Research paper

Use of Primary Fiber Fines as Organic Fillers in Papermaking

Vipul Singh Chauhan,[1,4) Nitin Kumar,[1)] Manoj Kumar,[2)]
S. K. Thapar,[3)] Swapan Kumar Chakrabarti[1)]

【Summary】

Primary fiber fines were screened out of virgin mixed hardwood chemical pulp through a Bauer McNett Fiber Classifier with 2 output materials of fibers and fines. The screened primary fiber fines were blended into the pulp to obtain pulps with no fines, and with 10 and 20% fines. The refining of all pulp samples was carried out in a PFI mill. The pulp with 10 and 20% fines respectively required 10.8 and 28.9% fewer PFI revolutions to obtain a 400 ml CSF level compared to the pulp without fines. At the same freeness level, the opacity of the paper increased with the addition of 10 and 20% fines by 1.7 and 2.6 points, respectively. Similarly, the formation of paper also improved by 2.0, and 10.2% with the respective addition of 10 and 20% fines to the pulp. The bulk and stiffness of the paper improved with the addition of fines up to a 450 ml CSF level. The strength properties, such as the breaking length, burst index, tear index, double fold, and Scott bond, decreased with the addition of fines.

Key words: fiber fines, freeness, opacity, organic filler, strength.

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[1)] Thapar Centre for Industrial Research & Development, Paper Mill Campus, Yamuna Nagar 135 001, Haryana, India.

[2)] Star Paper Mills Ltd., B.D. Bajoria Road, Saharanpur 247 001, Uttar Pradesh, India.

[3)] Anmol Polymers Pvt. Ltd., 1003 GD-IDL Tower, Netaji Subhash Place, Pitam Pura, New Delhi 110 034, India.

[4)] Corresponding author, email:vipchauhan@yahoo.co.in 通訊作者。

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研究報告

利用初生纖細物作為造紙之有機填料

Vipul Singh Chauhan,[1,4) Nitin Kumar,[1)] Manoj Kumar,[2)]
S. K. Thapar,[3)] Swapan Kumar Chakrabarti[1)]

摘　要

初生纖細物以一具Bauer-McNett纖維篩分機從混合樹種原生化學漿中篩選出，並與纖維部份分離。篩出的纖細物混入紙漿中以分別獲得不含纖細物以及含10與20%纖細物之紙漿，其分別較不含纖細物紙漿減少10.8與28.9%之PFI打漿紙轉數而達到400 ml CSF游離度之程度。於相同之游離度下，添加10與20%纖細物所抄紙張之不透明度分別增加1.7與2.6百分點。同時添加10與20%纖細物紙漿所抄之紙，交織分別改善了2.0與10.2%。紙之嵩度與剛挺度亦隨纖細物的添加而改善，至紙漿游離度450 ml CSF之程度。強度性質，如抗張斷裂長、破裂指數、撕裂指數、耐折度與Scott層間結合強度等則隨纖細物添加而減低。

關鍵詞：纖細物、游離度、不透明度、有機填料、強度。

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INTRODUCTION

Materials passing through a 76-µm (200-mesh) screen in Bauer McNett fiber classifier are generally termed “fines” (Wood et al. 1991, Biermann 1996). Fiber fines are essentially the detached portion of cellulosic material consisting of lignin, ray cells, tracheids, parenchyma cells (especially from hardwood and non-wood pulps, and small fiber fragments), and cellulosic debris, which are termed primary fines. Primary fines come from virgin unrefined pulp, whereas secondary fines are generated by the mechanical action imparted to pulp in the form of beating or refining (Casey 1980, Gess 1998).

The dimensions of fines are much smaller than fibers, typically 2~20 µm compared to 1000 µm for hardwood fibers. Fines typically have 5-times the surface area of fibers per unit weight, but it can be as much as 10-times. Fines also tend to swell and adsorb more water than fibers. Some typical fines levels in stocks are 40~60% for newsprint, 30~35% for fine papers, and < 25% for linerboard (Biermann 1996; Gess 1998).

Fines play an important role in the papermaking process, and they are materials of interest in the manufacturing process and in fundamental studies of paper technology (Paavilainen 1990, Springer and Kuchibhoitle 1992, Liu 2010). A well-planned management system for fines is considered vital for high productivity and product quality; higher productivity can be achieved because of variations in drainage properties of different fines and, consequently, on the running of paper machines. They can significantly affect the mechanical and optical properties of paper and the drainage properties of the pulp (Paavilainen 1990).

The use of fractionation techniques is

increasing in the pulp and paper industry. One reason is the possibility of removing and separately treating fiber fractions that may negatively affect pulp and papermaking. The fines fraction differs from the fiber fraction in that it has higher contents of lignin, metal ions, and extractives (Bacstrom and Brannvall 1999, Liitia et al. 2001, Ontto et al. 2002, Treimanis et al. 2009). Chemical pulp fines retard dewatering of the pulp suspension due to the high water-holding capacity of fines. The specific surface area of fines can be considered an important characteristic of the dewatering and bonding abilities (Giertz 1980).

Fines may provide several other benefits to the papermaking process. They increase the absorption of dyes at the wet-end section (Liu et al. 2010). Fines-free pulp was shown to be easily bleachable with higher brightness (Asikainen et al. 2010). Jaycock et al. (1976) measured the electrophoretic mobility and retention of papermaking stocks of fines-free pulps and compared them to pulps containing fiber fines. They showed that cellulose fines caused profound differences in the pattern of retention behavior, and the results can be qualitatively understood in terms of simple heteroflocculation theory.

Patel and Trivedi (1994) blended fines from bamboo-hardwood pulp, talc, and aggregates from mill white water solids into 36 different compositions. Variations in the strength and bonding properties of the 4 different fines studied were reported to differ from each other, indicating an interesting area for further studies.

Lin and Nazhad (2006) showed that secondary fines from eucalyptus pulp increased the paper strength, but retarded the drainage and decreased the opacity of the paper. The qualities of fines had a strong effect on the strength properties of paper and drainage of the pulp. The addition of premixed fines and fillers to a pulp furnish improved the retention, strength, and optical properties of the resulting paper at the cost of significantly reduced drainage (Lin et al. 2007).

