The Effect of Repeated Recycling at Different Levels of Addition (Virgin and Recycled Fiber) on the Surface Characteristic of Paper Before and After Calendering

Jasvinder Singh Sidhu
Western Michigan University

THE EFFECT OF REPEATED RECYCLING AT DIFFERENT LEVELS OF ADDITION (VIRGIN AND RECYCLED FIBER) ON THE SURFACE CHARACTERISTIC OF PAPER BEFORE AND AFTER CALENDERING

by

JASVINDER SINGH SIDHU

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ABSTRACT

The Effect of Repeated Recycling at differnet Levels of Addition (Virgin and Recycled Fibers) on the Surface Characteristic of Paper Before and After Calendering.

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Extensive work has been done on the physical properties of paper with recycling, however not much has been researched on the surface properties of paper. This thesis was intended to give more information on this fairly untouched area. An extra dimension was added with the inclusion of virgin fibers. Two loops were designed, one using the conventional 100% recycled fibers and the other, with an addition of virgin pulp. 100% never dried kraft hardwood, refined at 300 CSF, was used. All handsheets were made on the Nobel and Wood handsheet-maker and repeated reslushing was performed on the British Disintegrator. No additives, fillers, or sizing agents were used at any point, thus, recycling was only subjected to: slushing, sheet making, wet-pressing and drying. Calendering was also performed. The principal effect of recycling was the loss of the fiber bonding ability, noticeably in the first recycle for opacity and porosity (100% recycle). The addition of virgin fibers was interestingly seen to improve the brightness with recycling. This phenomena (an increase in brightness with the addition of virgin fibers in comparison to the original brightness) has to be further investigated. Calendering with its compacting and polishing action, decreased the opacity and increased the smoothness. Roughness and gloss did not show a significant change with recycling but with calendering a more smoother and glossier sheet was obtained, as expected.

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INTRODUCTION

In Europe, the government financially supports recycling, reinforcing the philosophy of the public and justifying the expense to industry of developing recycling. In the United States and Canada, by contrast, the manufacture of recycled paper is not financially supported by the government, making it less economically favorable for industry. Environmental protection legislation and increasing public environmental awareness will, however, continue to strengthen efforts to protect natural resources and develop recycling (1).

The president of the United States proposed that in 1994, it be mandatory to use at least 20% of recycled fiber in any product supplied to the government. This shows that the importance of recycling is an important issue.

A considerable number of researchers have examined what has been called the fundamental problems in recycling, i.e. how fibers are affected by recycling procedures, and what resulting effects are seen in papers made from those fibers (2). Investigations into the effect of recycling have been many and varied. Furnishes range from unbleached chemical pulps to mechanical pulps, including blends. Recycling procedures have used the British Standard handsheet machine, other sheet making procedures, pilot machines, or a combination of these. On occasions the recycled pulp has been beaten before each re-making, in which case the beating will be to a specific freeness, or to a specific paper property such as apparent density or breaking length. Drying of the handsheets has

been by the standard method or by a variety of heating methods. Fines may or may not have been recirculated during sheet making (3).

Surface characteristics of paper determine a host of different end uses: printability, absorption characteristics and converting operations such as the coating of paper. These properties are therefore important for paper made for writing and printing purposes. Understandably, a lot of research has been done towards acquiring a better understanding of the way in which the paper making process and the fiber properties determine the surface of paper. Newer pulping processes and demanding end use requirements are constantly posing new challenges to paper makers in this area. One of the newest furnishes is secondary fiber. Very little work has been done in the past to understand the effect of recycling on surface characteristics (3).

Recycled fibers are going to enter the paper making process in increasing quantities in the future and unlike in the past, they are not going to remain confined to the container board sector (4). This again shows the emphasis of recycling in the paper industry. As the need of recycled fibers introduced into fine paper increases, a higher and better understanding of fibers, its characteristics and nature, has to be gained. Smoothness is one important variable in fine paper, due to its use in writing and printing. A much higher emphasis and demand are put into them by customers. Calendering is used to develop smoothness and gloss in such products as coated and uncoated high quality printing paper.

The much accomplished revolution in surface properties of paper would not have been possible without calendering. The surface characteristics of paper control a variety of end uses like printing and coating of paper. Each of them uses a different mechanism towards achieving a higher gloss and smoothness. In general the rolls cause a depression or deformation on the fibrous rolls at the point of contact, and the deformation spreads out on either side of the nip. The intensity of action is governed by the amount of plastic flow and by the nip contact pressure (5).

There are three major types of calendering used in the industry for the improvement of surface and printing properties: supercalendering, machine calendering, and soft nip calendering.

A supercalender is an off machine method of calendering. It gives superior gloss and smoothness for coated and uncoated printing papers. The number of rolls can range from 9 to as high as 12. It consists of metal rolls and cotton rolls, which are stacked alternately and vertically. The metal roll causes depression in the cotton roll, which results in a difference in running speed. This difference in speed causes a friction and polishing action, which produces a smooth and glossy surface.

Machine calendering is also called hard nip calendering. It produces acceptable smoothness. The web printing surface is dependent upon sheet formation and profiles to the calender. Variations in these will create density variation when calendered since the steel/steel nip will compact the web to a constant caliper. It generally consists of either 4 or 6 metal rolls.

Soft nip calendering is becoming increasingly popular within the paper industry as an alternative to machine calendering. A soft calender nip consists of a polymer covered roll against a heated iron roll. A soft nip calender compresses both the web and polymer covering which ultimately widens the nip width. This in turn increases the residence time. Soft calendering produces a constant density with variations in caliper corresponding to basis weight variations. This creates a web surface where printing ink is evenly absorbed, producing a uniform printed image.

LITERATURE REVIEW

McKee (6), found that recycling causes a major reduction in breaking length, burst, and fold, with a lesser reduction in apparent density and stretch. Increase in tear, stiffness and air permeability are usually observed. The first recycle causes the greatest change in any property and this appears to be true regardless whether the virgin pulp was originally moist or dried. Figure 1, represents this general trend. With extended recycling, i.e. in excess of four recycles, most physical properties have stabilized, though there is some evidence that tear, in particular may go through a maximum before dropping back a little. Stock freeness generally shows a slight increase provided the pulp has not been rebeaten to restore physical properties, in which case a considerable decrease in freeness is observed.

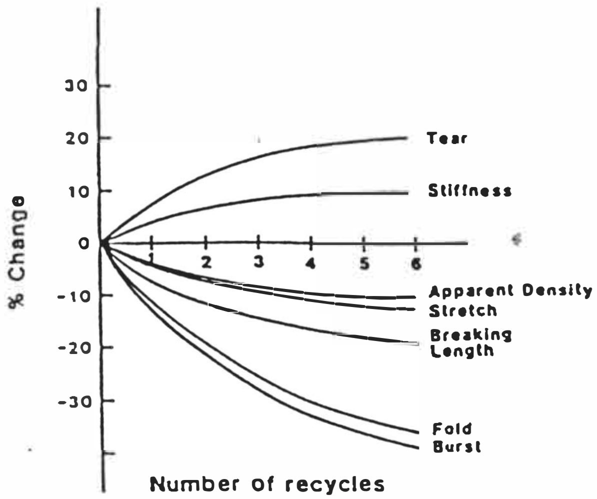

Fig. 1 The General Effects of Recycling: Percent Change in Properties as a Function of the Number of Recycles (3).

Surface properties such as smoothness, gloss, and IGT pick too have been rarely examined. Van Wyk et.al (7) noted a fall in IGT pick and McKee (6) observed a fall in z-direction strength.

