WEB MOISTURE PROFILE CONTROL FOR PAPER MACHINE

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The present invention relates broadly to paper machines, and is more particularly concerned with novel method and apparatus for controlling the moisture content across the width of a fibrous web being treated or produced.

It is known that many paper machines produce from time to time irregularities in "moisture profile," which is the term applied in the art to a graph of moisture content against the width of the paper being produced. The desired moisture level is represented by a straight horizontal line in this plot; however, the large number of variables present during operation of the modern paper machine make it essentially impossible to completely avoid the occurrence of moisture streaks longitudinally along the web being made.

Exemplary of some of the causes of moisture streaks are non-uniformity of delivery of water and fiber to the slice, irregular drainage in the Fourdrinier wire because of a number of factors such as the table rolls being in poor condition, plugged suction box covers, partial plugging of the suction press rolls or suction couch roll in local streaks, improper fitting of suction box seals across the machine perpendicular to the vacuum applied to the sheet or felt, and the showers on the machine may not be distributing water uniformly. Then too, the press nip pressures may not be uniform across the machine due either to improper crowning or to local imperfections in the roll surfaces or driers. In addition to the named irregularities of moisture profile arising from faulty maintenance or adjustment, it has been found that the principal cause of dry edges and a wet center section of the sheet arises from an over-drying at the edges because the dry outside air enters the paper machine at the side thereof, while moisture vapor driven off during the drying process tends to accumulate in the center of the machine and thereby impedes the drying rate in this particular location.

As is appreciated, certain of the mentioned causes of wet streaks can be corrected by adjustment and repair, although it is, of course, not always possible to shut down the machine to make such repairs because of the time involved. In other cases, the actual cause of the streak may not be known.

It is, accordingly, an important aim of the present invention to provide a novel method and means to accurately and uniformly control the moisture profile of a fibrous web being treated or produced.

Another object of the invention is to provide a method of drying a web of paper and the like, which comprises advancing a moist web toward a drying cylinder, examining said web for the presence of moisture streaks therein extending generally in the direction of travel thereof, and while said web is against said cylinder, directing against the transverse portions of the web containing such streaks a relatively greater volume of heated air than against other portions thereof to produce transversely across the web a relatively uniform moisture content therein.

A further object of this invention is to provide means for selectively directing high velocity and high temperature air against predetermined portions of the transverse width of a web of paper and the like received by a drying cylinder, said means comprising a hood supported adjacent said cylinder, means dividing the hood into a plurality of drying chambers, and means controlling the air discharged from each of said chambers into drying relation with the web to effect in accordance with the web moisture content a relatively higher degree of drying in predetermined portions of the transverse width of the web than in other portions thereof, so that the moisture content of the web is generally uniform transversely.

Other objects and advantages of the present invention will become more apparent during the course of the following description, particularly when taken in connection with the accompanying drawings.

In the drawings, wherein like numerals are employed to designate like parts throughout the same:

FIGURE 1 is a somewhat diagrammatic view of a drier section of a paper machine and embodying therein drying means constructed in accordance with the principles of this invention;

FIGURE 2 is a side elevation view of the drier means of this invention in association with an air pressure control system providing maximum utilization of the heat supplied to the drying means;

FIGURE 3 is a vertical sectional view of the drying means or hood of this invention positioned adjacent a conventional drying cylinder;

FIGURE 4 is a detail transverse sectional view taken through a form of plenum chamber that may be employed to carry out the invention, and illustrating a means for varying the width of the individual plenum chambers across the width of the web;

FIGURE 5 is a fragmentary plan view of a preferred form of perforated plate used in the hood means of this invention; and,

FIGURE 6 is a sectional view of the plate means of FIGURE 5, and showing in detail the configuration of a pair of orifices therein.