It is generally agreed that fines have a detrimental effect on the drainage and retention characteristics of pulp. While fines improve the strength properties of paper sheets through improved bonding area, secondary fines are far more effective than primary fines. Secondary fines reduce the light-scattering properties of a sheet and hence reduce the opacity of the paper (Pruden 2005). Sheet properties are affected by both the quantity and dimensions of the fines. The fines fraction affects drainability and structural and optical properties, and also enhances the effect of beating on air permeability and light scattering of the finished sheet (Luis et al. 2002).

In this study, primary fiber fines were screened out through a Bauer McNett fiber classifier and were added to a hardwood pulp in different proportions to analyze the effects on the pulp stock and paper properties.

MATERIALS AND METHODS

Materials

The bleached hardwood pulp of subabul furnish was collected from a BILT unit, APR, which originally had 575 ml Canadian standard freeness (CSF).

Methods

Bauer McNett fiber classification of the virgin pulp sample was carried out as per Tappi T 233 cm-95 (2002-2003 Tappi Test Methods). Fines which passed through a 200-mesh screen were collected on a 400-mesh screen covered with a filter cloth to ensure that the entire fines fraction was retained. These experiments were repeatedly carried out to collect a sufficient amount of fines. For these experiments, we blended the fines in 3 different ways; a) pulp without fines (pulp samples collected on the Bauer McNett Fiber Classifier); b) pulp with 10% fines (10% fines were added externally to the no-fines pulp); and c) pulp with 20% fines (20% fines were added externally in the no-fines pulp). All pulp furnishes were refined in a PFI mill (Hamzern Maskin as, Hamar, Norway) to achieve different freeness levels. The freeness of the pulps was measured on a CSF tester as per Tappi T 227 om-99 (2002-2003 Tappi Test Methods).

The drainage times of all combinations at different freeness levels were measured on a Lab Handsheet Former (Universal Engineering Corporation, Saharanpur, Uttar Pradesh, India) as per Tappi T 221 cm-99 (2002-2003 Tappi Test Methods). Paper handsheets with a basis weight of 70 g m^{-2} were prepared on a Lab Handsheet Former from the various unrefined and refined pulp furnishes. The properties of the paper handsheets were determined by conditioning them in a room with constant temperature (23±1℃) and humidity (50±2%) for 24 h. The breaking length of the paper was determined on an L&W tensile strength tester (model SE 060, Lorentzen & Wettre, Kista, Sweden) as per Tappi test method T 494 om-01 (2002-2003 Tappi Test Methods). The burst index was determined on an L&W bursting strength tester (model SE 181, Lorentzen & Wettre, Kista, Sweden) as per Tappi test method T 403 om-97 (2002-2003 Tappi Test Methods). The tear index was determined on an L&W tearing tester (model SE 009, Lorentzen & Wettre, Kista, Sweden) as per Tappi test method T 414 om-98 (2002-2003 Tappi Test Methods). The double fold of the paper was determined on an MIT folding endurance tester (model 1, Testing Machines Inc., New Castle, USA) as per Tappi test method T511 om-02 (2002-2003 Tappi Test Methods). The stiffness was determined on a Taber stiffness tester (model 150E; Lorentzen & Wettre, Kista, Sweden) as per Tappi test method T 566 om-02 (2002-2003 Tappi Test Methods). The internal bond strength of Scott bond paper was determined on a Scott bond tester (model B, Isimat, San Diego, CA, USA) as per Tappi test method T 569 pm-00 (2002-2003 Tappi Test Methods). The air permeance was measured on an L&W air permeance tester (model SE166, Lorentzen & Wettre, Kista, Sweden) as per Tappi test method T460 om-02 (2002-2003 Tappi Test Methods). The ISO opacity of the paper was measured on a Datacolor brightness tester (model SF 300, Datacolor, Lawrenceville, New Jersey, USA) as per ISO 2471:2008 (2002-2003 Tappi Test Methods). The formation of the paper was measured on a Paprican Microscanner (OpTest Equipment Inc., Hawkesbury, Canada).

RESULTS AND DISCUSSION

Effects of fines on the refining energy

The initial freeness of the unrefined pulp samples was influenced by the fines content in the pulp slurry. From Fig. 1, it can be observed that pulp without fines had the highest freeness value (675 ml) followed by pulp with 10% fines (648 ml), and 20% fines (575 ml). This clearly indicates that an increase in the fines content decreased the freeness of the pulp. This trend was also observed at other freeness levels. As expected, an increase in the number of PFI mill revolutions decreased the freeness of all pulp samples. To achieve ~400 ml CSF (a typical freeness level used in mills for hardwood pulps for producing fine paper), the PFI revolutions required for pulp without fines were highest (4150 PFI revolutions) followed by pulp with 10% fines (3700 PFI revolutions), and 20% fines (2950