It has been shown that the principle cause of the changes of sheet properties is the reduced bonding ability of the fiber. Using Water Detention Value (WRV) as a measure of fiber swelling, McKee (6) observed this trend of recycling, noting that the most rapid decrease occurred in the first two cycles. Loss of intrinsic fiber strength, though it has been observed by some researches is a lesser problem. Indeed on occasions it has been found not to change at all and even to increase. No explanation of this inconsistencies has been advanced. Reduced bonding ability on the other hand is a widely recognized phenomena, and has traditionally been described as "irreversible hornification", implying a stiffening and/or hardening of the fiber. Today it is agreed that this loss of flexibility and plasticity is due to the reduced swelling capacity of the fiber once it has been added into a paper.

Szwarcsztajn and et.al (8) found that for the fiber fraction the WRV could be recovered by beating, this was not the case for the fines fraction. The hypotheses that the loss of bonding ability of recycled fibers is due entirely to loss of swelling has been challenged by other researches. Essentially, they suggest that the phenomena may be the result of two effects: changes occurring principally to the surface of the fiber, and changes occurring principally to the bulk of the fiber. Eastwood et.al (9), for example, recycled once dried semi-bleached kraft on a pilot paper

machine and with rosin/alum sizing, noted that the relationship between apparent density and breaking length at each level of recycling was not linear, as it might have been expected to be if swelling controlled bonding by virtue of its effect on flexibility.

Effect of calendering

Calendering is a process where the sheet web is passed through a number of roll with loads applied to each of the rolls independently.

The effect of calendering on the recycled potential of both groundwood containing and woodfree paper has been examined by Gottsching et.al (10). They showed that the heavier the calendering, the greater the loss in breaking length of handsheets made from the calendered paper, and this effect corresponded to both a loss of WRV and a reduction in fiber length. Steel on steel nips were compared with steel on cotton nips (as in a supercalendering); the softer nip was found to do less damage. The cause of this phenomena is attributed simply to the mechanical forces in the nip compressing and damaging the fibers (10).

Soft nip calendering is becoming increasingly popular within the paper industry as an alternative to machine calendering. A soft calender nip consists of a polymer covered roll against a heated iron roll. In contrast to the machine calender where only the web is compressed within the nip, the soft nip compresses both the web and polymer covering which ultimately widens the nip width and reduces the specific nip pressure within the soft nip for a given

constant linear load. The residence time of the web within the nip is increased (11). See Fig.2.

Nothing has been mentioned in literature on the effect that super calendering has on the paper surface characteristics.

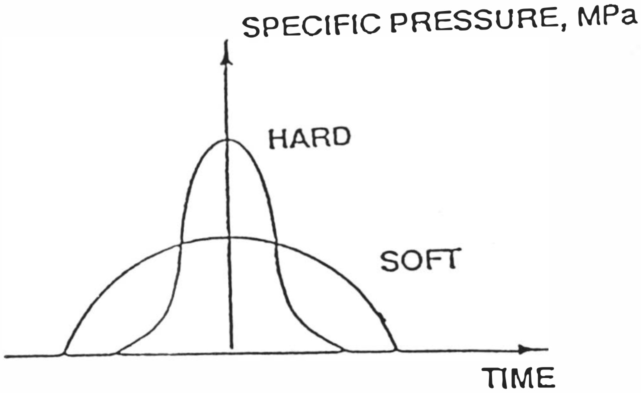

Figure 2. Effect of Calender Type on Specific Nip Pressure and Residence Time (11).

Blending with virgin pulp

Szwarcsztajn et.al (8) observed that virgin pulp had a disproportionally great effect in improving recycled pulp properties. They attributed it to the fact that a virgin pulp contains not only more "active" fibers, but also more "active" fines. Active fibers are referred to fibers that are not bonded. This means that the fiber has a higher relative bonded area and as such has a higher chance of bonding. They found that adding a beaten virgin pulp produced an even greater beneficial effect.

Although this observation has to be studied further, nothing has been done to see how virgin pulp will effect the surface characteristics of the recycled paper. Even if it does, will the surface characteristic change; and in which direction, upon calendering.

Chatterjee et.al (4), recycled kraft, ultra high yield sulfite and TMP pulps. They found that paper made from TMP pulps, gets smoother and denser with recycling. The rapid drop in the bonding potential of kraft pulp fibers with recycling causes an increase in porosity in kraft paper with recycling while porosity decreases significantly for TMP. They however did not recycle at different recycling levels. They did not add virgin pulp, at the respective recycling levels.

Paper reacts in three different ways when subjected to compressive loads. Firstly, it acts like an elastic medium that compresses like a spring. Secondly, it behaves like a plastic material and flows under stress. Thirdly, it has a memory of what happened to it previously (12,13). The outer surface of the paper is largely affected by what is happening inside the sheet in the calendering operation. It is the non-uniformity of the paper surface that determines the surface characteristic of the paper (13).

Calendering is a process where the sheet web is made to pass through a series of rolls arranged vertically with loads applied to each of the rolls independently. In this process the caliper of the sheet is reduced and the density is increased due to the compaction. A calender that uses iron rolls is termed as machine calender and is usually used in-line to the paper making process (14).

Skowronski et.al. (15), showed that the thickness of the paper increased during wetting and decreased during redrying, but the

recovery was not complete and there was a positive relationship between the increase in surface smoothness and the increase in thickness after redrying. It is also reported that the sheets that were calendered, the irreversible increase in surface smoothness and the swelling pressure was higher when compared to calendered sheets and it was high in the case of mechanical pulps.

PROBLEM STATEMENT AND OBJECTIVE

In this thesis an attempt was made to understand the differences in quality obtain by repeated recycling and the machine calendering process to quantify their response to surface properties. It was also intended to investigate the influence of virgin fiber and recycled fiber on the surface properties. Addition of virgin fibers, theoretically will give better surface properties. This is due to the conformability and higher RBA (relative bonded area) of virgin fibers. This will bring about a more uniform sheet of paper, and thus better surface properties. Apart from studying the change in surface characteristics of paper with repeated recycling, this study also looked at the response of recycled paper to calendering. This thesis was concerned in finding the number of times recycling can be performed and still achieve the desired surface properties (to which the surface properties can still remain at a satisfactory level) and how will calendering improve these properties.

Surface properties of paper are controlled by the forming process as well as the fiber characteristics. In the case of handsheets the forming process can be assumed to be identical and the only variable controlling the surface characteristics is the fiber properties. The influence of virgin and recycled fibers with the influence of fines is better understood when the surface properties are concerned. A better understanding of the nature of fibers will allow a better end use.

METHODOLOGY

Experimental Design

Repeated recycling at different levels of addition was done, in order to study its effects on the paper surface properties (smoothness, porosity, gloss, brightness and opacity).

At each level of addition, shown in Figure 4, virgin pulps (50%) was added to the existing stock. This was done so as to see the extent these virgin pulps will have towards the recycled broke, i.e. since virgin pulps are said to have "active" fibers and fine, and vice versa. Although this observation has to be studied further, literature review has shed little light as to how virgin pulp will effect the surface characteristic of the recycled paper, and vice versa. Even if it does, will the surface characteristics change?. The subsequent effect of these surface fibers will then be better understood in relation to the surface characteristics

Apart from studying the change in surface characteristics of paper with repeated recycling, the influence of calendering on the surface characteristics of paper with the addition of virgin fiber was also studied.

Experimental Procedure

This study was divided into four phases:

1. Initial paper was made from 100% softwood (refined to 300 CSF) on the Noble and Wood handsheet maker. Each handsheet was wet pressed and dried at 250°F twice.