Referring now to the drawings, there is shown somewhat diagrammatically in FIGURE 1 a dry end section 10 of drying apparatus of a paper machine with which the instant invention is of important application. The dry end section 10 comprises a first row of horizontally aligned drying cylinders or drums 11a-d of which four are shown in the exemplary embodiment illustrated, and a second row of horizontally aligned drying cylinders 12a-d staggered with respect to the drying drums 11 of the first row. A web of paper W passes alternately about the drying cylinders 11 and 12, and is maintained in contact with the surfaces of the drying cylinders 11a and 11b by a felt 13 and against the surfaces of the drying drums 12a-d by a felt 14. A suitable number of rollers 15 are arranged to guide the felt 13, and rollers 16 guide the felt 14. The drying arrangement described will be recognized as of essentially conventional construction, and in performance of the drying cycle, the cylinder or drum 11d may be a steam drier supplied with relatively cold water to cause condensation on the surfaces thereof from surrounding moist atmosphere, the condensate being picked up by the web W traveling over this drier to restore a portion of the moisture removed by any over-drying. However, by proceeding in accordance with the instant invention, and as will be described hereinbelow, effective uniform moisture control throughout the transverse width of the web W may render unnecessary the use of the steam drier 11d.

It has been noted hereinafter that moisture irregularities can arise from various causes, and as is known, fall-
ure to correct the moisture level across the sheet results in a finished product having a poor grade finish thereon. In accordance with this invention, selected portions of the web having excess moisture therein are impinged by a high velocity and high temperature air stream under the control of the paper machine operator, and thereby a substantially uniform or uniform moisture profile is obtained. Since particular longitudinally extending portions of the paper web are subjected to accelerated drying, over-drying of the entire transverse width of the sheet is minimized, and accordingly, rewetting the sheet is not essential in order to bring its moisture level to a particular desired value.

Web moisture profile control means provided by applicants is indicated generally in FIGURE 1 by the numeral 17, and it may be seen therefrom that such means are located in close wrapping relation to the drying cylinder 11c, although identical means could additionally be employed in association with the drier drum or cylinder 12d, if heat that felt 14 would be removed from such drum. Upon reference also to FIGURES 2 and 3, it will be observed that the control means 17 is preferably in the form of an arcuate housing 18 supported by a suitable means in close relation to a portion of the circumference of the cylinder 11c and extending a sufficient distance thereon to be effective with the wrap of the web W during travel along this portion of the circumference of the rotatable drum 11c. The housing 18 preferably extends entirely along the axial length of the drum 11c and is provided with opposite end walls 19 (one of which is shown) and inwardly extending bottom walls 20, which may be in the form of shutters hinged at 21 to the housing 18 to permit ready accessibility to the apparatus for threading the web therethrough when required. The shutters or bottom walls 20 are maintained in the closed position of FIGURE 3 during machine operation, and suitable spring means may be employed to hold said shutters closed and in the close relation to the drier cylinder surface indicated in the drawings.

The housing or hood 18 is preferably of sheet metal construction and is provided at a plurality of transversely spaced locations along its arcuate length with outwardly extending conduits 22 which connect interiorly of the housing 18 with a central head or plenum 23, which in turn communicates by conduits or ducts 24 and 25 with drier heads or plenums 26 and 27 circumferentially spaced from the plenum 23. While three of such plenums are illustrated, the number thereof may vary, and additionally, the hood or housing 18 may be in separable sections, rather than a single unit extending entirely across the width of the cylinder 11c as shown.

It will be observed that the plenums 23, 26 and 27 have a transverse width coextensive with the hood or housing 18 and accordingly coextensive with the axial length of the drying cylinder 11c. Each plenum supports interiorly a partition or baffle member 28 dividing said plenums into a plurality of transversely adjacent plenum chambers 23g, 26a and 27a, the chambers of the plenum 23, 26 and 27 being accurately aligned one with the other, and being in communication by means of the ducts or conduits 24 and 25. It is thus to be seen that a single outwardly extending conduit 22 serves a single chamber of either of the plenums 23, 26 and 27.

Each plenum is arcuately curved along its surface adjacent the cylinder 11c and supported therein and extending transversely across the width of each plenum is a perforated plate member 29, the structural details of which will be specifically described hereinafter. The plenums 23, 26 and 27 are in other respects of generally triangular configuration when viewed in end, although, of course, the shape thereof may be widely varied.