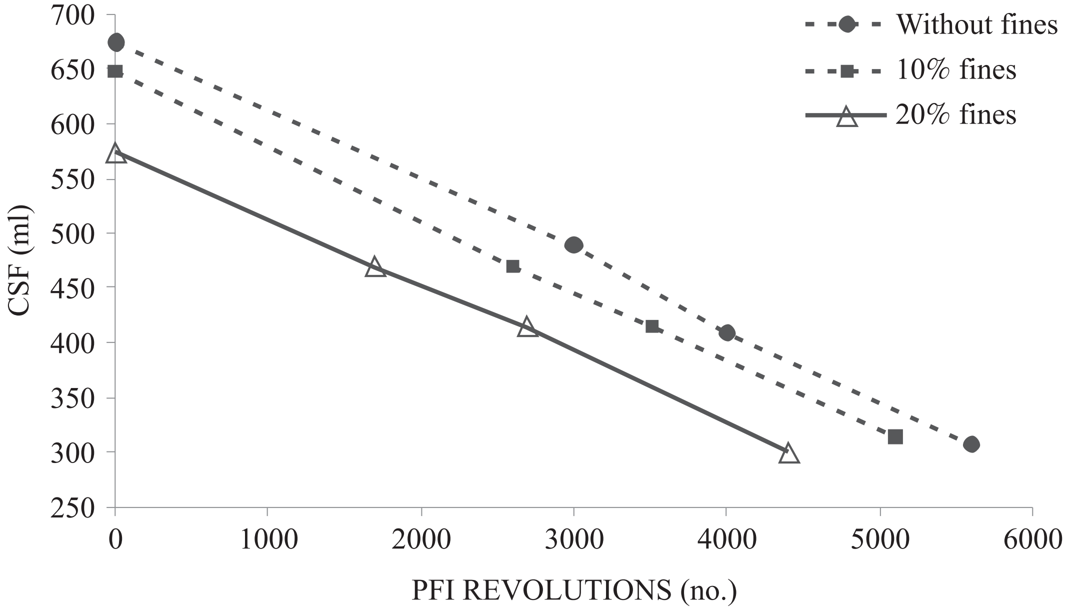

Fig. 1. Effects of primary fines on the freeness and refining energy of pulps.

PFI revolutions). It was obvious from these results that the primary fines added to pulp furnish was helpful in decreasing the energy requirement during beating and refining.

Effects of fines on the drainage time of the pulp

The drainage time at all freeness levels was affected by the presence of fines. Compared to the 400 ml CSF value, the drainage time was lowest for pulp without fines (5.8 s) followed by pulp with 10 (6.3 s) and 20% fines (6.7 s) (Fig. 2). Giertz (1980) showed that the fines have a greater water-holding capacity and so affect the drainage properties. The results obtained from our study also showed a similar trend. The other assumption was that the fiber fines filled the voids among the fibers, thus blocking the passage of water that was draining out of the structure. It was also noted that the drainage time of pulp furnishes increased with increased refining due to the generation of secondary fiber fines.

Effects of fines on paper properties

Bulk

It is well known that refining causes fibers to naturally collapse and hence reduces the bulk. A similar trend was observed with all combinations. As shown in Fig. 3, the bulk of the paper made from pulp with fines was initially higher than the pulp without fines. At 500 ml CSF, the bulk values of paper made from pulp without fines, and with 10 and 20% fines were 1.63, 1.66, and 1.69 ml g^{-1}, respectively. However after reaching a particular level of freeness, i.e., 450 ml CSF, the reverse trend was observed. Pulp with 10 and 20% fines more readily collapsed compared to that without fines. Respective bulk values of paper made at 400 ml CSF were 1.40, 1.35, and 1.31 ml g^{-1}. This was possibly because pulp with added fines required less refining energy to attain a particular freeness level compared to pulp without fines, hence a smaller impact on the bulk was observed up to a level of 450 ml

CSF, but below the 450 ml CSF level, the refining intensity caused the fines to more easily collapse compared to pulp without fines.

Breaking length

Refining provides a higher surface area to fibers, thus improving fiber-to-fiber bond-

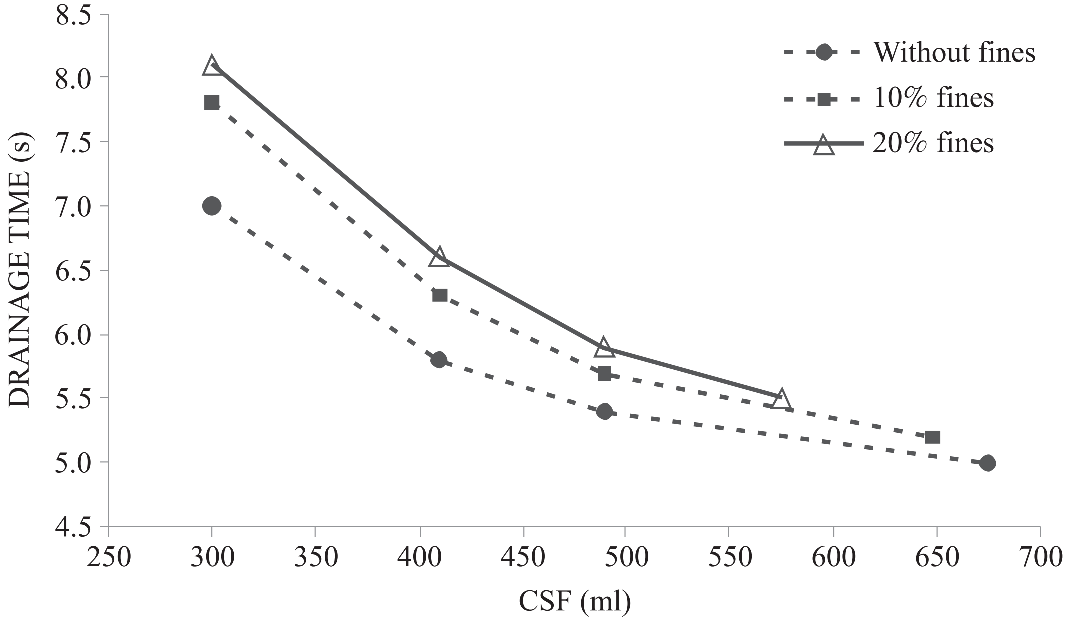

Fig. 2. Effects of primary fines on the drainage time of pulps at different freeness levels.

