Jan. 8, 1963 K. B. LATIMER ETAL 3,071,869

WEB DRYING APPARATUS

Filed Oct. 16, 1958 3 Sheets-Sheet 1

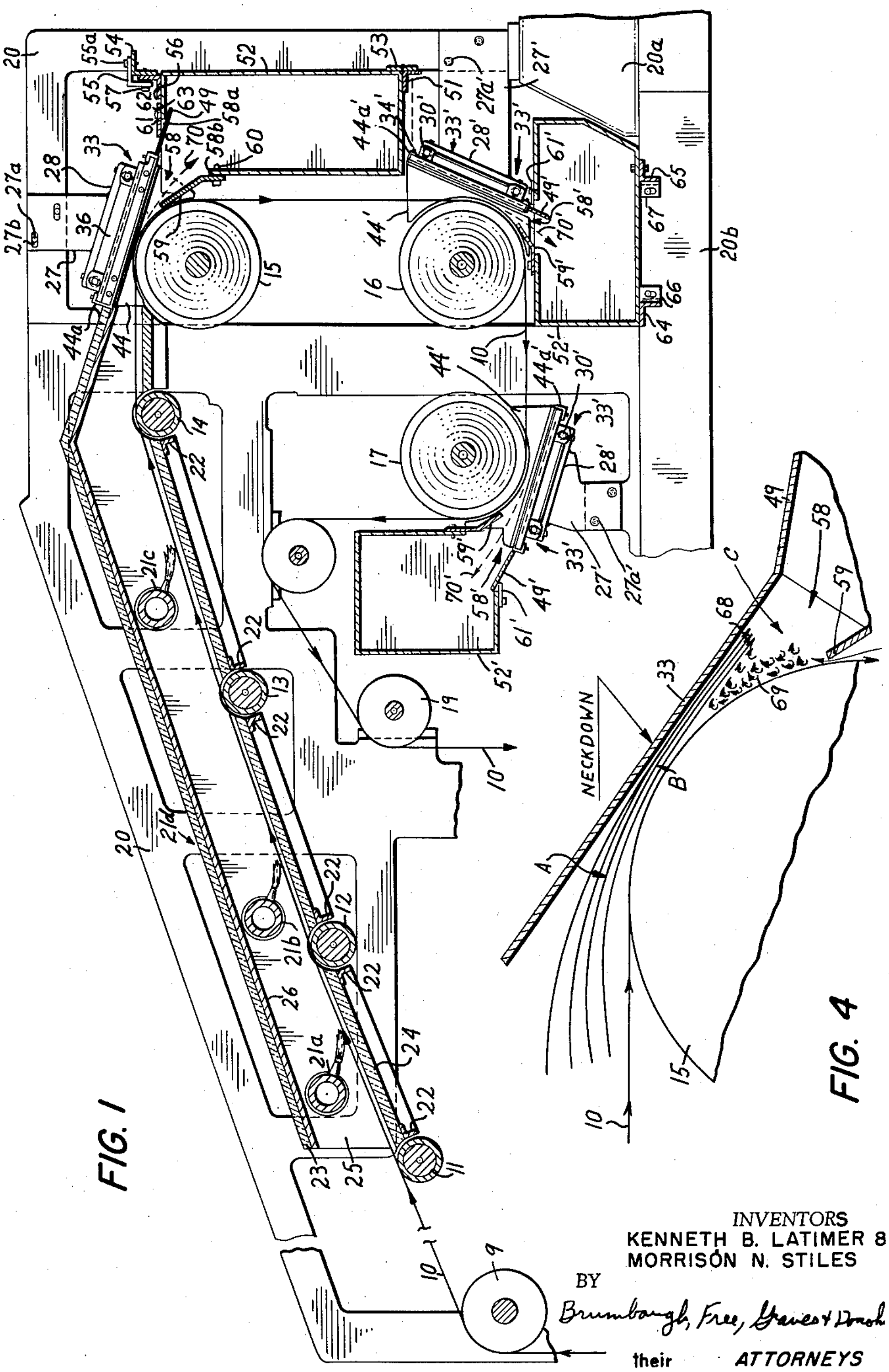

FIG. 1

FIG. 4

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WEB DRYING APPARATUS