2. Repeated repulping (4 times) of the paper was done on the British Disintegrator. Handsheets was made on the Noble and Wood

handsheet maker. Two sets of handsheets were made. One set is entirely repeated 100% recycled pulp, and to the other set 50% virgin pulp was added to 50% of recycled pulp.

3. Five of the handsheets made at each stage were calendered and five handsheets were not calendered. The rest were be reslushed for the next set of handsheets.

4. Measurement of the surface properties.

The diagram of the recycling process is seen in Fig.3.

This study was designed to discover how calendering and recycled fiber content will affect the surface properties of recycled paper.

Repeated recycling was carried out on paper made from 100% hardwood. No additives associated with a commercial recycling process was introduced into the process. Recycling therefore was restricted to repeated slurring and handsheet making on the Noble and Wood handsheet maker, wet pressing, drying, and repulping with the British disintegrator. Precautions was taken to ensure that no fines were lost from the recycling loop. The Noble and Wood has a recycling loop. This loop ensures that fines are not lost, but recycled back into the stock.

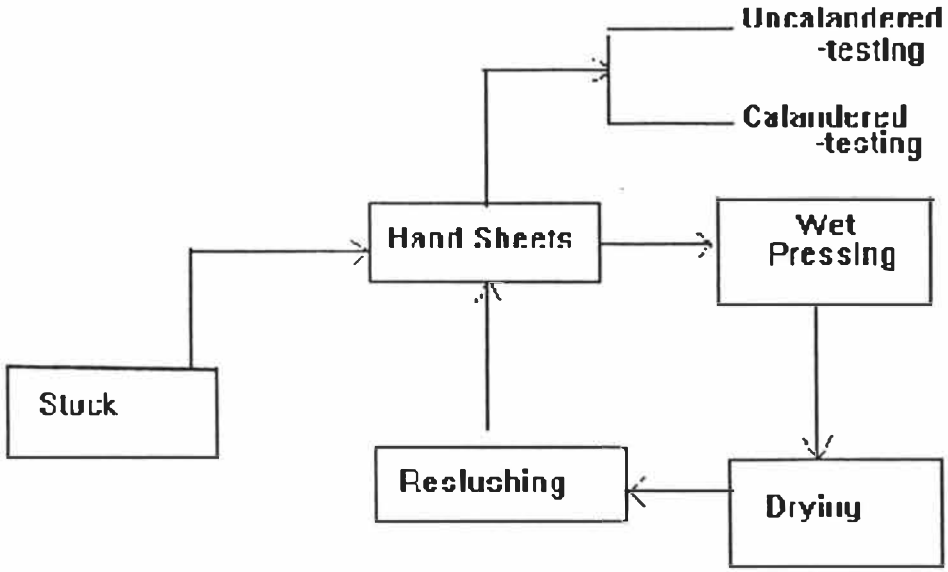

Figure 3. Flow diagram of this recycling experiment.

All handsheets made at each recycling stage were:

1. Tested for its surface characteristics (smoothness, porosity and gloss) and for optical properties (scattering coefficient and absorption coefficient).

2. Calendered and tested for the same characteristics mentioned above.

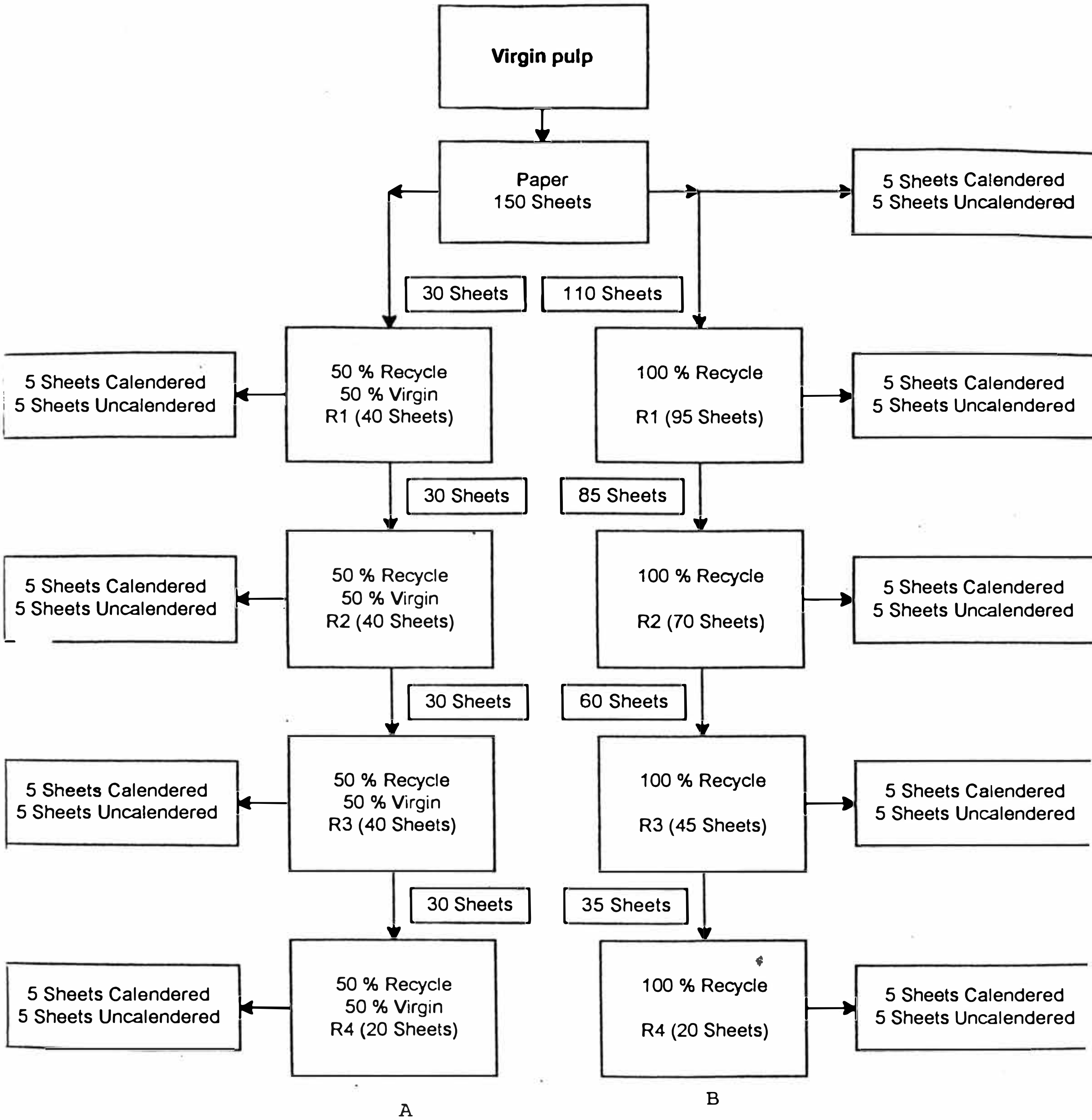

Figure 4. Schematic of Experimental Design

Figure 4 gives a schematic illustration of the experimental part of this thesis. Initially 150 handsheets were made with virgin pulp on the Noble and Wood. Refining was done on the Valley Beater at 300 CSF (canadian Standard Freeness). The virgin pulp used was 100% hardwood. 10 of the 150 handsheets made from the initial stage was tested, i.e. 5 before calendaring and 5 after calendering. The rest 140 handsheets was then split into two parts, labelled as Part A and Part B (as seen in Figure 4).

