Fig. 4

Fig. 5

Fig. 6

Fig. 7

Fig. 8
ABSTRACT OF THE DISCLOSURE

A rotary cylinder dryer is disclosed which has an improved condensate removal system which makes possible the drying of webs at even higher speeds than heretofore attainable with increased drying uniformity and with no increase in steam requirements. Thus, a particular relationship disclosed between structural elements of the dryer which enables the above advantages to be attained. In particular, the radially outermost ends of the removal nozzles are closely spaced from the inside surface of the dryer shell a distance of less than a predetermined maximum spacing of 1/2 inch.

This invention relates to a rotary cylinder dryer and, more particularly, to dryer drums used in paper machines of the type normally referred to as "Yankee" dryers, and to an improved condensate removal system for use thereon.

Traditional Yankee dryers generally consists of a cylindrical shell, spaced heads extending radially across the shell to close the open ends thereof, journals for rotatably carrying the shell, and means for introducing steam into the interior of the shell and for withdrawing condensate therefrom.

In the prior art paper machine Yankee dryers, steam is admitted to the interior of the dryer and is in contact with the entire interior surface of the dryer shell. It is intended that at least the steam adjacent the inner surface of the shell have a uniform temperature throughout so that, ultimately, a uniform amount of heat will be conducted through the shell resulting in uniform drying of a paper web arranged in partial wrapping engagement with the outer surface of the dryer shell. In attempts to attain this end, elaborate arrangements have been devised to insure a relatively uniform system of steam supply and steam withdrawal. In addition, a large variety of steam supply nozzles and removal nozzles have been devised to accomplish more uniform emission of steam into the dryer chamber and to accomplish a more rapid and more uniformly thorough removal of condensate from the inner surface of the dryer shell.

To fully appreciate the significance of the invention and the degree of advance in the drying art, one must be aware of the limiting factors involved in rotary drum dryers. The basic drying ability of a drum dryer is measured by the total heat transferred to the outside surface of the dryer shell per unit of time. In large measure, this quantity of heat transferred is determined by the temperature of the steam adjacent the inner surface of the shell and the thickness of the shell and condensate layer thereon. Due to fairly rigid boiler codes controlling the design and size of pressure vessels, the lower limit of shell thickness and upper limit of steam pressure and temperature is easily reached.

However, there is opportunity for improvement in condensate removal systems which reduce the thickness of the relatively insulating condensate layer from the inside surface of the dryer shell. There is also opportunity for improving the quality of the drying process so as to prevent defects being created in the paper webs being dried due to "hot spots" in the dryer shell and uneven heat transfer.

The present invention relates to improvements in both of the above areas and, furthermore, surprisingly accomplishes these improvements while utilizing substantially the same steam volume as before and, in some instances, even less than before. Even more surprising is the fact that a web can be dried under the above improved conditions at a slightly higher web speed than previously experienced. It can be seen that all of these advances in quality and output are important and especially so in a business where machines require such a large capital investment and operate substantially continuously and at the highest capacity possible.

It is well known that the layer of condensate upon the shell is often not uniform in coverage and thickness, and therefore, differentially insulates portions of the dryer shell, preventing optimum and uniform heat transfer from the steam to the outer surface of the shell. This results in uneven drying of the paper web upon the shell and the creation of noticeable hot spots on the shell surface which mark and physically degrade the paper web. In other instances, cold spots are created in the surface of the dryer shell between hotter areas, and the resulting paper web will have damp spots left in it where the paper web overlying the cold spots was insufficiently dried.

However, in spite of all of the elaborate condensate removal systems and steam supply nozzle designs devised, considerable difficulty has been experienced in achieving uniform heat transfer and drying of a paper web. These difficulties have become more pronounced with the increased speeds at which dryers have been operated in order to achieve optimum production under present paper manufacturing conditions and processes.

In view of the difficulties and shortcomings of prior Yankee dryers and condensate removal systems therein, it was completely unexpected and surprising to discover a new and improved Yankee dryer construction and associated condensate removal system which not only reduces or eliminates the problems experienced in the prior art but makes possible the commercial use of a Yankee dryer at even higher speed than heretofore attainable. The invention provides a Yankee dryer construction incorporating a condensate removal system construction according to a particular relationship between various elements of the Yankee dryer, which relationship appears to enable the new and improved results to be obtained.

It is believed that although uniform distribution of steam supply nozzles and condensate removal nozzles was rather elaborately provided for in the prior art drying systems, no provision was made or account was taken of the velocity of the steam in the areas adjacent to the inner surface of the dryer shell. It is a well known principle of thermodynamics that maximum heat transfer from a fluid medium to a solid will be effected at the point where the fluid medium passes over the solid with the highest velocity. In most prior art Yankee dryer designs, this area appears to be in the region adjacent to the removal nozzles or, where steam supply nozzles are positioned adjacent the inner surface of the dryer, in regions adjacent those nozzles.