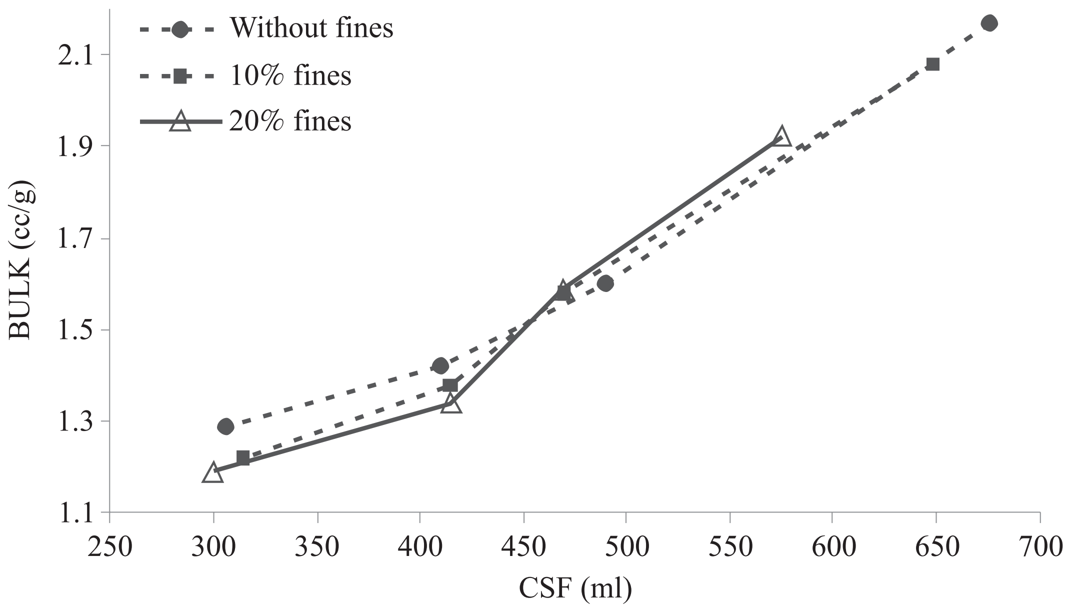

Fig. 3. Effects of primary fines on bulk values of paper at different freeness levels.

ing. A similar trend was noted at increased refining rates for all combinations. As shown in Fig. 4, the breaking length decreased with an increasing fines content in the pulp. The results revealed that the fines content adversely affected the breaking length of the paper. This was because the fiber fines fit in among the fibers, which affected fiber-to-fiber bonding by reducing the relative surface bonding area. At 400 ml CSF, breaking lengths of the paper were 6500, 6400, and 6000 m for the pulp without fines, and with 10 and 20% fines, respectively. Breaking lengths of paper at 300 ml CSF were around 6800, 6700, and 6400 m for pulp without fines, and with 10 and 20% fines, respectively. A similar trend was observed with further decrease in the freeness of the pulp.

Burst index

A similar trend was also observed for the burst index as we found for the breaking length. As shown in Fig. 5, the burst index was highest for paper produced from the pulp without fines followed by pulp with 10 and 20% fines. This trend was noted at all freeness levels. At higher freeness levels, differences in burst index values were greater compared to those at lower freeness values of the pulp. Initially, the burst index of the unrefined pulps was quite low and increased with refining of the pulp. At 400 ml CSF, the burst index was highest for pulp without fines (5.1 kN g^{-1}) followed by pulp with 10 (4.9 kN g^{-1}) and 20% fines (4.6 kN g^{-1}).

Tear index

The tear strength of a pulp depends upon the fiber morphology. The higher the fiber length is, the higher is the tear index. The addition of fines to a pulp reduces the average fiber length, hence affecting the tear strength. Figure 6 also shows the same trend. If compared at the 500 ml CSF level, the tear index of paper produced from pulp without fines was highest (9.1 mNm^2 g^{-1}) followed by

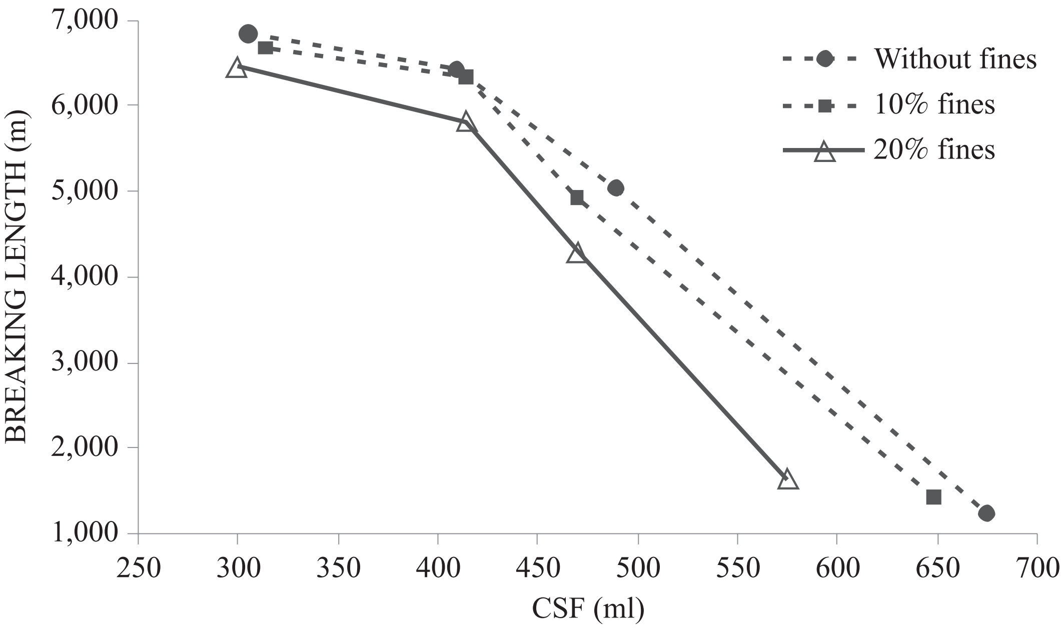

Fig. 4. Effects of primary fines on the breaking length of paper at different freeness levels.

pulp with 10 (8.0 mNm^2 g^{-1}) and 20% fines (7.7 mNm^2 g^{-1}). Results of the tear index differed from the previously discussed strength properties of paper. Initially, the tear index of unrefined pulps was lower, increased with increasing refining to some extent depending on the nature of the pulp, and then decreased with further refining. Maxima for the tear

