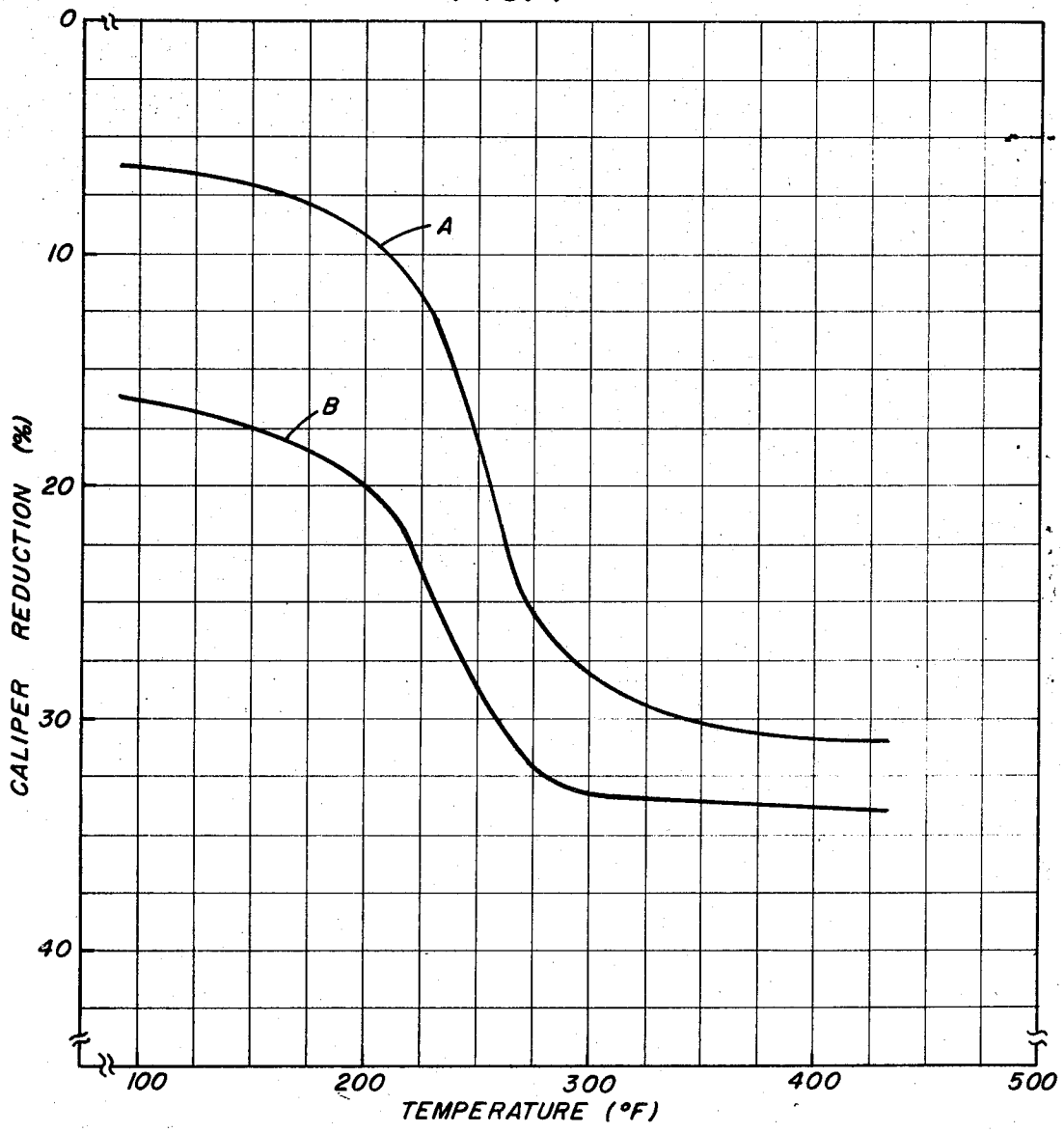
March 7, 1972 R. C. MACK ET AL 3,647,619