Looking at Part A, 30 handsheets (from 150 handsheets), were brought down for the successive stages in this part. All of the 30 sheets were reslushed in the British Disintegrator to be used in the handsheet making in the R 1 (recycling one) stage. This reslushed pulp made up the 50% of recycled pulp. This reslushed pulp was mixed thoroughly with the same amount of virgin pulp (which made up the rest 50%). 40 handsheets were made at this stage. 10 handsheets (5 calendered and 5 uncalendered), were removed and tested. The rest of the 30 handsheets were reslushed in the British Disintegrator and used for the next stage, i.e. R 2 (recycling two). The reslushed broke, which will now be recycled once, made up the 50% recycled broke. This was then added on to 50% virgin pulp. 40 handsheets were again made at this stage, from which 10 were taken out (5 calendered/5 uncalendered) and tested. The same logic and procedure follows through when moving from R 2 to R 3 (recycled three) and to R 4 (recycled four). At R 4, 20 handsheets were made. This low number is due to the fact that only 10 handsheets were required to be tested and this is the last stage

of recycling, so no pulp was required to be used for the following stage.

Part B shows the path for 100% recycled pulp. At each level of recycling, i.e. R1 or R2 or R3 or R4, the pulp used was carried down from the stage before. As mentioned, out of the 150 handsheets made at the initial stage, 110 handsheets were carried down to the various recycling stages. All of the 110 handsheets were reslushed using the British Disintegrator. Using the reslushed pulp, 95 handsheets were made on the Noble and Wood, from which 10 handsheets (5 calendered/5 uncalendered) were removed and tested. This made up the recycling one (R1) stage. The rest 85 handsheets were reslushed, from which the pulp was used to make 70 handsheets. As before 10 handsheets were removed and tested for surface properties. This stage will be the R2 (recycled two). The remaining 60 handsheets were reslushed in the British Disintegrator, so that the pulp used were subsequently reused to make 45 handsheets from which 10 of them were removed and tested. This stage on the other hand was called R3 (recycled three). The remaining 35 handsheets were reslushed and 20 handsheets were made to complete the four recycling sequences that will be studied. And once again at this stage 10 handsheets were tested and studied for its surface characteristics.

The soft nip calender machine in the coating lab at WMU was used. The conditions used were 30 psi pressure and 4 nips.

Measurement of surface properties

1. Roughness and Porosity of the conditioned handsheets were measured on the Parker-Print-Surf.

2. Brightness, Opacity, Scattering Coefficient and Absorption Coefficient of the conditioned handsheets were measured on the Brightmeter.

3. Gloss at 75° degrees was measured on the Hunter gloss meter in accordance to T480.

All the above tests were carried out on handsheets made, calendered or not.

RESULTS AND DISCUSSION

Figures 1 to 7 shows the relation of the surface properties with number of recycling (with 100% recycled fibers and with the addition of 50% virgin fibers), for calendered and uncalendered sheets. Table 1 shows the summary of the experimental data. Table 2 shows the advantages and advantages of recycling on the surface properties before and after calendering.

Figure 1 showed that opacity increased with recycling for 100% recycled fibers, but this increase was only significant in the first recycle (R1). The loss of bonding potential, known also as the hornification effect contributed towards this observation. Fiber loses its bonding ability with recycling, and as such the 100% recycled fibers will have lower bonding. This lower bonding will increase the air gap between the fibers. An increased air gap will increase the interface available for light interaction, and subsequently will increase its scattering. This will lead to an increased in the scattering coefficient with recycling. This is seen in Figure 2, (from original to R1) where the scattering coefficient increased as the opacity increased for 100% recycling. The sheet is seen to be bulkier, with an increase in caliper (as shown in Table 1). This increase in caliper again shows that the air gap between the fibers increased, leading to a increased in opacity as observed. During the first recycled, an increase in opacity from 76.5% to 81.8% was observed. The opacity increased gradually from R1-uncalendered (82%) to R4-uncalendered (84%).This showed that the biggest loss in the fiber bonding ability was seen

in this fist stage. The loss in bonding ability is less prevalent after the first recycle.

Figure 1 also showed that the opacity decreased with the addition of virgin fibers during recycling. The inclusion of virgin fibers adds "active" fibers which brings about better bonding. A better bonding led to a decrease in bulk and caliper (Table 1) and subsequently a reduction in the light scattering effect. This observation holds true since the scattering coefficient (Figure 2) decreased with the addition of virgin fibers.

An interesting observation was seen after calendering. Opacity of 100% recycled fibers calendered and uncalendered followed the same general trend. On the other hand, with the addition of 50% virgin fibers a slight decrease in opacity was observed. In this process the caliper of the sheet is reduced (Table 1) and the density is increased due to the compaction. This will reduce the air spaces between the fibers and as such will reduce its scattering power and subsequently the opacity.

Figure 3 did not show a significant difference in brightness between original and R1 for both cases of 100% recycled fibers or adding 50% virgin fibers. However, the improvement in brightness was progressive from R1 to R4 with the addition of 50% virgin fibers. This improvement was observed with or without calendering. With 100% recycled fibers the decreased in brightness was progressive. The addition of virgin fibers increased brightness by 6.3% (uncalendered) and by 7.2% (uncalendered), as shown in Table 2. The absorption coefficient is seen to reduce (Figure 4) with the

addition of virgin fibers. This observation is consistent with theory which states that brightness is inversely related to the absorption coefficient. An explanation for the increase in brightness with the addition of recycled fibers compared with the original brightness, however has to be further investigated.

With the decreased in the bonding potential with 100% recycled fibers a more porous structure should be observed. This phenomena was seen in Figure 5. A more porous structure should have a more bulkier sheet, i.e. a higher caliper, which is seen in Table 1. Porosity decreased with the addition of virgin fibers.

Calendering was seen to reduce the porosity of the sheet. The mechanical action of the calender stack in compacting the fibers led to a denser sheet. This corresponds to a lower caliper reading as observed with calendering. Calendering reduced the porosity of both 100% and 50%/50% recycled sheets by about two times.

Figure 6 showed that roughness for both 100% and 50%/50% recycling did not show a significant change. This observation was also seen by Chatterjee et.al. This observation however, correlates well to Figure 7 for gloss. In theory a glossier sheet should have a smoother (lower roughness) sheet. Figure 7 showed that there was no significant change in gloss with recycling. However, calendering decreased roughness by 7%, i.e. the smoothness increased by 7% for 100% recycling. This can be seen in Figure 6 and in Table 1. Gloss also showed an improvement with calendering. This is because of the polishing effect of smooth steel rolls on the sheet as it passes between them.