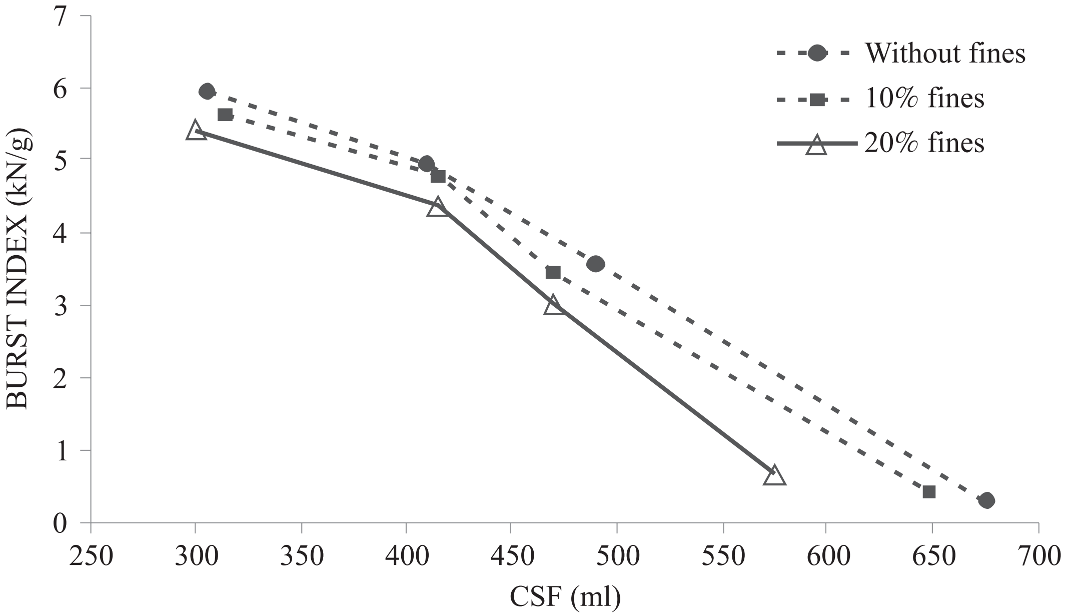

Fig. 5. Effects of primary fines on the burst index of paper at different freeness levels.

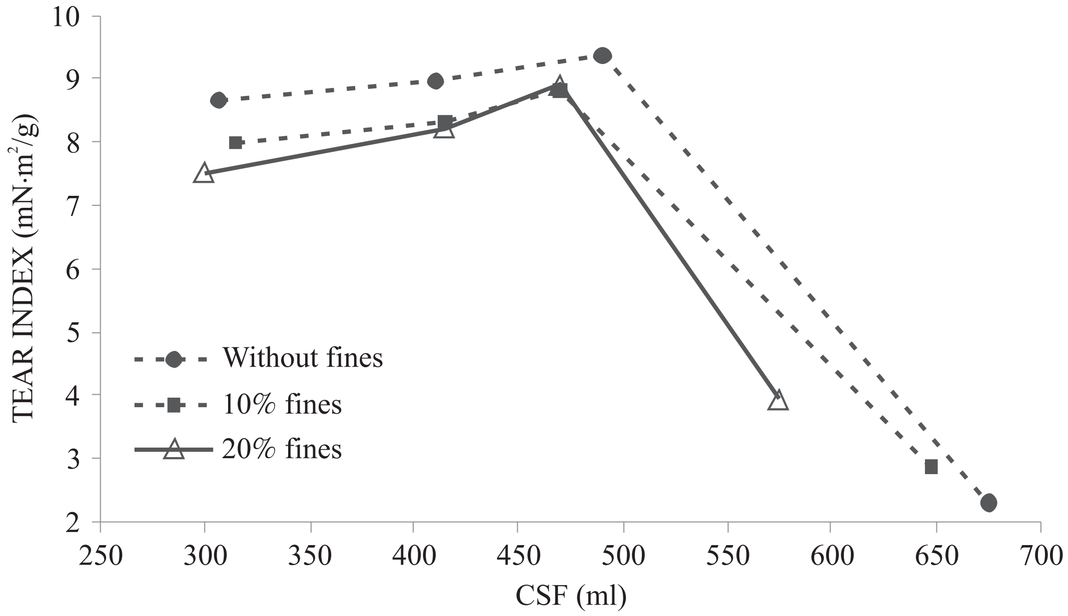

Fig. 6. Effects of primary fines on the tear index of paper at different freeness levels.

index were achieved at different freeness levels for different combinations. At a 300 ml freeness level, the tear index of pulp without fines, and with 10 and 20% fines were around 8.6, 8.0, and 7.5 $mNm^2 g^{-1}$, respectively.

Double fold

As shown in Fig. 7, the double fold value was initially very low, but dramatically increased with an increased refining rate. There were no major changes observed in the double fold value up to a 450 ml CSF level. At a 500 ml CSF level, the double fold value of paper produced from pulp without fines was highest (30) followed by pulp with 10 (20), and 20% fines (12), while at 400 ml CSF, double fold values respectively increased to 147, 140, and 115. The results revealed that the fines in the pulp affected the double fold value of the paper. The double fold value of paper depends upon the length of the fibers and the extent of fiber-to-fiber bonding. That is why the reduction in the double fold value was higher with a higher proportion, i.e., 20%, of fines. A similar trend was observed at 300 ml CSF where double fold values of pulp without fines, and with 10 and 20% fines further increased to 405, 380, and 330, respectively.

Stiffness

The stiffness of paper is directly linked with the bulk of the paper sheet. The higher the bulk is, the higher is the stiffness of a sheet. For the bulk, it was observed that the bulk of paper with fines was higher than that of pulp without fines up to a freeness level of 450 ml. The results obtained for stiffness followed a similar trend to that of bulk. As shown in Fig. 8, stiffness values of paper produced from unrefined pulp without fines, and with 10 and 20% fines were 1.41, 1.60, and 1.68 mN·m, respectively; however their freeness values differed. Freeness values of pulp without fines, and with 10 and 20% fines were 675, 650, and 575 ml, respectively. The difference in stiffness of the paper was noted