HIGH PRESSURE CALENDERING OF A PAPER WEB BETWEEN HEATED CALENDER ROLLS HAVING NON-RESILIENT SURFACES

Filed Nov. 10, 1969 3 Sheets-Sheet 1

FIG. 1

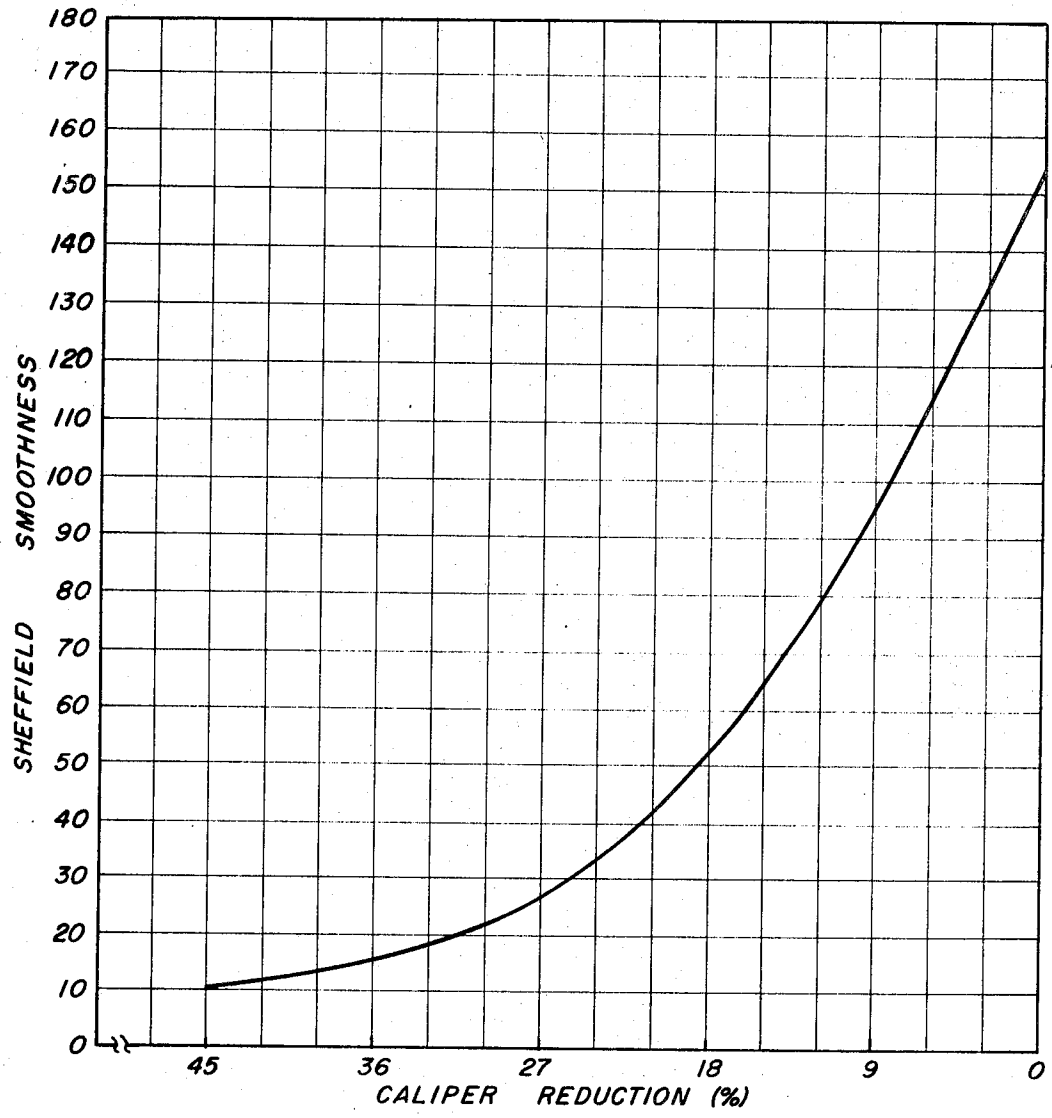


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FIG. 2



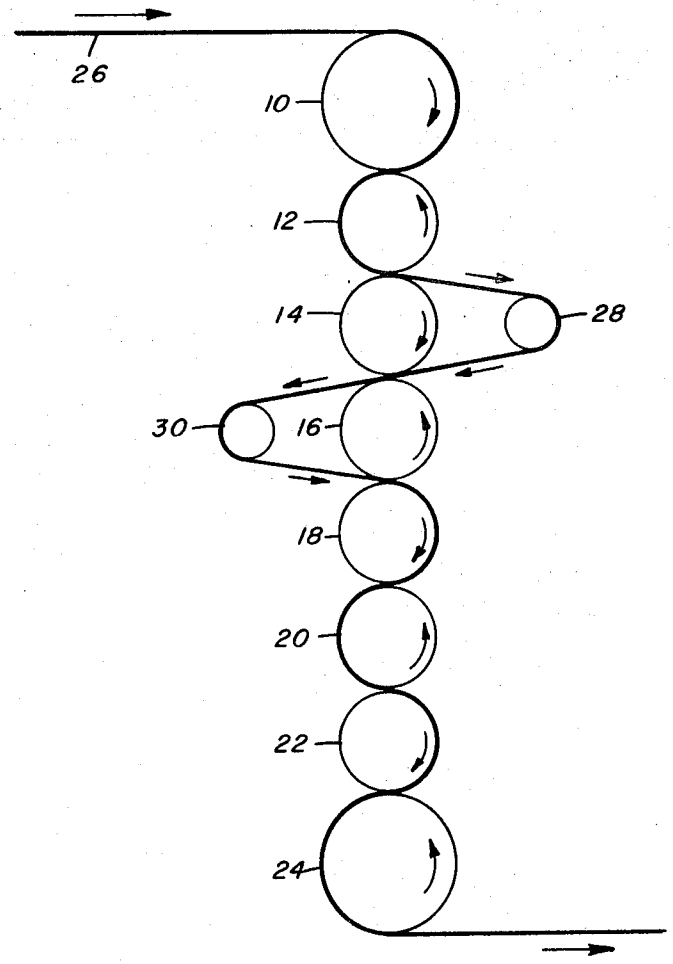
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FIG. 3



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HIGH PRESSURE CALENDERING OF A PAPER WEB BETWEEN HEATED CALENDER ROLLS HAVING NON-RESILIENT SURFACES

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Int. Cl. D21f 11/00
U.S. Cl. 162—206 5 Claims

ABSTRACT OF THE DISCLOSURE

High density paper which has high surface smoothness and high gloss and is especially well adapted for use as a photographic paper is prepared by hot calendering a paper web, with the web being passed through at least one nip defined by heated calender rolls having hard smooth non-resilient surfaces and directed along a path which prevents it from wrapping around the heated rolls. The desired combination of physical properties in the paper is obtained by exerting a pressure on the web in the range from about 10,000 to about 50,000 pounds per square inch while maintaining the heated calender rolls with a surface temperature in the range from about 250° F. to about 500° F. and providing an initial water content in the web which is at least about two percent by weight but is below the water content at which blistering of the paper occurs.

This invention relates in general to the manufacture of paper and in particular to a novel paper calendering process for the production of high density paper having high surface smoothness and high gloss.

As ordinarily employed in the paper-making art, and as utilized herein, the term "calendering" refers to a process in which a web of paper is passed between the nip of a pair of non-resilient rolls, such as rolls made of cast iron or steel, to impart a uniform caliper and surface finish to the paper. Typically, a calender will comprise several rolls arranged in a vertical stack and only the bottom roll will be driven. On the other hand, the term "supercalendering" refers to a process in which a web of paper is passed between the nip defined by a non-resilient roll, such as a roll of cast iron or steel, and a resilient roll such as a rubber-faced roll or a cotton fiber-filled roll. Typically, a supercalender will comprise alternate resilient and non-resilient rolls arranged in a vertical stack or a non-resilient master roll with two or more resilient rolls positioned at spaced intervals about the periphery of the master roll. Calenders are normally utilized "on-machine," i.e. in line with the paper-making machine, but may sometimes be used in an "off-machine" operation. Supercalenders are normally utilized "off-machine," i.e., supercalendering is usually carried out independently of the paper-making process as a separate operation.