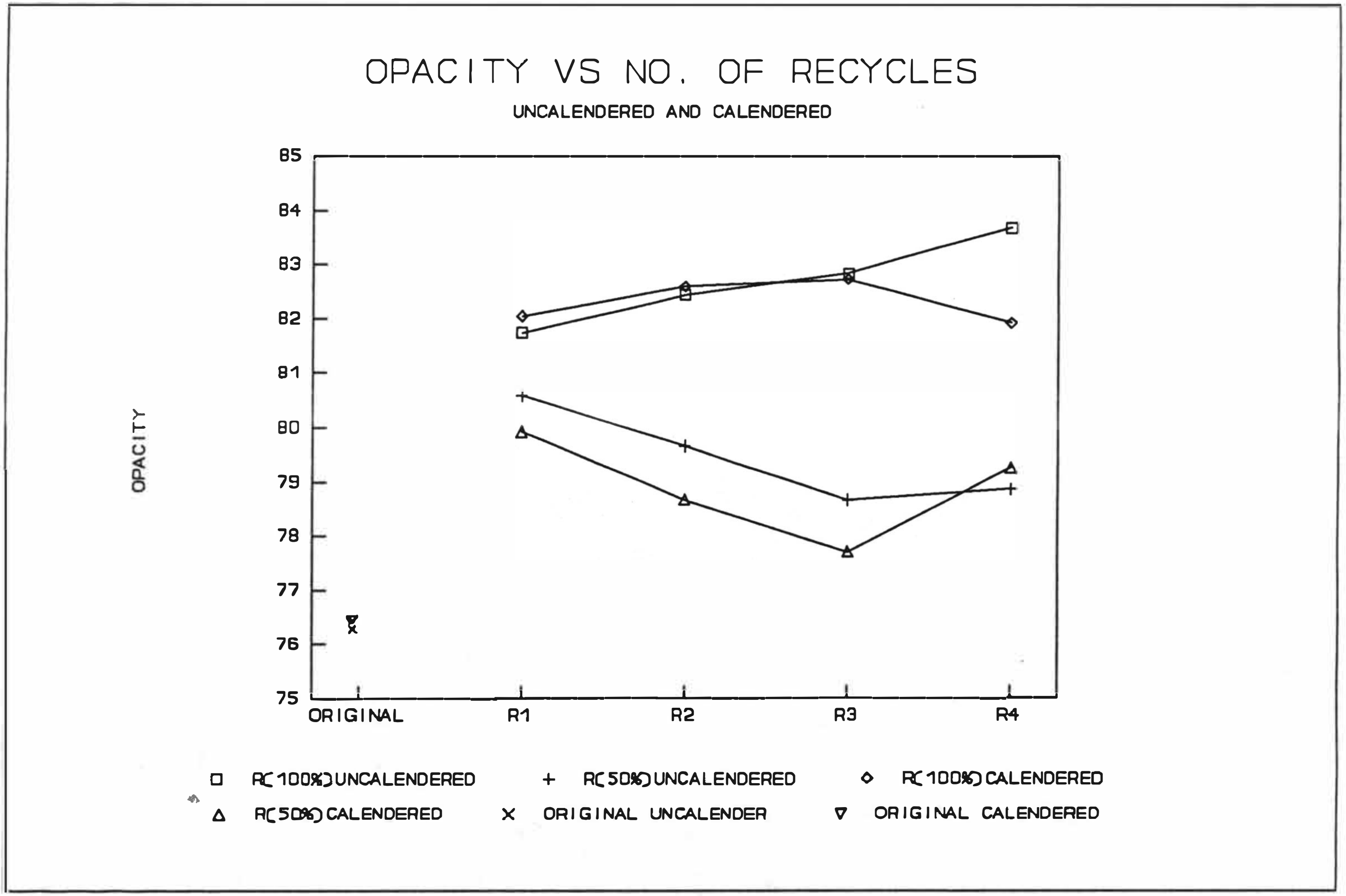

Figure 1. Opacity VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

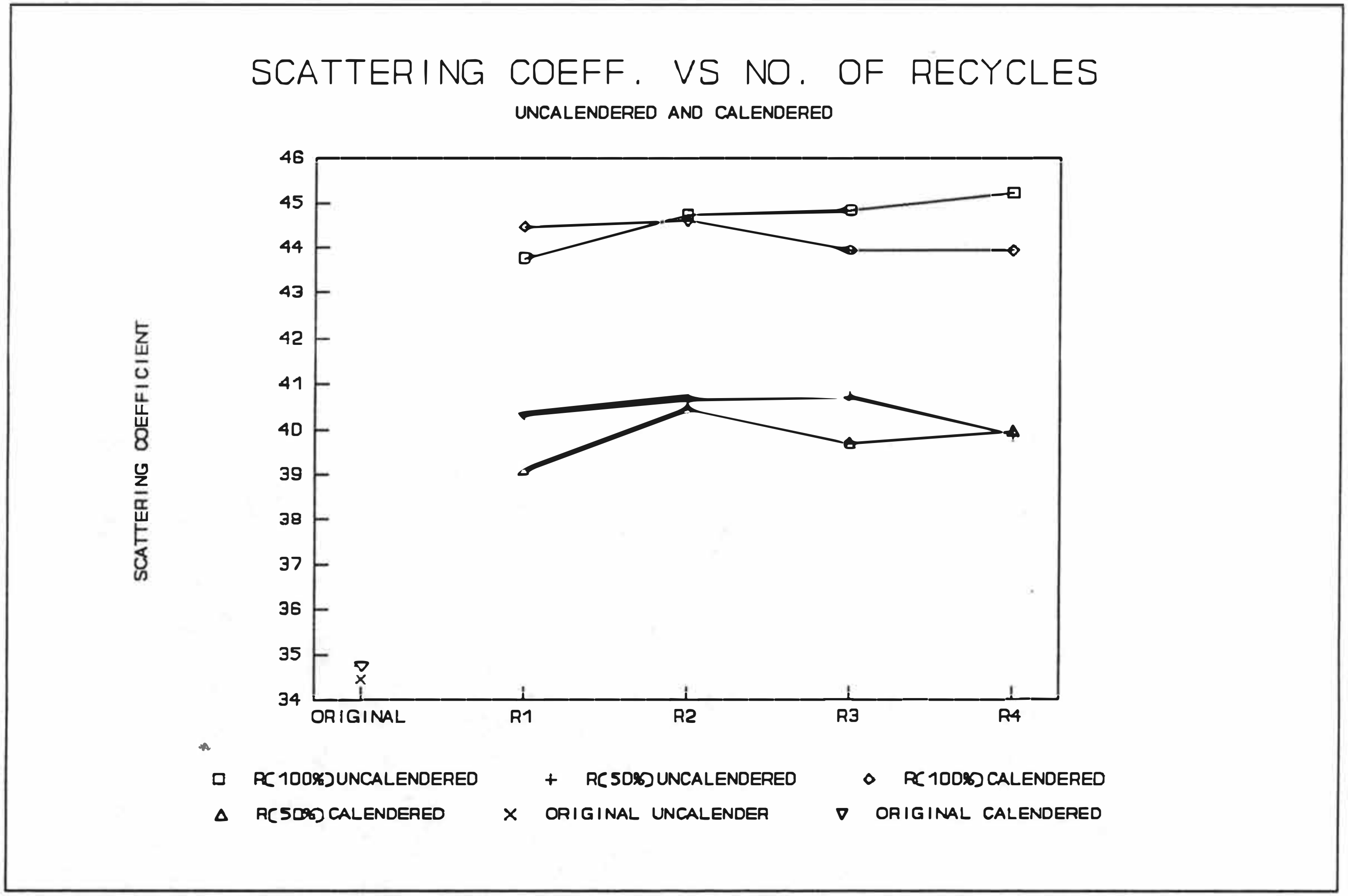

Figure 2. Scattering Coefficient VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