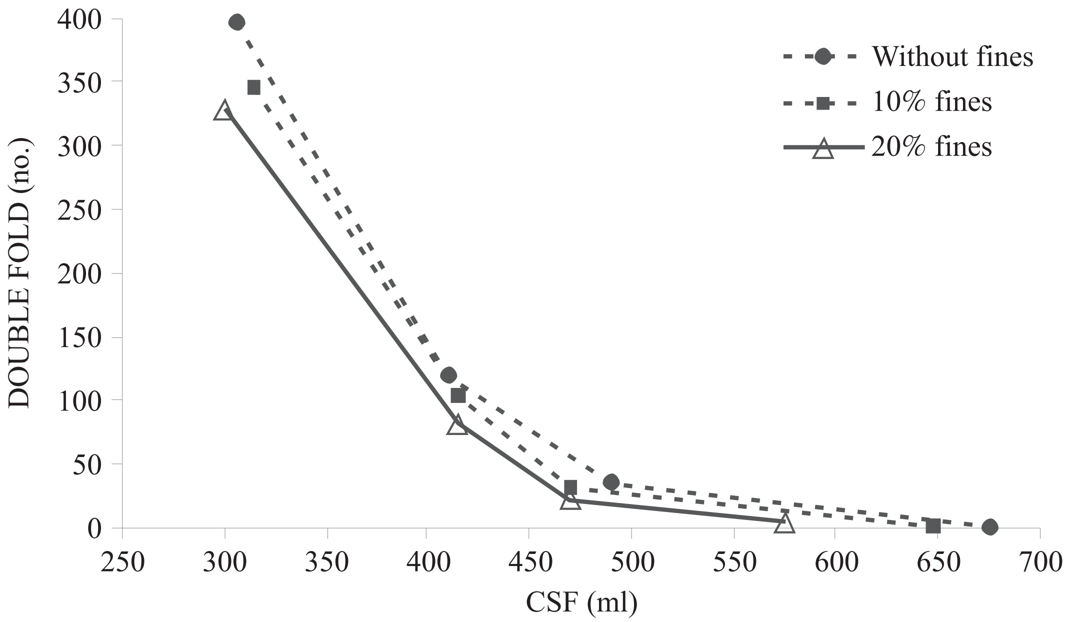

Fig. 7. Effects of primary fines on double fold values of paper at different freeness levels.

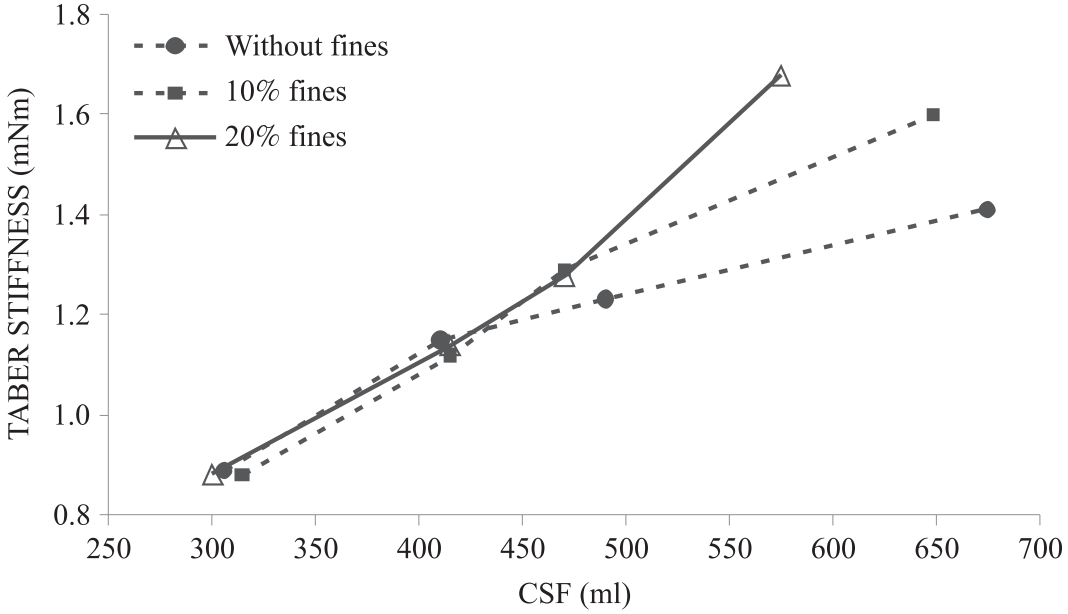

Fig. 8. Effects of primary fines on the stiffness of paper at different freeness levels.

up to a freeness level of 450 ml; a lower freeness level did not change the stiffness of paper made without or with fines. At lower freeness levels, stiffness values of paper produced from pulp without fines, and with 10 and 20% fines were similar.

Scott bond

The Z-directional (thickness direction) strength was demonstrated through a Scott bond test. As shown in Fig. 9, loss of Z-directional strength was noted with fines-containing pulp at all freeness levels. At 500 ml CSF, the Scott bond values of paper made from pulp without fines, and with 10 and 20% fines were 290, 260, and 200 J m^{-2}, respectively. Further increasing the refining of the pulp increased the internal bond strength of paper for all pulp and fines combinations. At 400 ml CSF, the highest Scott bond was achieved with pulp without fines (600 J m^{-2}) followed by pulp with 10 (580 J m^{-2}) and 20% fines (520 J m^{-2}). The reason is that the fiber fines disperse throughout the sheet structure as filler and fit in among the fibers, thus reducing the fiber-to-fiber contact, which affects the overall strength of a sheet. A positive effect on the Z-directional strength was noted with refining of the pulp, as refining makes the paper more resistant in the Z-direction because of an increased surface area.