At the present time, most papers used for duplicating and printing purposes are subjected to a calendering process utilizing a calender which is operated "on-machine" and at moderate pressures, such as a pressure of 10,000 to 15,000 pounds per square inch, for the purpose of controlling cross-machine caliper profile so as to produce an acceptably even roll. The paper is then finished in an "off-machine" supercalendering operation in which the loading applied to the supercalender is greater than that utilized in the calendering step. The resilient high pressure nips of the supercalender burnish and compress the paper, giving it a pleasing gloss and surface smoothness and bringing about some increase in density. In this type of paper, low density is desired

as the intention is to provide a paper with the most substantial "feel" for the lowest mass, so that conditions are selected to provide as low a density as is feasible while still providing adequate smoothness and gloss. Typically, both the calendering and supercalendering operations are carried out at moderate temperatures, such as temperatures of about 150° F. to 200° F. However, where it is desired to produce low density paper having especially good gloss characteristics, use is sometimes made of a process as "gloss supercalendering" or "thermoplanishing" in which elevated temperatures, in excess of 250° F. and up to as high as about 600° F., are utilized. As an illustration of the prior art in the field of gloss supercalendering, reference may be made to U.S. Pats. 3,190,212, issued June 22, 1965, to L. A. Moore and 3,230,867, issued Jan. 25, 1966, to B. J. H. Nelson.

In contrast with the low density paper referred to above, photographic paper, with its need for maximum stiffness and planar smoothness, requires the densest possible sheet. In addition, it must have very high surface smoothness and very high gloss. The "gloss supercalendering" process is not suited to the manufacture of paper of this type since it produces a paper characterized by low density instead of the high density which is needed and because it is unable to provide a surface with the degree of smoothness needed. On the other hand, calendering at normal temperatures, e.g. 150° F. to 200° F., but with the use of extremely high pressures, e.g. pressures of about 100,000 pounds per square inch or more, will give high density paper with excellent smoothness and gloss properties. However, these extreme pressures require uneconomically massive equipment and are very prone to distort the paper, which precludes their use in actual practice.

It has now been discovered that high density paper which has high surface smoothness and high gloss and is especially well adapted for use as a photographic paper can be obtained by a calendering process which utilizes both high temperatures and a substantial initial water content in the paper web. In carrying out this process, the web is directed along a path which precludes wrap of the web around the hot calender rolls, thereby rendering feasible the simultaneous use of high temperatures, high pressures and a substantial water content in the web. The novel calendering process of this invention is unique in the papermaking art in view of the combination of operating conditions utilized, i.e. the water content, the temperature, the pressure, and the contact time (as determined by web speed and the path of travel of the web). While the effects on paper of calendering pressure, water content and web speed at normal calendering temperatures are well known in the paper industry, the use of high temperatures in a calendering process, as distinct from a supercalendering process, has not been a commercial practice and published information in this area is extremely meager. Some data on the effects of variations in temperature, pressure and water content in calendering of paper have been reported (see, for example, M. Jackson et al., "The Role of Nip Temperatures and Surface Moisture in the Calendering and Supercalendering Processes," Svensk Papperstidn, 69, No. 5, 131, March 1966 and W. H. de Montmorency, "The Calendering of Newsprint: A Laboratory Study of Temperature and Pressure Effects," Pulp Paper Mag. Can. 68 T–326 to T–345, July 1967, but there has not been described heretofore a calendering process which is capable, without the use of a subsequent supercalendering operation or a second calendering at higher pressures, of producing paper with the combination of high density, high smoothness and high gloss necessary in a high quality photographic paper.

In accordance with this invention, the paper web is passed between at least one nip defined by heated calender rolls having hard smooth non-resilent surfaces. The particular material from which the rolls are constructed is not critical as long as they have surfaces which are hard, smooth and non-resilient. Rolls made of cast iron or steel, in accordance with conventional practice in the paper calendering art, are suitable. A two-roll calender can be utilized with the web being passed through the nip a number of times in succession under increasing pressure. However, under most circumstances it will be convenient to employ a calender comprised of several rolls arranged in a vertical stack, with each roll positioned in nip-defining relationship to the rolls adjacent thereto and a lowermost roll, usually of larger diameter than the other rolls, connected to the drive means. At least two of the rolls in nip-defining relationship to each other are heated to maintain their surfaces at an elevated temperature, as hereinafter described, so that as the paper web is passed through the nips of the calender it traverses at least one high temperature nip. The calender rolls may be heated by any suitable means, for example, by flow of high pressure steam or a heat transfer fluid through passages in the rolls or by means of electrical heating coils within the rolls.

