on fibre cutting, investigation based on disc refining is required before commercial application can be considered. In addition, cost benefit analysis is required to determine whether fractionating high kappa numbers pulp followed by sulfonation of coarse fibres enriched fraction may be economically viable.

These results indicate that if fractionation and sulfonation are employed, it may be possible to utilise pulp at Kappa numbers above 60 in sack paper manufacturing. This may contribute to an increase in production capacity as well as maximisation of the utilisation of the softwood resources. Furthermore, re-mixing of fine and coarse enriched fraction after being separately refined at appropriate refining energy energies may also be beneficial to other paper grades. This approach may lead to optimising refining energy and pulp quality as opposed to refining pulp with heterogeneous fibre mixtures (*3*).

Table 5
Comparison between unsulfonated and sulfonated coarse fibre enriched fraction pulp samples - strength properties at 550 ml CSF

Strength properties	Unsulfonated PFI beating at 6000 rpm	Sulfonated PFI beating at 5000 rpm
TEA Index (kJ/g)	1.9±1.4	1.7±1.2
Tensile Index (kNm/g)	76.0±0.8	75.0±0.6
Burst Index (kPa.m^2/g)	6.0±0.3	6.0±0.6
Tear Index (mN.m^2/g)	7.6±1.2	7.5±0.9
Apparent density (g/cm^3)	0.89±0.9	0.9±1.2
Air flow resistance (Gurley s/100ml)	11.0±1.7	7.0±1.4
Stretch (%)	3.6±0.2	3.4±0.4

CONCLUSIONS

- The potential of fractionating high Kappa number softwood kraft pulps by hydrocyclone has been demonstrated. The best fractionation can be achieved using feedstock consistency of 0.25% at reject ratio of 30.
- Sulfonating the coarse fibre enriched fraction can improve the refining energy efficiency. Comparison of the sulfonated and control (unsulfonated) pulp samples at a target freeness of 550 ml CSF showed that the sulfonated pulp sample could require 17% less beating/ refining energy.
- Industrial acceptance of this concept will require careful economic assessment of refining options and fractionation/sulfonation costs

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