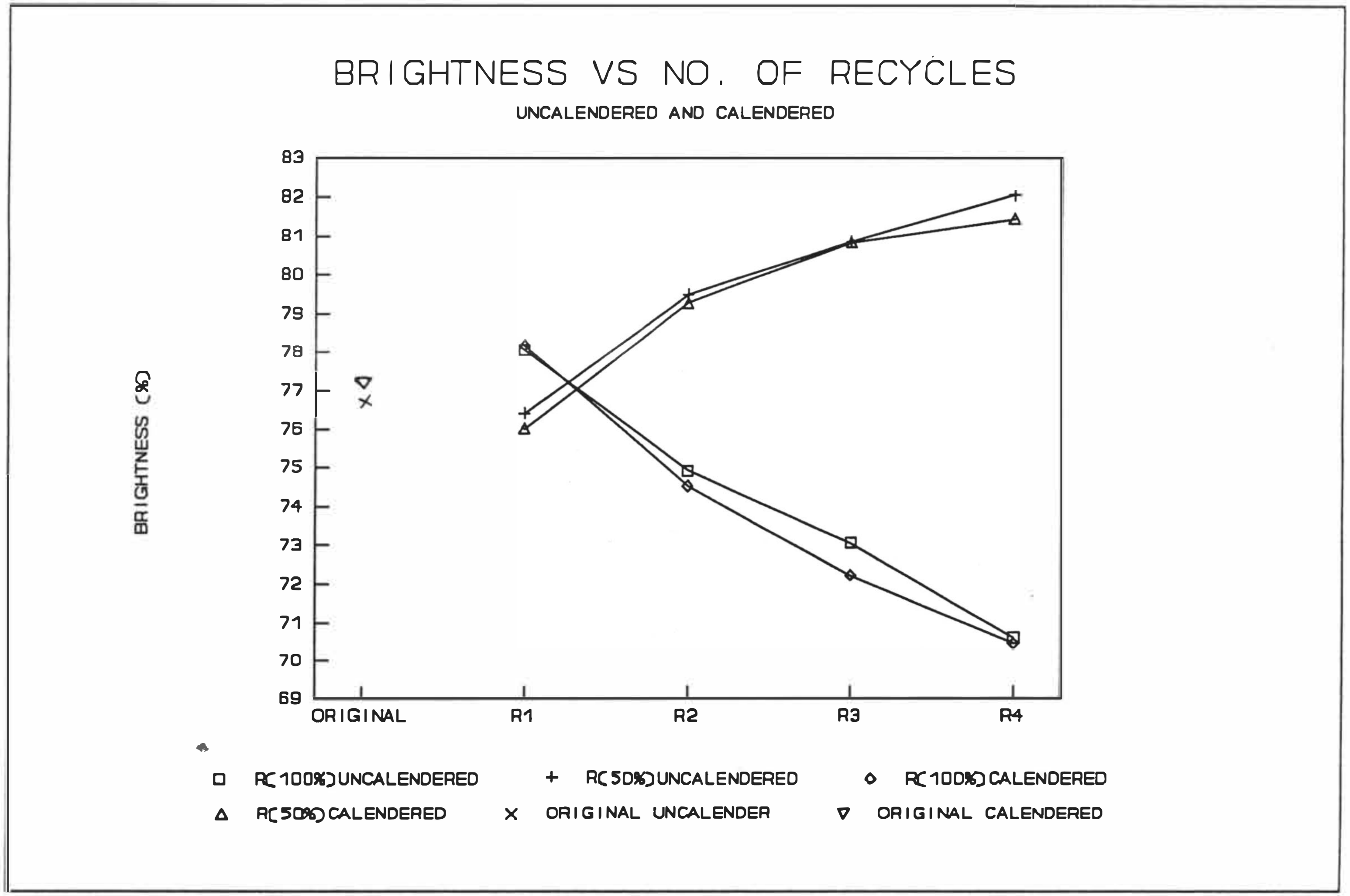

Figure 3. Brightness VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

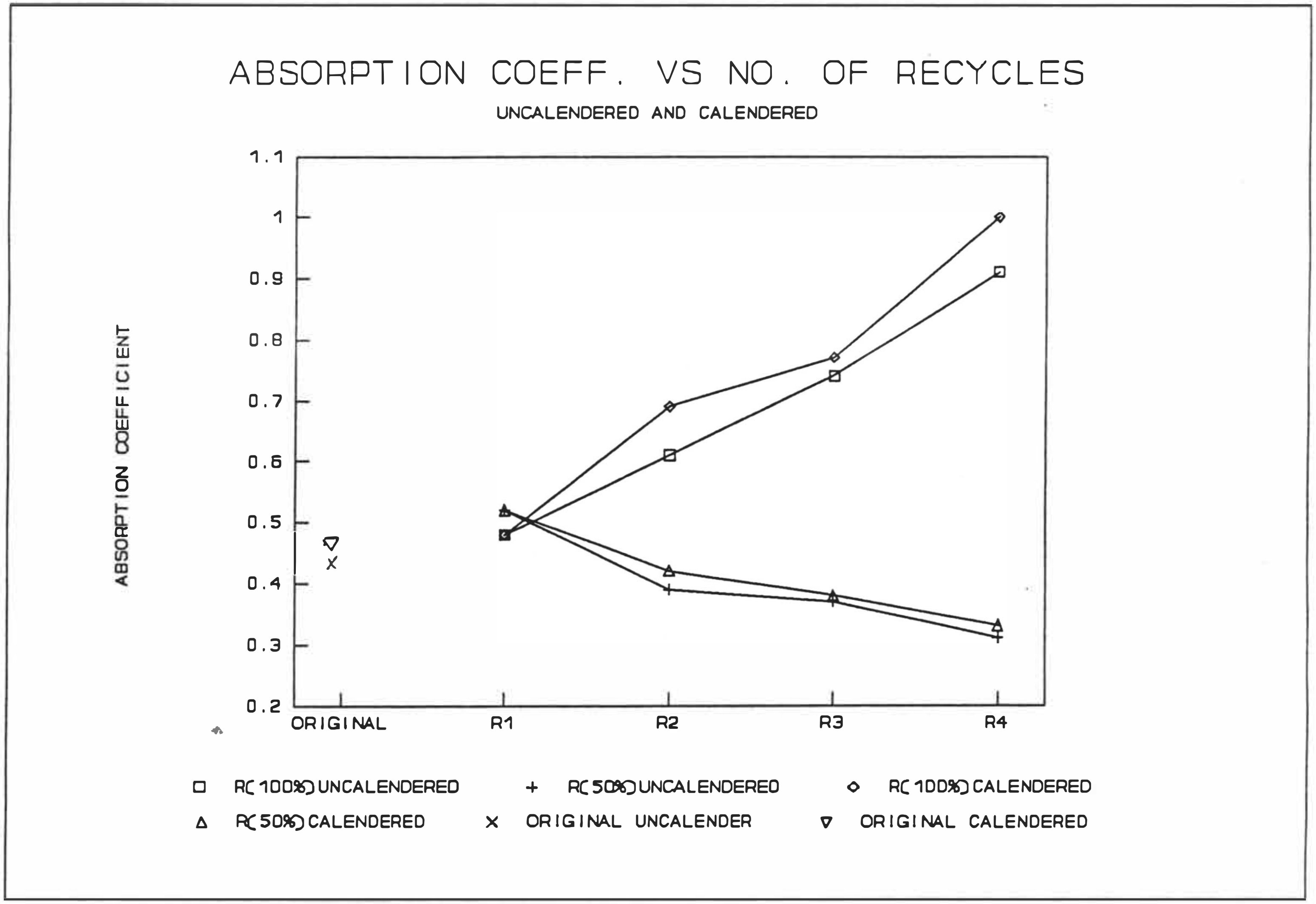

Figure 4. Absorption Coefficient VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