The invention is further described herein with reference to the accompanying drawings wherein:

FIG. 1 is a graphical representation of the effect of calender roll temperature on caliper reduction for a typical photographic paper stock calendered at a fixed web speed, pressure and initial water content.

FIG. 2 is a graphical representation of the relationship between caliper reduction and surface smoothness for the paper of FIG. 1.

FIG. 3 is a schematic illustration of a typical multiroll calender stack suitable for carrying out the method of this invention.

To produce high density paper with high surface smoothness and high gloss by the method of this invention it is necessary that the paper web, having a suitable initial water content as hereinafter described, pass through at least one nip defined by heated calender rolls having a surface temperature in the range of from about 250° F. to about 500° F. Temperatures of less than about 250° F. result in the formation of paper in which the properties of high density, high gloss and high smoothness are not achieved in the degree desired, whereas temperatures in excess of 500° F. may cause damage to the paper. Preferred temperatures are in the range from about 300° F. to about 400° F. The use of these elevated temperatures brings about a reduction in caliper and corresponding increase in density which is much greater, for a given pressure, web speed and water content in the web being calendered, than can be achieved at conventional calendering temperatures, such as a temperature of 150° F. to 200° F. This is illustrated by FIG. 1 which is a plot of caliper reduction versus the temperature of the calender roll for a typical photographic paper stock, the web speed having been fixed at 32 feet per minute and the initial water content in the web being 5 percent by weight. Curve A represents the results obtained when the paper web was passed once, at several different temperatures, through the nip of a two-roll calender having 10½ inch diameter rolls equipped with electric heating coils and loaded to exert a pressure on the web of 16,500 pounds per square inch, while curve B represents the results obtained at several different temperatures when the paper web was passed through the nip a total of nine times in succession with the pressure increasing from 16,500 pounds per square inch in the first pass to 30,500 pounds per square inch in the ninth pass in order to simulate a nine nip calender pressure schedule. Consideration of FIG. 1 indicates that calender roll temperature has a very great effect on caliper reduction. Thus, for example, much greater caliper reduction is achieved with a single nip at

300° F. than with nine nips at 100° F. The effect of temperature on caliper reduction is especially pronounced at temperatures of from about 200° F. to about 300° F.

Calender stacks utilized in the method of this invention may be constructed in the conventional manner so that details of such construction need not be set forth herein. The calendar stack should be designed to exert a pressure on the web in the range of from about 10,000 to about 50,000 pounds per square inch. The loading necessary to exert such a pressure on the web may be calculated by means of known mathematical relationships, for example as described in "Stress Distribution And Strength Condition Of Two Rolling Cylinders Pressed Together" by Eugene I. Radzimovsky, University of Illinois, Engineering Experiment Station, Bulletin Series No. 408, published by the University of Illinois, Urbana, Ill. Pressures below about 10,000 pounds per square inch are insufficient to give high density paper with high smoothness and high gloss while those above about 50,000 pounds per square inch cause an excessively large loss in the strength of the paper. Preferred pressures for the purposes of this invention are in the range from about 20,000 to about 40,000 pounds per square inch.

Web speed may be varied over a wide range with satisfactory results. Thus, the web speed selected may vary from as low as about 10 feet per minute to as high as about 2000 feet per minute, or more, as desired. More typically, the web speed chosen will be in the range from about 200 to about 500 feet per minute.

In carrying out the method of this invention, the initial water content in the web is a highly important feature. It has been found that at constant pressure, web speed and roll temperature, caliper decreases with increasing water content up to a point where the caliper levels out and actually starts to go slightly upwards again. If the paper is examined closely at this point, the surface will be seen to exhibit a slight bumpiness. If calendering is carried out at increasingly higher water contents from this leveling-out point, a condition is reached where the sheet starts bubbling or blistering, i.e., splitting apart internally. The location of this blistering point, in terms of water content, is a function of the temperature level and temperature profile in the thickness direction which the web achieves in the calendering nip. Thus, the "critical" water content in the method of this invention varies with the type of paper and with temperature, pressure and web speed. In accordance with this invention, the initial water content of the web, i.e., the water content of the web at the start of the calendering process, is established at a level which is at least about two percent by weight of the web but is below that at which blistering of the paper occurs at the particular combination of temperature, pressure and web speed selected. If the calender is operated "on-machine" it will ordinarily be a simple matter to control the amount of drying to which the web is subjected as it is removed from the paper-making machine to give the desired water content. When the calender is operated "off-machine" it may, in some instances, be necessary to add water to the web before calendering. It is usually desirable to operate with as high a water content as is feasible as this gives maximum increase in density and maximum improvement in smoothness and gloss. The maximum permissible water content for a given set of conditions, i.e. the water content at which blistering occurs, can be easily determined by routine experimentation with the particular paper and calender involved.