The present invention involves the application of the principle that to achieve uniform drying, the areas of the inside surface of the dryer shell in which substantial differential steam velocity is experienced must be reduced to fall within a certain critical relationship with other design parameters of a dryer shell.

Although the present invention removes condensate from the inner surface of the shell generally in the conventional manner, that is, by sweeping it toward and
into removal nozzles by steam flow, the removal nozzles of the invention are designed and constructed and positioned relative to the inner surface of the dryer shell in a particular manner. Thus, their design parameters fall within a certain critical relationship relative to their distance from the inner surface of the shell and the thickness of the shell, whereupon the advantageous features of the invention are achieved.

The critical elements of the design is the outside diameter of that portion of the removal nozzle most adjacent to the inner surface of the dryer shell. Most condensate removal nozzles employed in the prior art have been arranged in a somewhat scoop-like or broad fashion so that the condensate residing on the inner surface of the shell would be gradually swept toward and into the nozzle by means of the velocity of the steam supplied to the dryer chamber and exiting through the removal nozzles. It is now apparent that by employing such removal nozzles having flared outward ends, the steam was caused to move at a relatively high velocity peripherally inwardly from all sides of an area on the dryer shell directly radially outward from the outer end of the nozzle. Accordingly, greater heat transfer was effected in these areas and, hence, resulted in propagation of a higher temperature region through the dryer shell creating a hot spot on the surface of the shell and causing diffusion of the steam. In accordance with the invention, the outer cross-sectional major axis or diametric measurement of the radially outermost end of the removal nozzles has a predetermined relationship to the thickness of the dryer shell so that the area of the inner surface of the dryer shell directly radially outward from the outer end of each removal nozzle is of restricted size. These areas represent the regions where the velocity of the steam is substantially differently increased from other portions of the dryer. By limiting the size of these areas, the overheated portions or regions of the dryer shell into which a greater amount of heat is transferred due to increased steam velocity are reduced or eliminated toward the outer surface of the shell due to the conduction of excess heat into adjacent portions or areas of the dryer shell.

Another feature of the invention is the distribution of removal nozzles within the dryer chamber. It is believed that the use of more closely spaced nozzles in dryers according to the invention is one factor which improves dryer efficiency and uniformity of operation. Thus, the increased removal nozzle concentration, both axially and circumferentially, not only reduces the thickness of the condensate layer overall, but also ensures a more uniformly thick condensate layer. This is due to the removal action of many relatively small cross-sectional area removal nozzles rather than of fewer relatively large cross-sectional area removal nozzles.

Additional objects and advantages of the invention will become apparent from the following detailed description of preferred embodiments thereof, when read in conjunction with the accompanying drawings, in which:

**FIGURE 1** is an elevation view of a dryer of the invention.

**FIGURE 2** is a sectional view of the dryer shown in **FIGURE 1**, taken along lines 2—2 of **FIGURE 1**.

**FIGURE 3** is a greatly enlarged sectional view of the header support means taken along line 3—3 of **FIGURE 1**.

**FIGURE 4** is a greatly enlarged sectional view of a typical condensate removal nozzle constructed and arranged on a dryer shell in accordance with the invention and illustrating some of the relationship involved.

**FIGURE 5** is a greatly enlarged sectional view of a relatively conventional condensate removal nozzle and a portion of a dryer shell, schematically illustrating the manner in which isothermals propagate through the shell with this arrangement.

**FIGURE 6** is a greatly enlarged sectional view of a condensate removal nozzle of the invention and a portion of a dryer shell, schematically illustrating the manner in which isothermals propagate through the shell with this arrangement, and

**FIGURE 7** and **FIGURE 8** are greatly enlarged sectional views of alternative arrangements of condensate removal nozzles and headers relative to a dryer shell in accordance with the invention.

Referring to **FIGURE 1** of the drawings, there is shown a dryer drum 10 of the invention, only the lower half being shown in section and only one header unit and associated nozzles being shown for simplification of description of the instant invention. The dryer drum 10 includes a cylindrical shell 11 having open ends closed by annular heads 12 and 13, secured to the ends of the shell 11, as by bolts as is well known, and extending radially across the ends of the shell 11. The shell 11 and the spaced apart heads 12 and 13 define an interior chamber 14 within the dryer 10.