Each inlet conduit 22 formed on the hood or housing 18 supports therewithin a damper 30 to selectively open or close any one of said conduits to control the heated air flow to a particular arcuate row of plenum chambers 25a, 26a and 27a, whereby high velocity and high temperature air is impinged against the sheet along that transverse portion thereof wherein moisture streaks are present. The dampers 30 may be pivotally connected to a particular position within each conduit 22 by suitable motor means (not shown) remotely controlled by the paper machine operator. Any particular set of plenum chambers may discharges air against the web in accordance with the operator's detection of wet streaks or other moisture irregularities in the sheet when the source of said irregularities is upstream of the drying cylinder 11c.

Each inlet conduit 22 to the central plenum 23 connects with a main header pipe 31 (FIGURE 2) closed at one end and connecting at its opposite end with a conduit 22 leading to a heater 33, which in turn connects with a conduit or a pipe 34. The latter pipe has a branch portion 34a therein, and a damper 35 controls the extent of opening of said portion, and in cooperation with an exhaust fan 36, regulates the moisture balance in the system. The conduit 34 further connects with a blower 37 receiving a conduit 38 connecting with branch conduits 39 (two of which are shown) leading to the interior of the hood or housing 18, the branch conduits 39 connecting with the conduit 38 by a common connecting conduit 40. The blower 37 being connected to an exhaust 41 in one or both end walls 19 of the hood or housing 18 and function in the manner now to be described, to remove spent air from within an outer plenum chamber 41 defined by the inner surfaces of the hood 18, the opposite end walls 19 thereof and the bottom walls or shutters 39.

Referring particularly to FIGURE 2, it should be especially noted that in the system disclosed the exhaust fan 36 is effective to maintain a slightly sub-atmospheric pressure in the return portion of the system, and accordingly, replacement or make-up air is permitted to enter the outer plenum chamber 41 only in sufficient and relatively small quantities to prevent the loss of heated air to the surrounding atmosphere. The quantity of air so entering will replace the saturated air exhausted via the fan 36. The advantage of this is that heat supplied to the system is conserved, and in this connection it is important to note that the outer plenum 41 tends to retain the heat in the heated air supply. Further, with reference to the exhaust fan 36, this fan is arranged to remove a controlled fraction of the spent air from the outer plenum 41 in such quantities that a desired moisture balance is maintained in the system, and by positioning of the damper 35, and/or the exhaust fan 36, the relative humidity may be controlled by exhausting a controlled quantity of the saturated air to a particular or pre-selected constant value. The blower 37 on the other hand, pressurizes the air received from the outer plenum 41 through the conduits 38—40, and directs this air through the conduit 34 into the heater 33, where the temperature is raised to the desired level for effective drying action. In this manner, there is a controlled re-circulation of the heated air, the temperature of which is controlled by the heater 33 and the velocity controlled in turn by the blower 37 by its pressurizing function.

It will also be appreciated that the hood 19 may be operated at slightly above atmospheric pressure, permitting a loss of moist air from the hood. In this arrangement, the exhaust means is reversed in function and supplies make-up air to the system.