A reduction in the caliper of the paper as a result of calendering at elevated temperatures, as herein described, is accompanied by a corresponding improvement in surface smoothness and gloss. This is illustrated by FIG. 2 which is a plot of Sheffield Smoothness against caliper reduction. The greater the caliper reduction achieved, the lower the value for Sheffield Smoothness and, thus, the higher the surface smoothness. Accordingly, the beneficial effect of increasing roll temperature could have been dem-

onstrated equally well by plotting surface smoothness in place of caliper reduction in FIG. 1.

It is conventional practice in both calendering and supercalendering methods known to the art to permit the web to wrap around the rolls of the calender or supercalender. However, it is an important feature of the method of this invention that the web be directed along a path which precludes wrap around of the web with those rolls of the calender which are maintained at the high temperatures hereinbelow described. It is only by this means that calendering can be carried out without blistering of the paper occurring, when utilizing a combination of pressure, temperature and water content that will result in production of high density paper with high surface smoothness and high gloss. More specifically, by the requirement that the web be directed along a path which precludes wrap around with the high temperature rolls it is meant that the web must travel along a path which is tangential to these rolls at the line of contact between the rolls or that it deviate from such path only to a limited extent so that the angle subtended by the arc over which web to roll contact occurs is less than about 90 degrees.

It has been determined that blistering of the paper will occur if the major portion of the web reaches the boiling point of water in the nip. To avoid this, it is necessary to select an appropriate initial water content for the conditions of temperature, pressure and web speed employed and to avoid significant wrap around, as hereinbefore described. It is also necessary that the initial temperature of the web, i.e. the temperature of the web at the start of the calendering operation, should not be so high that when he web passes through the hot nip a slight increase in temperature will bring it above the boiling point and cause blistering. In this regard, it is preferred that the initial web temperature not be greater than about 150° F.

FIG. 3 provides a schematic illustration of a multiroll calender which is suitable for carrying out the method of this invention. The calender comprises a vertically-aligned stack of eight rolls each of which is made of a smooth hard non-resilient material, such as chilled cast iron, and is mounted in nip-defining relationship with the rolls adjacent thereto. Suitable drive means as well as means for loading the calender to the desired pressure (not shown) are provided in accordance with conventional practice in the paper calendering art. Uppermost roll **10** and lowermost roll **24** are of larger diameter than intermediate rolls **12, 14, 16, 18, 20** and **22**, each of which is of the same diameter. As a typical illustration, rolls **10** and **24** may have a diameter of 20 inches and each of the other rolls may have a diameter of fourteen inches. Intermediate rolls **12, 18, 20** and **22**, as well as uppermost roll **10** and lowermost roll **24**, are maintained at a low temperature, such as room temperature or slightly higher, while rolls **14** and **16** are maintained at an elevated temperature such as, for example, a temperature of 300° F. A paper web **26**, taken from a supply roll or directly from the papermaking machine (not shown) and having a moderate water content, such as about 5 weight percent of water, passes partially around roll **10**, which serves to impart a suitable degree of tension to web **26**, then between the nip defined by rolls **10** and **12** and then partially around roll **12** and between the nip defined by rolls **12** and **14**. From this point, web **26** travels around fly roll **28**, the function of which is to preclude web **26** from wrapping around high temperature roll **14**, then between the nip defined by rolls **14** and **16** and around fly roll **30** which serves to prevent web **26** from wrapping around high temperature roll **16**. Web **26** then passes in sequence through the remaining nips, partially around rolls **24** and thence to a take-up reel (not shown).