Journals 16 and 17 are attached to the heads 12 and 13 respectively, and extend axially outwardly therefrom to be received by suitable bearings (not shown) for rotatably mounting the dryer drum 10. In the embodiment shown, each of the journals 16 and 17 is provided with an axial bore 18 and 19, respectively, which extends into the chamber 14 through the heads 12 and 13 of the dryer drum 10. A source of steam (not shown) is connected by means of a conduit 20 to the axial bore 18 within journal 16 which extends through head 12 and opens into the chamber 14 allowing the flow of steam into the dryer chamber. It will be apparent that many types and arrangements of steam supply nozzles could be used to accomplish the function of inserting steam into the dryer chamber with varying effects and degrees of success, largely unimportant to the instant invention.

A header 22, comprising an elongate hollow pipe closed at both ends adjacent the heads 12 and 13 of the dryer drum 10 is disposed adjacent to but spaced from the outer periphery of the chamber 14 defined by the inner surface of cylindrical shell 11. Thus, the header 22 is slightly spaced radially inwardly from the inner surface of the cylindrical shell and is substantially parallel to the cylindrical axis of the dryer drum 10. The header 22 has a plurality of removal nozzles 23 opening into its interior and extending from header 22 to a position less remotely spaced from the inside surface of the cylindrical shell 11. The interior of the header 22 is connected by means of a conduit 24 to the axial bore 19 of an inwardly extending end of the journal 17 passing through the head 13 of the dryer drum 10. In this manner the chamber 14 is connected by means of the removal nozzles 23, header 22, conduit 24 and inwardly extending journal 17 to a point exterior of the chamber 14 and the dryer shell 11 so as to allow outward fluid flow of condensate and steam from within the chamber 14 of the dryer drum 10.

Although only one such header 22 and conduit 24 have been shown in **FIGURE 1** for purposes of clarity and simplification, it should be clearly understood the use of a plurality of such headers 22 spaced in a manner to be subsequently described and each being connected to the exterior by a conduit 24 is contemplated in dryers according to the invention. Furthermore, more than one conduit 24 can be employed for each header 22 and different arrangements of removal nozzles 23 can be utilized successfully. A typical arrangement of removal nozzles 23, headers 22 and conduits 24, etc., is shown more clearly by **FIGURE 2**.

The header could be of a substantially different design but primarily serves as a primary collection chamber into which a group of removal nozzles feed condensate and steam. As shown in **FIGURES 7** and **8**, a single header could be used as the collection chamber for several circumferentially spaced elongate groups of nozzles.
The nozzles may be arranged in axial alignment with each other in each elongate group, as shown in FIGURES 1 and 2. Alternatively, the nozzles may be arranged in elongate groups extending axially across the dryer, but not in axial alignment.

The nozzles 23 comprise cylindrical tubes but the term "tubes" is intended to include any duct member or conduit which will serve to convey steam and condensate from the surface to header 22. The cross-section may be any configuration and need not be necessarily circular. Orientation should be clearly understood at this juncture. Part of the invention stems from the discovery and realization that maximum heat transfer through the dryer shell 11 from a given steam flow and steam temperature and pressure depends upon minimizing the thickness of the condensate layer on the inner surface of the shell 11 to the greatest extent possible at all points. It has been discovered that prior art dryers did not fully appreciate this discovery and that, in any event, their constructions certainly did not maximize heat transfer, especially with regard to the degree of condensate removal or uniformity. The spacing of removal nozzles prior to this invention was generally too great resulting in large areas on the inside surface of the dryer shells where relatively thick layers of condensate were built up and maintained. This spacing was felt necessary to accommodate a relatively small total number of removal nozzles per dryer of a given size compared to the number employed in dryers of the invention. Correspondingly, each of the removal nozzles employed had a relatively large inside diameter adjacent the radially outermost ends thereof to accommodate the relatively large area of the total steam and condensate flow required to be carried by the nozzles.

Dry drum dryers of the invention, on the contrary, employ a much greater number of removal nozzles 23, each having a smaller inside diameter, thereby balancing and providing the capacity to handle the total steam flow of the dryer. In addition, these smaller nozzles are spaced much more closely together, in accordance with the invention, to more evenly control and more closely restrict the thickness of the condensate layer. The use of such nozzles and such a distribution pattern adjacent a cylindrical dryer shell has surprisingly resulted in the additional benefit and advantage of reducing or eliminating hot spots on the outside surface of the dryer shell.

In accordance with the invention, the removal nozzles 23 should be spaced apart from each other in an axial direction across the dryer shell by a distance of no more than 12 inches. The more preferred spacing is a distance of no more than 6 inches, while the most preferred spacing is a distance of no more than 3 inches. These figures are based upon a dryer drum having a diameter of up to 10 feet, but would be equally applicable to larger diameter dryers.