Air permeance

As shown in Fig. 10, increasing the degree of refining and decreasing the freeness value increased the value of the air permeance, i.e., decreased the porosity of the paper. When the refining increased beyond a particular level, the fibers became flattened and thus increased the packing density. The production of fines or fibrils with refining also caused blockage of air passages through the paper sheet. There was no effect of the addition of fines on the air permeance value up to a freeness of 450 ml CSF, but further refining of the pulp produced higher air permeance values for fines-containing pulps. The reason for the reduction in porosity of the paper was that the fines fit into voids among the fibers and thus retarded the passage of air. At 500 ml CSF, the air permeance values for all pulp samples were only around 2~4 s/100 ml. At 400 ml CSF, air permeance values increased to around 14, 23, and 24 s/100 ml for

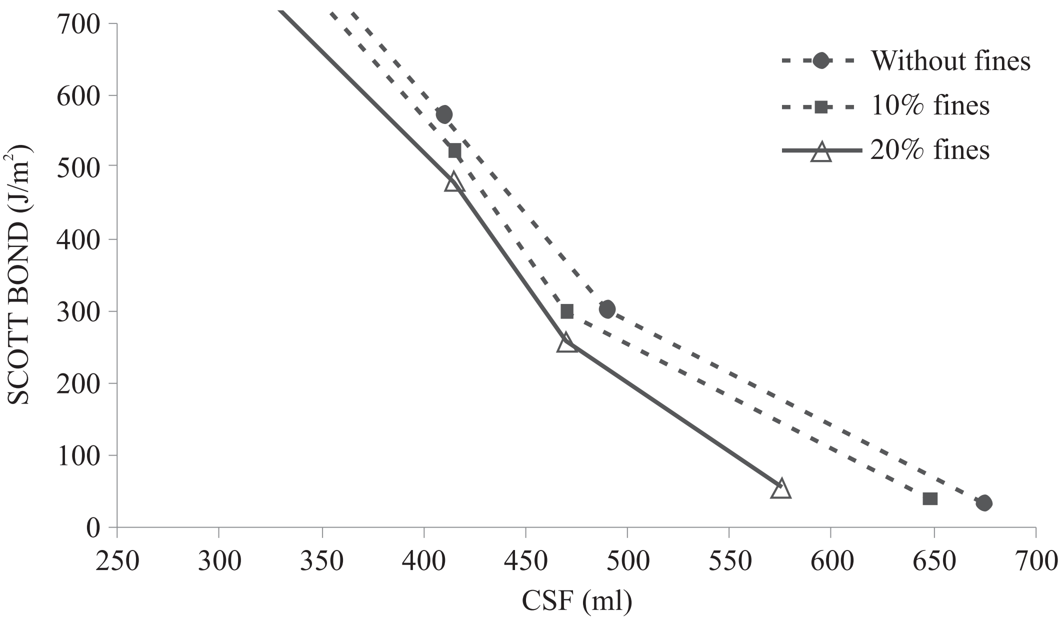

Fig. 9. Effects of primary fines on Scott bond values of paper at different freeness levels.

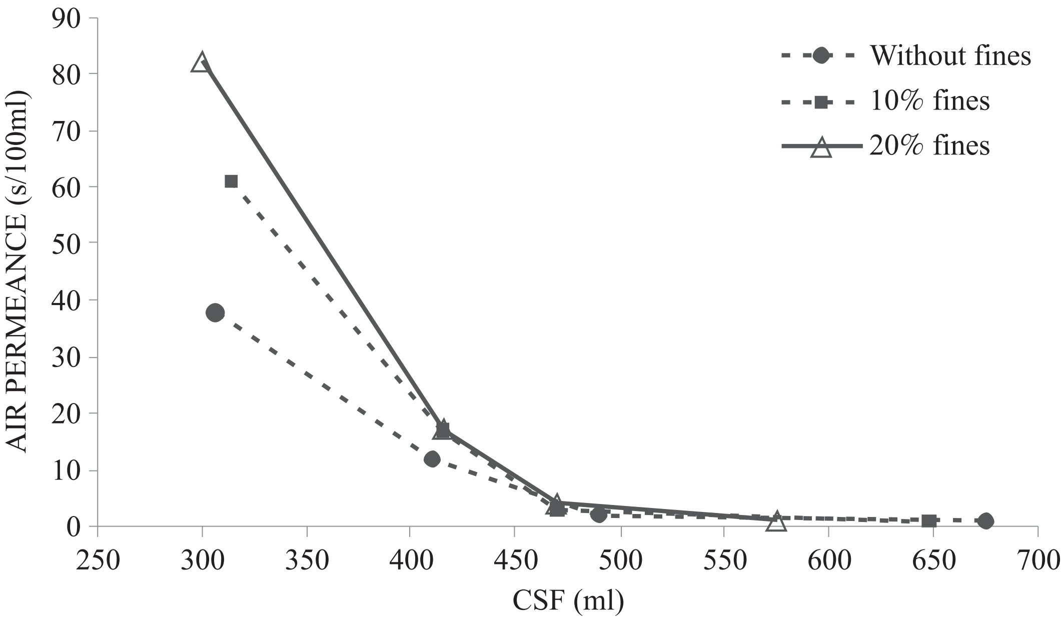

Fig. 10. Effects of primary fines on the air permeance of paper at different freeness levels.

the pulp without fines, and with 10 and 20% fines, respectively. A further reduction in freeness to 300 ml respectively increased the air permeance values of paper to 40, 66, and 82 s/100 ml.

Opacity

The opacity of paper depends upon the light-scattering capacity from the sheet structure. The scattering coefficient is linked to the number of voids and the solid-air interface. The higher the solid-air interface is, the higher is the ability to scatter light by the sheet. The refining of fibers decreases the number of voids due to flattening of the fibers thus affecting the opacity of the paper. Similar results were obtained in the present study. As shown in Fig. 11, the opacity of paper increased with the addition of fines to the pulp; as the amount of fiber fines increased, the number of voids in paper matrix also increased and produced the gap in between fibers which, in turn, increased the light scattering and opacity of paper. At a constant freeness level, the opacity of paper made from pulp with a higher amount of primary fines was higher. At 500 ml CSF, opacity levels of paper made from pulp without fines, and with 10 and 20% fines were around 75.8, 77.3, and 79.4% ISO, respectively. At a lower CSF value of 300 ml, respective opacity levels decreased to around 73.8, 74.6, and 75.0% ISO.