A further structural feature of the instant invention is the particular configuration of the perforated plate 29 supported by each of the plenums 23, 26 and 27. Referring now to FIGURE 5 and 6, it will be seen that the plate 29 is provided with a plurality of nozzle openings 42 arranged when the plate is viewed in plan in groups of three which form an equilateral triangle which is slightly askew from the sheet travel direction indicated by the arrow applied to FIGURE 5. Each nozzle opening 42
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5 is defined by an inwardly flared throat portion 43, and it has been found that this flared configuration reduces orifice losses and permits high velocity jets of air to operate to scrub away the surface film of saturated moisture vapor traveling with the paper web W. Further, the flared nozzles promote a cyclonic turbulence between the air jets issuing from the openings 42, this turbulence being indicated generally in the directions of the arrows applied to FIGURE 6. Experience has demonstrated that the most desirable results are obtained by relatively close control over the diameter of the openings 42, measured between the points a and b, and the ratio of area of the openings 42 to total area of the plate 29. Specifically, the desirable range of diameters of the openings 42 is between 14 and 58 inch, with an optimum diameter of 8% inch at present preferred, and a ratio of hole or open area to total area of between 1 and 3, and most preferably 1.5% in work performed to date. The thickness of the perforated plate 29 is presently preferred to be 1/8 inch, and the holes or openings 42 therein may be either extruded or drilled, the latter technique providing a plate having the advantage of better strength and rigidity. The preferred spacing of the body portion of the plate 29 from the surface of the web W traveling about the drying cylinder 11c is such that the hole diameter and ratio of hole area to total area are within the suggested limits. This spacing appears at present to provide optimum heat transfer and drying rate in accordance with the equation

\[ h = C \alpha P \]

where:
- \( h \) = heat transfer coefficient in B.t.u. per hour per square foot per degree Fahrenheit
- \( C \) = coefficient depending upon hole size and spacing
- \( P \) = the pumping power required to deliver the air, and
- \( n \) = exponent approximately equal to 0.25

Pursuing the above equation in work performed to date, it has been found that coefficient \( C \) reaches a maximum value when the perforated plate 29 is one inch from the web W, and when the hole diameter is 8% inch and the open area is 1.5% of total area. The desired transverse width of the plenum chambers 23a, 26a and 27a is one foot which provides an equivalent width along the paper web W being dried. When the transverse partitions 28 are spaced one foot each from other, the air supplied to the plenum chambers is at about 400°F. and the open area of the holes 42 is 25%, then each plenum chamber 23a, 26a and 27a has a total drying area of 6.3 square feet per foot of width at an air supply of 1890 cubic feet per minute per foot of width, based upon 15,000 feet per minute maximum velocity. Under the exemplary conditions stated, the drying will be about 35 pounds of water per foot of width per hour at 2,000 feet of web per minute. This amounts to about 35% of a sheet weight of approximately 30 lbs. per ream, and it may be seen therefrom that by the moisture control means 17 of this invention, 3% variations in the moisture level can be leveled out with only a single control means 17 located in the manner of FIGURE 1. It is, of course, appreciated that other moisture control units may be utilized should it be required to control larger variations in moisture content, although such variations are rather infrequent. Further, the use of two nozzles would normally be indicated when working with 2000 f.g.m. newsprint.

In particular applications, it may be desired to control the drying area along a width less than the preferred one foot spacing of the transverse partitions 28. For this purpose, the partitions may be arranged for transverse movement, and an exemplary structural arrangement for this purpose is shown in FIGURE 4. A plenum or drying head 44 similar to the plenum 26 and having a perforated plate 29 forming the bottom wall thereof has a baffle member 45 extending transversely thereacross and spaced inwardly of a top wall 46 of the plenum 44. The baffle member 45 is parallel to the perforated plate 29 and the undersurface thereof is slidable engaged by transverse partition members 47 threaded in opposite end walls 49 and 50 of the plenum 44. The threaded rod 48 may be rotated under action of a hand crank 51 to move the partition members 47 in a transversely adjustable direction so that heated air from a connecting conduit 52 is impinged against the moving web along a transverse width less than the suggested one foot section. The partition members 47 may be moved transversely under action of motor means, and it is, of course, appreciated that the adjustment means may take forms other than that specifically disclosed in FIGURE 4.