The nozzles 23 are arranged in rows, and aligned along the length of each header. However, they may be staggered from header 22 to header 22 or may be arranged differently, but preferably are arranged in spaced axially aligned elongate groups across the cylindrical dryer drum.

The headers 22 also have a desired circumferential spacing from each other around the inner periphery of the shell 11 and the chamber 14. Thus, the headers should be spaced apart from each other by a distance of no more than 36 inches. The more preferred spacing is a distance of no more than 24 inches, while the most preferred spacing is a distance of no more than 18 inches.

An additional feature of the invention is the spacing of the radially outermost open ends 25 of the removal nozzles 23 from the inner surface of the dryer shell 11. FIGURE 3 illustrates the manner in which headers 22 are supported on the dryer shell 11 and adjustably moved toward or away from the inner surface thereof. A plurality of internally threaded bosses 27 depend radially outwardly from the sidewall of each cylindrical header 22 along an axially aligned segment of its periphery. A threaded support member 28 is threaded into each boss 27. This is accomplished by a lock nut 29 for maintaining it in the finally selected position. The opposite end of member 28 extends into contact with a support boss 30 on the inner surface of the shell 11 to firmly position the header 22 within the chamber.

Flexibility of conduits 24 allows radial outward and inward movement of headers 22 upon adjustment and rotation of support member 28. This is facilitated by arranging conduits 24, between headers 22 and journal 17, in a manner other than radial and perpendicular to the axis of the dryer drum 10 and journal 17 as shown in FIGURES 1 and 2. Centrifugal force tends to hold headers 22 in position in contact with the inner surface of shell 11 during rotation of dryer drum 10. In some instances, the ends of headers 22 are slidably attached to and supported by heads 12 and 13 to insure support of the headers 22 when rotation of the dryer drum 10 ceases.

In order to minimize the thickness of the condensate layer on the inner surface of the cylindrical shell 11, in accordance with the invention the radially outermost open ends 25 of removal nozzles 23 are spaced from the inner surface of shell 11 by a lesser distance than has been the case in dryers of the prior art. Thus, in order to sweep condensate from the inner surface of shell 11 and carry it radially inward through the removal nozzles 23, the cross-sectional area of the passage through the removal nozzles should preferably be greater than the area represented by the outside circumference of the radially outermost end 25 of the removal nozzle 23 multiplied by the distance between the surface of a condensate layer directly outward from such outermost end 25. That area represents the minimum area through which the steam and condensate are forced to pass and, therefore, represents the area where the greatest velocity is attained by the steam causing it to pick up condensate.

FIGURE 4 is an illustrative cross-sectional view looking along the axis of the invention and illustrating the above principle and the manner in which it is advantageously applied to a dryer of the invention. Thus, a condensate layer 32 is shown as it appears on the inner surface of the cylindrical shell 11. The shell thickness is indicated by the reference character T while the thickness of the condensate layer directly beneath the outermost end 25 of removal nozzle 23 is indicated by t. The inside diameter of removal nozzle 23 is represented by d while the outside diameter of the outermost end 25 of removal nozzle 23 is indicated by D. The distance between the outermost end 25 of removal nozzle 23 and the surface of condensate layer 32 directly outwardly outward from the nozzle is represented by s. The total distance between the inner surface of the shell 11 and the outermost end 25 of removal nozzle 23 is represented by S.

From the above diagram it is now possible to accurately describe the desired dimensions and spacing of the nozzles relative to the thickness and inner surface of the shell 11. It has been found that in a dryer having nozzles spaced apart from each other, as described above, that S should have a value of less than ½ inch and preferably ⅛ inch or even less. In this instance, it can be seen that the value of t will be reduced to a minimum and thus, in the area of shell 11 radially outward from nozzles 23, the level of the condensate will be reduced to a minimum causing a flow of condensate toward those areas from the regions of condensate on the dryer shell having minimal thickness.

It will also be noted that the cross-sectional area of the nozzle, equal to $\pi d^2/4$, should generally be greater than the value of the circumference of the nozzle $\pi D$, multiplied by $s$. This insures that the space where the greatest steam velocity occurs is between the outermost end 25 of the nozzle 23 and the inner surface of shell 11. Because of this velocity, the steam picks up condensate.
Another preferred relationship, which should be maintained in a dryer of the invention, involves the relationship of the area on the inner surface of shell 11 which is directly beneath the outer end 25 of each removal nozzle 23, and the thickness of the shell T. It has been found that this relationship can be expressed as a ratio of D to T and should be between about 1:4 and about 1:10. Thus, the greater the value of T is in proportion to D, the greater is the tendency for a higher temperature area on the inner surface of the dryer shell to dissipate and distribute itself in the dryer shell before propagating through the shell to the outer surface thereof and forming a hot spot. The temperature difference between any hot spot which does form and the adjacent portion of the dryer surface is much less. Also, the area of any hot spot which does occur is much smaller. The preferred ratio of D to T is between about 1:6 and about 1:10. The significance of this ratio can be more clearly seen by referring to FIGURES 5 and 6.