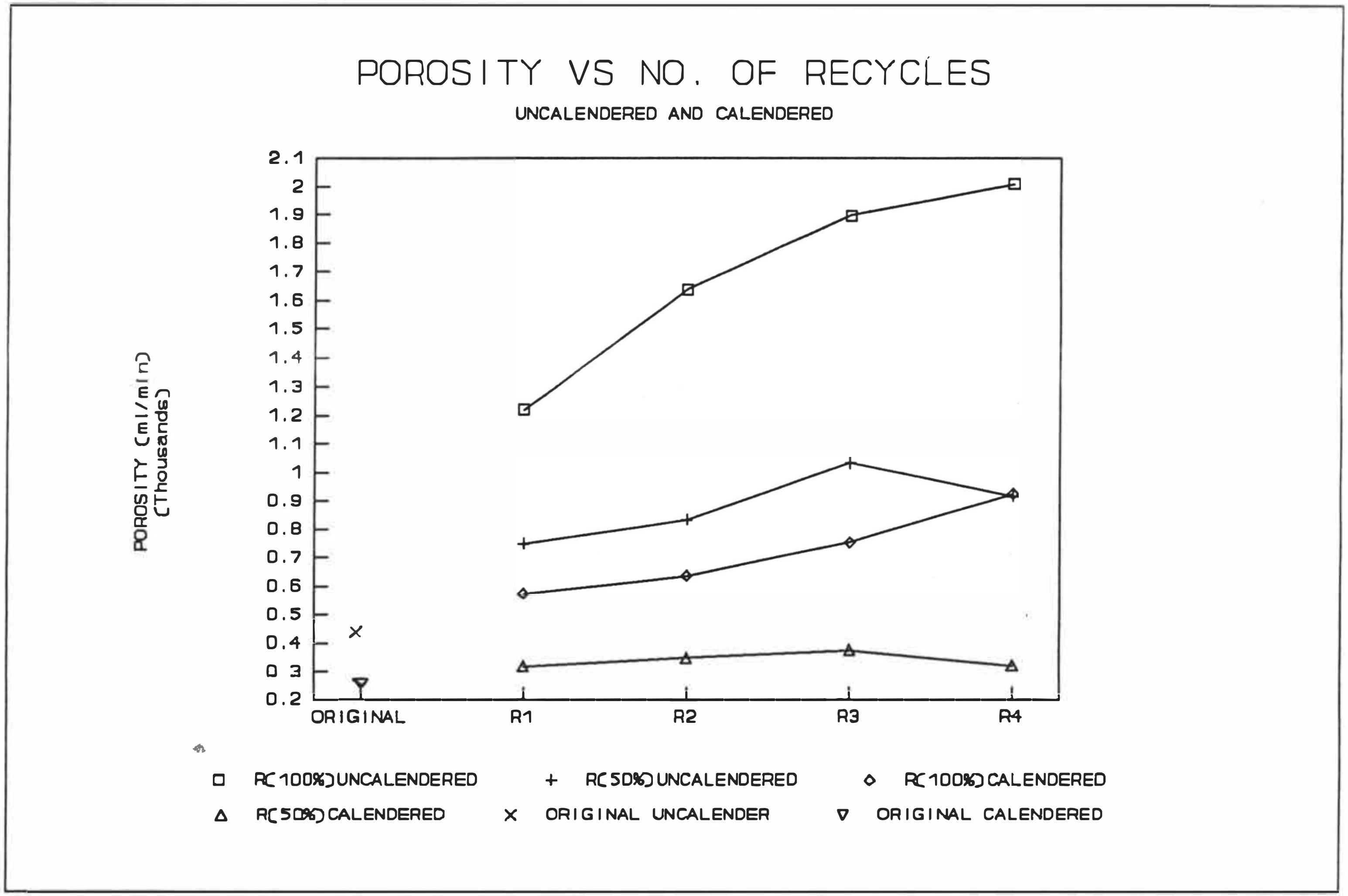

Figure 5. Porosity VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

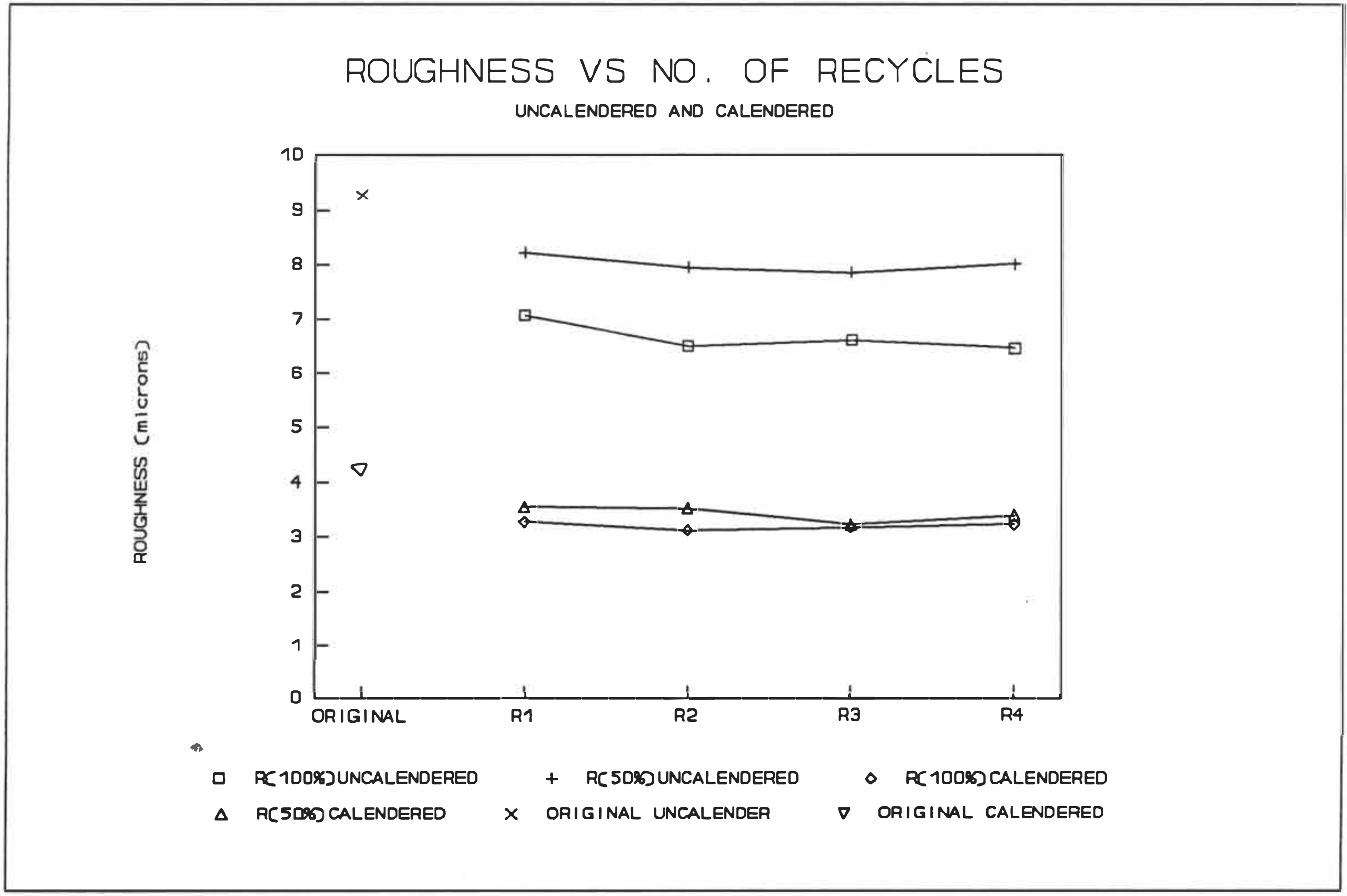

Figure 6. Roughness VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

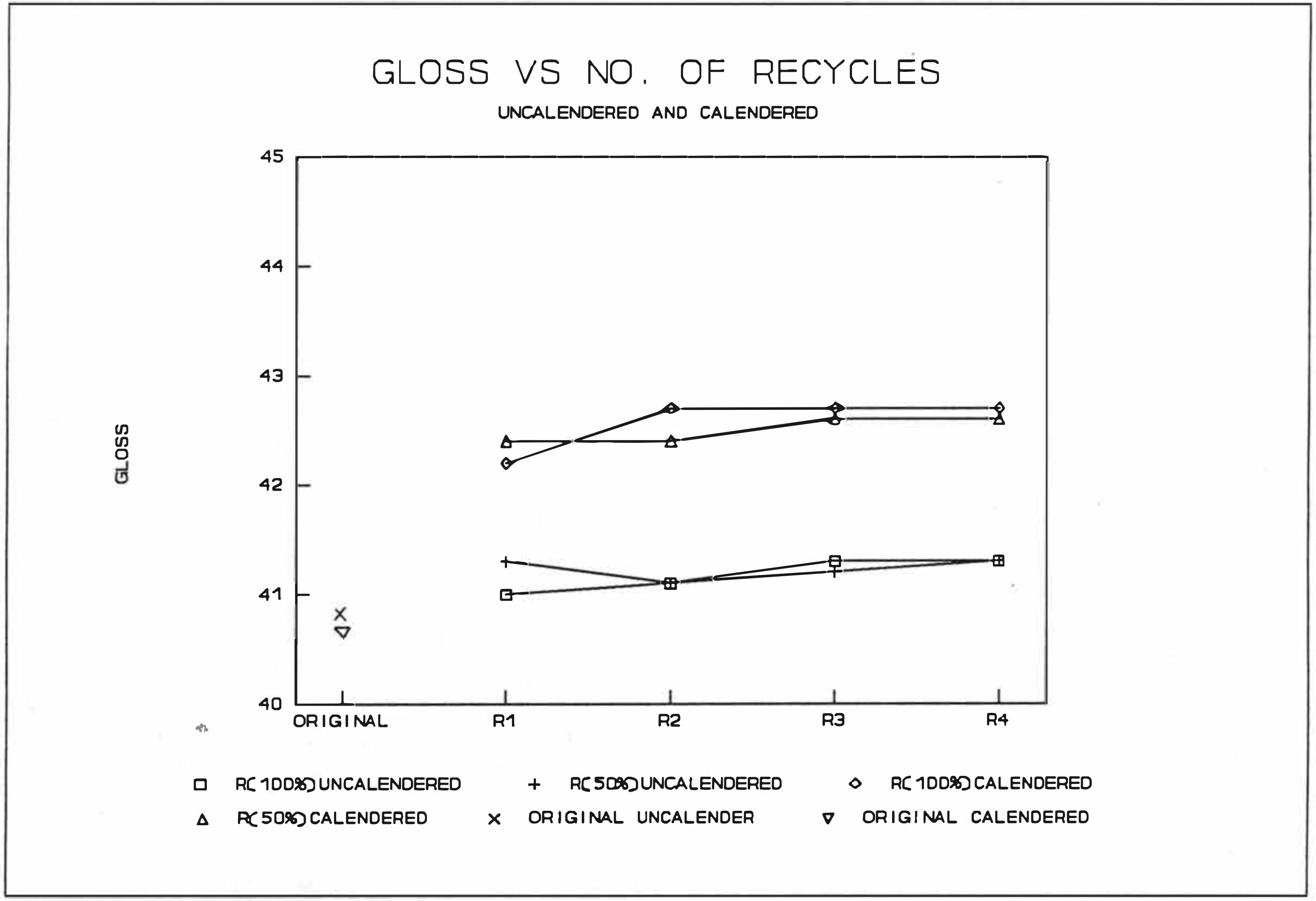

Figure 7. Gloss VS No. of Recycles R(100%) and R(50%/50%). Uncalendered and Calendered.

Table 1

Uncalendered

	Original	100% R1	100% R2	100% R3	100% R4	50% R1	50% R2	50% R3	50% R4
Brightness	76.90	78.04	74.91	73.05	70.59	76.41	79.48	80.84	82.05
Absorption	0.42	0.48	0.61	0.74	0.91	0.52	.39	.37	.31
Opacity	76.34	81.73	82.43	82.84	83.69	80.57	79.65	78.66	78.86
Scatt.Coef.	34.67	43.76	44.73	44.83	45.22	40.35	40.64	40.69	39.86
Roughness	9.25	7.06	6.49	6.59	6.43	8.21	7.95	7.85	8.00
Porosity	423.5	1220.0	1637.0	1897.0	2008.0	750.3	83.25	1039.0	914.0
Gloss	40.8	41.0	41.1	41.3	41.3	41.3	41.1	41.2	41.3
Caliper	4.9	5.3	5.4	5.6	5.7	5.1	5.3	5.0	5.0

Calendered

	Original	100% R1	100% R2	100% R3	100% R4	50% R1	50% R2	50% R3	50% R4
Brightness	77.19	78.17	74.52	72.22	70.44	75.99	79.27	80.82	81.43
Absorption	0.47	.48	.69	.77	1.00	.52	.42	.38	.33
Opacity	76.55	82.04	82.59	82.72	81.91	79.92	78.67	77.70	79.25
Scatt.Coef.	34.75	44.45	44.59	43.93	43.92	39.11	40.44	39.68	39.95
Roughness	4.16	3.26	3.11	3.15	3.20	3.53	3.5	3.2	3.36
Porosity	226.4	573.8	635.6	750.7	921.0	317.9	348.2	373.4	318.4
Gloss	40.6	41.0	41.1	41.3	41.3	41.3	41.1	41.15	41.3
Caliper	3.3	3.6	3.6	3.6	3.6	3.4	3.3	3.2	3.3

Table 2

The Effect of Recycling on the Surface Properties of Paper

	Uncalendered		Calendered	