As will be apparent from consideration of FIG. 3, web **26** is permitted to wrap around the low temperature rolls, i.e. rolls **10, 12, 18, 20, 22** and **24**, but is guided by fly rolls **28** and **30** along a path which precludes it from wrapping around the high temperature rolls, i.e. rolls **14** and **16**. This, of course, is only one example of a suitable calender stack and the number and arrangement of the high temperature rolls can be varied, as desired. However, if more than two high temperature rolls are employed then additional fly rolls associated therewith are required to avoid wrap around of the web with the high temperature roll surface.

Roll **10** serves as the roll through which loading is applied to the stack while roll **24** serves to support the other rolls and acts as the drive roll. Roll **12** is employed to effect some initial caliper reduction at a low temperature. This is not essential but it is advantageous since wrinkling of the paper may occur if the first roll it contacts is at a very high temperature, such as 400° F. High temperature rolls **14** and **16** effect substantially all of the caliper reduction so that the web could be withdrawn after passing between the nip defined by rolls **16** and **18**. However, it is desirable that the web pass around one or more low temperature rolls, such as rolls **20, 22** and **24**, to accomplish cooling of the web.

The method of this invention is most advantageously employed as an "on-machine" process with the calender being utilized at the point in the paper-making process where calendering is ordinarily employed, i.e. following partial drying of the web. However, it is also feasible to make use of the method of this invention in an "off-machine" operation and it can be used, if desired, to improve the smoothness and gloss and increase the density of paper that has already been calendered in a conventional calendering process.

The invention is further illustrated by the following examples of its practice.

Example 1

A bleached sulfite paper having a basis weight of 42 lbs. per 1000 ft.^{2} was calendered in a two-roll calender, each of the two rolls being 10½ inches in diameter, made of steel, and equipped with electrical heating coils. Calendering was carried out with a web speed of 32 feet per minute, a roll temperature of 300° F., an initial water content in the web of 5 percent, and with the web initially at room temperature. In a first test in which the web was passed through the nip only once and the pressure exerted on the web was 16,500 pounds per square inch, the caliper reduction achieved at 300° F. was 28.3 percent, as compared with 6.4 percent when the temperature was 100° F. and all other conditions were the same. In a second test, the web was passed through the nip nine times in succession with the roll temperature at 300° F. and the pressure increasing from 16,500 pounds per square inch in the first pass to 30,500 pounds per square inch in the ninth pass. Results obtained are reported in Table I which includes, for purposes of comparison, the properties of the uncalendered paper and those of the same paper calendered under identical conditions except that the roll temperature was 100° F.

TABLE I

Property	Paper calendered at— 300° F.	100° F.	Uncalendered paper
Caliper reduction (percent)	32.8	16.5	
Sheffield smoothness (face-dry)	26	70	154
Sheffield smoothness (wire-dry)	27	94	229
Perkins Mullen (p.s.i.)	47	46	48
Valley acid penetration (seconds)	465	426	425
Schopper wet tensile (kg.)	34	35	36
Scott bonding strength	122	120	132
Opacity	96	97	97
Elmendorf length tear (kg.)	96	114	120
L & W length stiffness	192	263	320
M.I.T. fold (length)	6	5	4
Two minute expansion	1.50	1.40	1.35
Percent:			
Swell	50	36	26
Bulk	20	10	3

As demonstrated by the data reported in Table I, greatly improved smoothness and much greater caliper reduction are achieved by calendering at a high temperature.

As far as the other physical properties of the paper are concerned, the high temperature does not cause much change in Mullen, acid penetration, wet strength, Scott bonding strength or opacity, causes some decrease in tear strength and in L & W stiffness, and causes some increase in M.I.T. fold, expansion, percent swell and percent bulk.

Example 2

The paper described in Example 1 was calendered by a single pass through the calender described in Example 1 at various conditions of temperature, pressure, web speed and initial water content. In each instance, the web was initally at room temperature. The conditions employed in calendering and the values obtained for percentage caliper reduction are reported in Table II.