FIGURE 5 is a greatly enlarged sectional view of a condensate removal nozzle of conventional size relative to the thickness of shell 11 and illustrates the manner in which heat is propagated or transferred through the shell 11. In the embodiment shown, the ratio of D to T is approximately 1:2 and the lines 33, representing isothermal lines within the shell 11, illustrate the formation of a hot spot on the exterior surface of shell 11. It can be seen that, assuming a temperature differential between the inside surface 34 and the outside surface 35 of shell 11 of approximately 60° F., each of the isothermal lines represent a temperature difference of 10° F. Accordingly, FIGURE 5 indicates the formation of hot spots which could create temperature differentials in approximately circular areas having a diameter equal to or greater than D of 30° F. or more. As described above, such hot spots cause degradation of the paper being dried on the dryer.

FIGURE 6 illustrates a similar diagrammatic view incorporating a removal nozzle 23 spaced closer to the inner surface 38 of shell 11. The relationship of D to T in this diagram is approximately 1:6 and a similar temperature difference is maintained generally between inner surface 38 and the outer surface 39. An analysis of the isothermal lines 40, again representing 10° F. temperature differentials, illustrates the relatively small area of the hot spot created on the outer surface 39 of shell 11. Additionally, and even more significantly, it should be noted that the hot spot in this arrangement not only has a greatly reduced diameter but, furthermore, has a temperature which does not exceed the temperature of other portions of outer surface 39 by more than 10° F. Because of the relatively short length of time in which a given portion of a paper web is in contact with the outer surface 39 during the normal drying operation, a hot spot having this size and this relatively small temperature differential is normally insufficient to degrade the paper web or to mark its surface. Thus, assuming the web is passing over a dryer having a diameter of approximately 10 feet at a speed of approximately 2000 feet per minute, the web is not in contact with the surface of the dryer for much more than about 0.5 second.

FIGURES 7 and 8 illustrate different arrangements of nozzles in accordance with the invention. Thus, in some instances, it may be desirable to employ a single header for a plurality of rows or nozzles extending across the surface of a dryer, especially where alignment of those nozzles is critical and where provisions for regulating spacing of the ends of the nozzles from the inner surface of the dryer shell are rather elaborate. It also provides a means for obtaining increased nozzle distribution and concentration without unduly crowding the dryer chamber with headers or other nozzle supporting equipment. This arrangement provides a means to limit the length of circumferential path which condensate must follow to reach a removal nozzle and, accordingly, results in a reduction in condensate layer thickness.

In each of the above-described embodiments of the invention, it should be pointed out that certain parameters which must be held constant in any type of dryer application have not been altered. For example, as pointed out earlier the thickness of the dryer shell is considered to be a fixed dimension due to the regulations controlling design of boilers or other pressure vessels. Similarly, the volume of steam supplied to the dryer has not been varied, nor has the temperature of steam supplied to the dryer been altered. The invention achieves a superior degree of condensate removal and a superior uniformity of heat transfer through the dryer which greatly increase the dryer performance without varying the above constant parameters.

It is recognized that numerous changes and modifications can be made in the above-described embodiments without departing from the spirit and scope of the invention.

What we claim is:

1. A dryer of the rotary-cylinder type, a cylindrical shell, a head closing each end of said shell, said shell and said heads defining a chamber, means for supplying steam into said chamber through one of said heads, a plurality of spaced apart removal nozzles disposed adjacent the inside surface of said shell, said tubes having a circular cross-section and an inside diameter no greater than about 3/8 inch at the radially outermost end portions thereof, the outermost open ends of said tubes being spaced radially inwardly from the inner surface of said shell by a distance no greater than about 3/8 inch and being spaced apart from each other in an axial direction across said dryer shell by a distance of no more than about 3 inches, and means connecting said removal nozzles with the exterior of said shell through one of said heads for removing steam and condensate from said chamber, including a plurality of headers extending longitudinally across the axial width of said dryer and disposed about the periphery of said chamber in positions spaced from and adjacent to the inner surface of said dryer shell, said headers being arranged to terminate within said headers, said headers being circumferentially spaced from each other by a distance of no more than about 20 inches.

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