	R(100%)	R(50%/50%)	R(100%)	R(50%/50%)
Brightness	−8.2%	+6.3%	−8.7%	+7.2%
Opacity	+9.6%	−3.2%	+7.0%	−3.5%
Roughness	Showed a change with calendering			
Porosity	+3.7x	+1.2x	+3.1x	+0.4x
Gloss	Showed a change with calendering			

Conclusion

1. Brightness decreased and opacity increased progressively for 100% recycling. This is seen for both uncalendered and calendered papers.

2. The addition of virgin fibers improved brightness (uncalendered by 6.3%, calendered by 7.2%) and gave smoother paper.

3. Porosity increased but roughness did not show a significant improvement with recycling in both cases.

4. Calendering improved smoothness by 7%.

5. The principal effect of recycling was the loss of the fiber bonding ability, noticeable in the first recycle for opacity and porosity (100% recycle).

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APPENDIX A

The following was the method used for the repulping of the handsheets towards subsequent handsheet making.

British Disintegrator

1. Dilute the sample to 2000 ml (1.2% consistency) with water at 20°C and disintegrate in the standard disintegrator at the 3000 rpm to 50000 revolutions. Since some pulps are particularly resistant to disintegration and may required more than 50000 revolutions to clear them of fiber bundles it may be necessary to extend the time of disintegration.
2. After disintegration, dilute the stock to 7.2 liters (0.3% consistency) with water. Stir the diluted stock well to ensure proper mixing. Measure out 400 ml of the stock 0.3% slurry for each handsheet to be form into separate containers.