As above described, the web moisture profile control means 17 of this invention is provided with transverse partitions 28 in the plenums 23, 26 and 27, and damper means 30 in the conduits 22 serving each plenum chamber 23a, 26a and 27a in the plenums. By this nozzle arrangement, utilizing the perforated plates 29 and the fan and blower structure of FIGURE 2, particular portions along the transverse width of the web W are impinged by high velocity and high temperature air to scrub away the saturated vapor film and improve heat transfer thereby in selectable zones to permit accelerated drying in said zones. However, it is also within the contemplation of this invention that the transverse partitions 28 or 47 may be eliminated and the damper means 30 omitted so that uniform volumes of heated air are admitted to each of the plenums 23, 26 and 27. In the latter mentioned arrangement, the air supplied is controlled at a relatively higher humidity, and thereby advantage is taken of the relationships between the equilibrium moisture content of the web and the surrounding vapor conditions of pressure and temperature. This may be shown by the following equation illustrating that the drying rate approaches zero at some definite moisture level above zero, depending upon the temperature of the air and the vapor pressure of the moisture present in the air. This equation is:

\[
e = \frac{h(T_{sat} - T_{sheet})}{h_{le}} = K(P_v\text{ sheet} - P_v* - P_v\text{ air})\]

in which:
- \( e \) = evaporating rate in lbs. per hr. per sq. ft.
- \( h = \) heat transfer coefficient, air to sheet, in B.t.u. per hr. per sq. ft., per degree Fahrenheit
- \( K = \) evaporation constant for hood (lies in the range 1-10)
- \( P_v\text{ sheet} = \) vapor pressure (saturation) corresponding to sheet temperature
- \( P_v = \) a fictitious retard parametric pressure due to the water bonding forces in dry sheets
- \( h_{le} = \) latent heat of evaporation, B.t.u. per lb.

The preferred arrangement, however, employs the separating partitions to sectionalize the hood for zone drying control whereby the paper machine operator, upon detecting moisture streaks in the web, may remotely control the supply of heated air to particular plenum chambers so as to provide in this manner a conformity of moisture content which represented in the plot of moisture profile shows acceptably small irregularities. In either arrangement, however, the hood 17 incorporates in the plenums thereof perforated plates 29 having the nozzle hole diameter and open area to total area relations described, as well as the fan and blower arrangement of FIGURE 2 which uses a higher pressure differential as well as slightly sub-atmospheric pressure in the exhaust system thereof to permit maximum utilization of
the heat supplied and limiting the fan horsepower to an economic level.

Various modifications may be effected in the structures and procedures herein disclosed without departing from the novel concepts of the present invention.

We claim as our invention:
1. In a drier particularly adapted to dry a fibrous web of material and in combination with a rotatable drying drum having a web traveling thereabout, a hood extending about a portion of the circumference of the drying drum, at least one drying head in said hood having a bottom wall generally conforming to said drying drum and the web traveling thereabout and having a plurality of air impingement nozzles leading therethrough, a plurality of parallel spaced baffles within said drying head and conforming to and extending along said bottom wall in the direction of rotation of said drying drum and dividing said drying head into a plurality of adjacent plenum chambers, an air supply duct, individual conduits leading from said air supply duct to said plenum chambers, means for supplying heated air to said air supply duct and withdrawing spent air from said hood, valve means in said conduits operable to control the distribution of air across the width of the web, and means operable to vary the spacing of said baffles along said bottom wall at the selection of the operator of the dryer.

2. In a drier particularly adapted to dry a fibrous web of material and in combination with a rotatable drying drum having a web traveling thereabout, a hood extending about a portion of the circumference of the drying drum, at least one drying head in said hood having a bottom wall generally conforming to said drying drum and the web traveling thereabout and having a plurality of air impingement nozzles leading therethrough, a plurality of parallel spaced baffles within said drying head and conforming to and extending along said bottom wall in the direction of rotation of said drying drum and dividing said drying head into a plurality of adjacent plenum chambers, an air supply duct, individual conduits leading from said air supply duct to said plenum chambers, means for supplying heated air to said air supply duct and withdrawing spent air from said hood, valve means in said conduits operable to control the distribution of air across the width of the web, and means operable to vary the spacing of said baffles along said bottom wall and the width of the adjacent plenum chambers at the selection of the operator of the dryer, comprising a shaft extending across said drying head through said baffles and having threaded engagement with said baffles for moving said baffles along said bottom wall upon rotation of said shaft.

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