Formation

The fines content of the pulp enhances the formation of paper through filling in gaps within the paper matrix. Moreover, the distribution of fines in a paper sheet is better than that of fibers due to the shorter lengths of the former. Formation was measured in terms of a formation index. A higher formation index indicates better formation. The formation index was measured at freeness levels of 500 and 400 ml. As shown in Fig. 12, the formation index of paper was highest with pulp with 20% fines. The distribution of fines through-

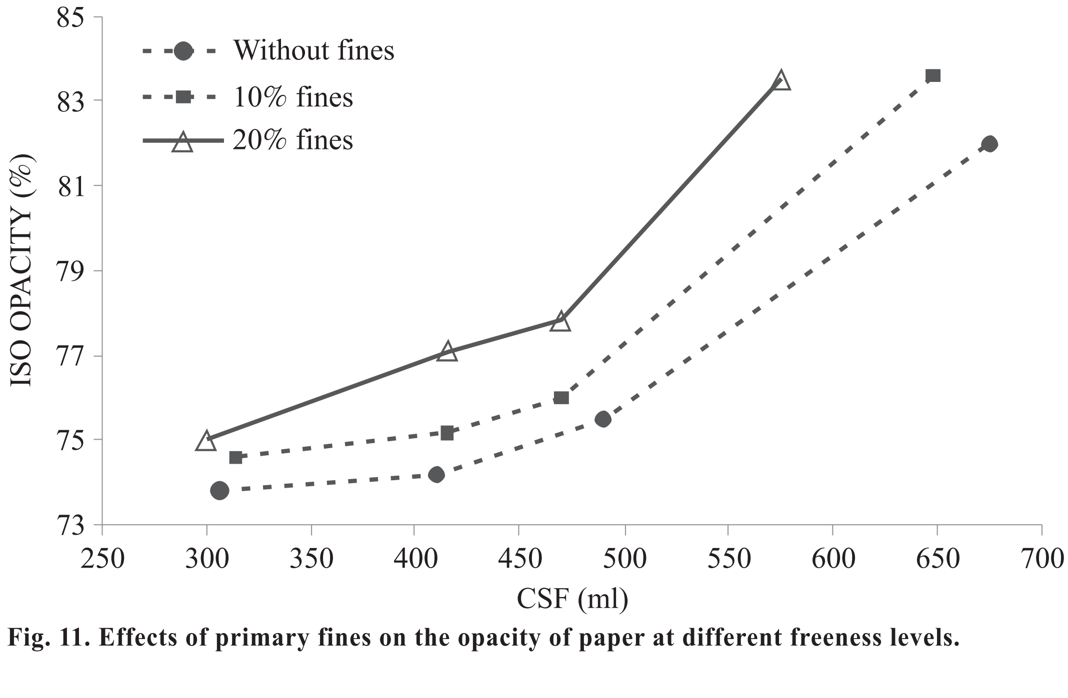

Fig. 11. Effects of primary fines on the opacity of paper at different freeness levels.

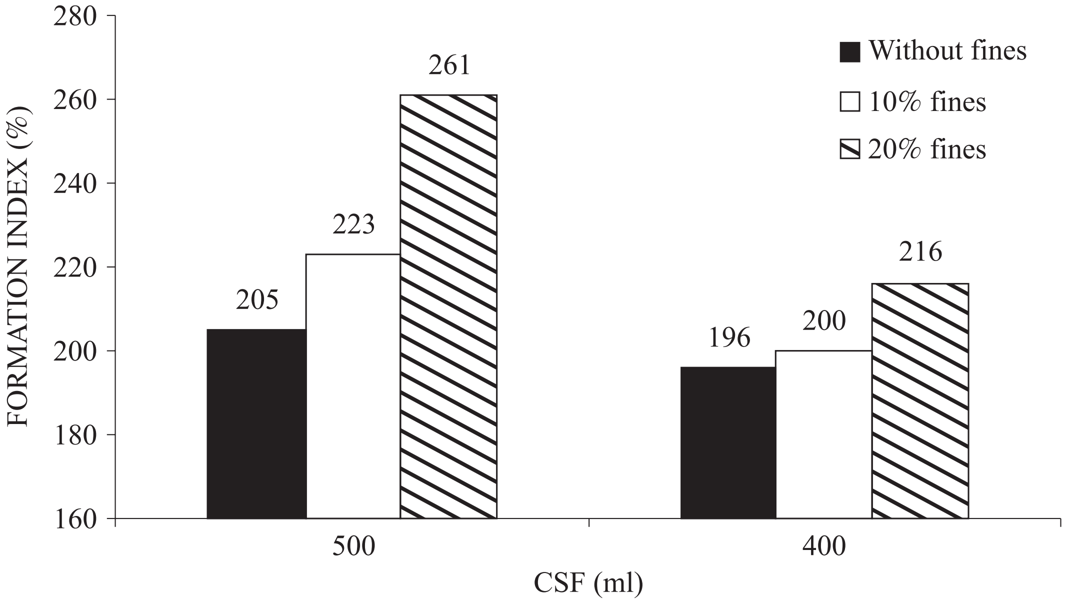

Fig. 12. Effects of primary fines on the formation of paper at different freeness levels.

out the sheet structure reduced the tendency to make large flocs by fitting in among the fiber-to-fiber interspaces.

CONCLUSIONS

The addition of fiber fines to the pulp had both positive and negative effects on the paper quality. Fiber fines help reduce the refining energy to attain a particular level of freeness compared to pulp without fines and pulp with fewer fines. The 450 ml CSF level was found to be critical for some properties like the bulk, stiffness, porosity, and tear index. Bulk and stiffness of the paper were improved with the addition of fines up to a 450 ml CSF level. Improvements in opacity and formation of the paper were observed with the addition of fines at all freeness levels. The porosity of the paper decreased with the addition of fines below a 450 ml CSF level. The other paper strength properties like breaking length, burst index, tear index, double fold, and Scott bond decreased with the addition of fines. Fines content in the pulp also affected the water drainage rate. Refining of pulp improved the breaking length, burst index, and Scott bond of paper at all freeness levels, while tear index improved up to a 450 ml CSF level, and double fold improved below a 450 ml CSF level. The bulk, drainage rate, stiffness, porosity, opacity, and formation index were reduced with refining.

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