TABLE II

	Temperature of calender rolls (° F.)	Pressure exerted on web (p.s.i.)	Web speed (ft./min.)	Initial water content (percent)	Caliper reduction (percent)
Test No.:					
1	265	20,000	32	2.5	13.5
	265	20,000	32	5.0	22.0
	265	20,000	32	7.5	27.3
2	265	32,000	32	2.5	19.8
	265	32,000	32	5.0	26.8
	265	32,000	32	7.5	30.1
3	265	45,000	32	2.5	24.5
	265	45,000	32	5.0	30.1
	265	45,000	32	7.5	37.6
4	300	20,000	32	2.5	24.2
	300	20,000	32	5.0	32.7
	300	20,000	32	7.5	36.8
5	300	32,000	32	2.5	24.3
	300	32,000	32	5.0	32.8
	300	32,000	32	7.5	37.3
6	300	45,000	32	2.5	25.6
	300	45,000	32	5.0	33.3
	300	45,000	32	7.5	38.3
7	305	32,000	32	2.5	24.0
	305	32,000	32	5.0	33.1
	305	32,000	32	7.5	38.7
8	305	45,000	32	2.5	27.9
	305	45,000	32	5.0	36.1
	305	45,000	32	7.5	40.2
9	305	32,000	50	2.5	22.4
	305	32,000	50	5.0	30.6
	305	32,000	50	7.5	36.3
10	305	45,000	50	2.5	26.0
	305	45,000	50	5.0	34.7
	305	45,000	50	7.5	39.6
11	400	20,000	32	2.5	37.4
	400	20,000	32	5.0	(1)
	400	20,000	32	7.5	(1)
12	400	32,000	32	2.5	38.7
	400	32,000	32	5.0	(1)
	400	32,000	32	7.5	(1)
13	400	45,000	32	2.5	39.5
	400	45,000	32	5.0	(1)
	400	45,000	32	7.5	(1)

[1] Under these conditions of temperature, pressure, web speed and water content, blistering of the paper occurred so no caliper measurements were made.

The data presented in Table II show that, with the other variables held constant, the caliper reduction increases with increasing temperature, increases with increasing pressure, increases with increasing water content in the web and decreases with increasing web speed. As previously indicated, an increase in caliper reduction corresponds to an improvement in smoothness and gloss.

As will be apparent to one skilled in the art from the description and examples provided herein, the method of this invention provides important advantages over calendering or supercalendering processes known heretofore. Thus, for example, high density paper with high surface smoothness and high gloss is produced in a single operation as contrasted with the prior use of "on-machine" calendering followed by subsequent "off-machine" supercalendering. By virtue of the combination of high roll temperature together with a substantial water content in the web, reduction in caliper and improvement in smoothness can be achieved by using lower pressures and/or fewer calender nips than were required in the calendering processes of the prior art. Thus, it may, in some instances, be feasible to replace multi-roll calender stacks with two-roll stacks. As an illustration of a still further advantage, papers which must be extremely thin so that a maximum amount of paper can be incorporated in a roll of given size, e.g. papers for use in recording instruments, are advantageously produced by the method of this invention in view of the substantial caliper reduction that can be effected without significant loss in strength. The invention is also well suited to the production of photographic papers, especially papers intended for manufacture of photographic paper base of the resin coated type.

The invention has been described in detail with particular reference to preferred embodiments thereof, but it will be understood that variations and modifications can be effected within the spirit and scope of the invention.

We claim:

1. A method of preparing high density paper having high surface smoothness and high gloss, which comprises passing a paper web through at least one nip defined by heated calender rolls and directing it along a path which precludes wrap around of the web with the heated calender rolls, said heated calender rolls having hard smooth nonresilient surfaces with a surface temperature in the range from about 250° F. to about 500° F. and exerting a pressure on said web in the range from about 10,000 to about 50,000 pounds per square inch, said web having an initial water content which is between about two percent by weight of the web and below that at which blistering of the paper occurs at the combination of temperature, pressure and web speed which is utilized.

2. The method as described in claim 1 wherein the surface temperature of said calender rolls is in the range from about 300° F. to about 400° F.

3. The method as described in claim 1 wherein the pressure exerted on the web is in the range from about 20,000 to about 40,000 pounds per square inch.

4. The method as described in claim 1 wherein the surface temperature of the calender rolls is about 300° F., the pressure exerted on the web is in the range from about 20,000 to about 40,000 pounds per square inch, the initial water content in the web is at least about 5 percent by weight, and the web speed is in the range from about 200 to about 500 feet per minute.

5. The method as described in claim 1 wherein said web is passed through at least one nip defined by calender rolls which are not heated before passing between said heated calender rolls.

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U.S. Cl. X.R.

100—38, 93 P, 162 R; 162—361