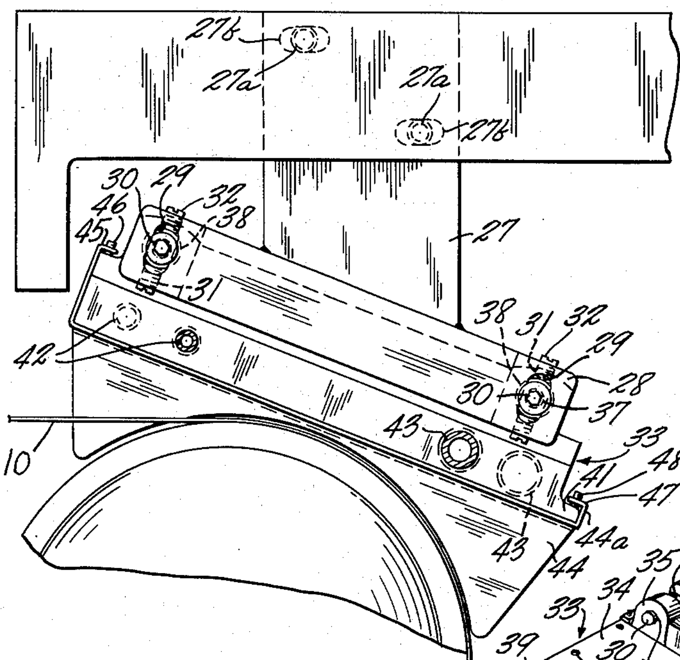

FIG. 3.

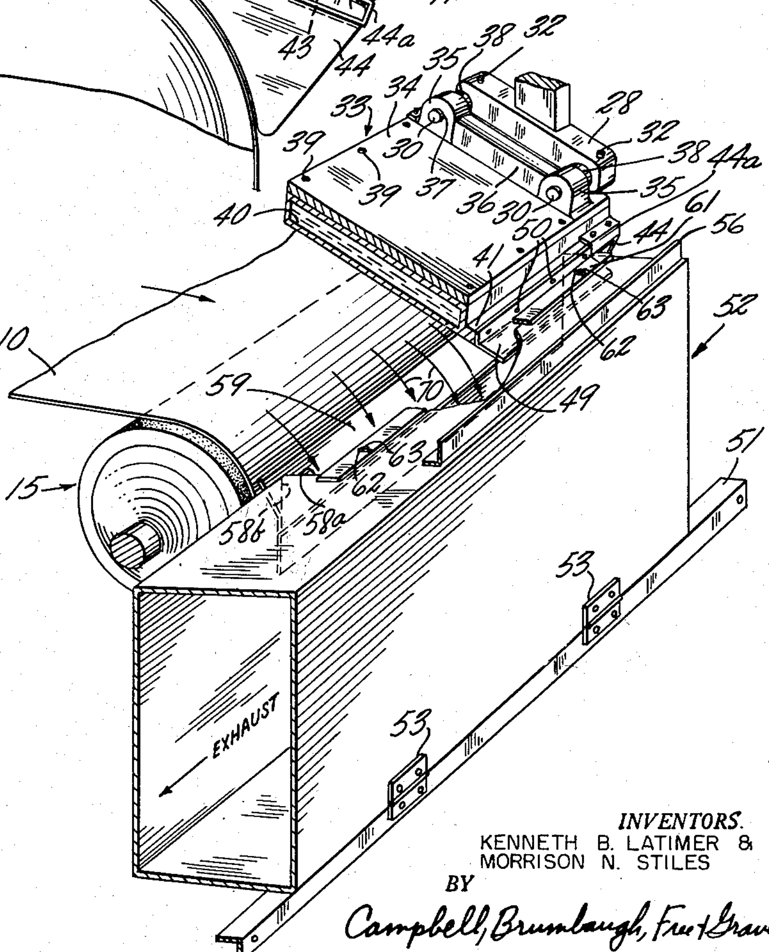

FIG. 2.

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WEB DRYING APPARATUS

Filed Oct. 16, 1958 3 Sheets-Sheet 3

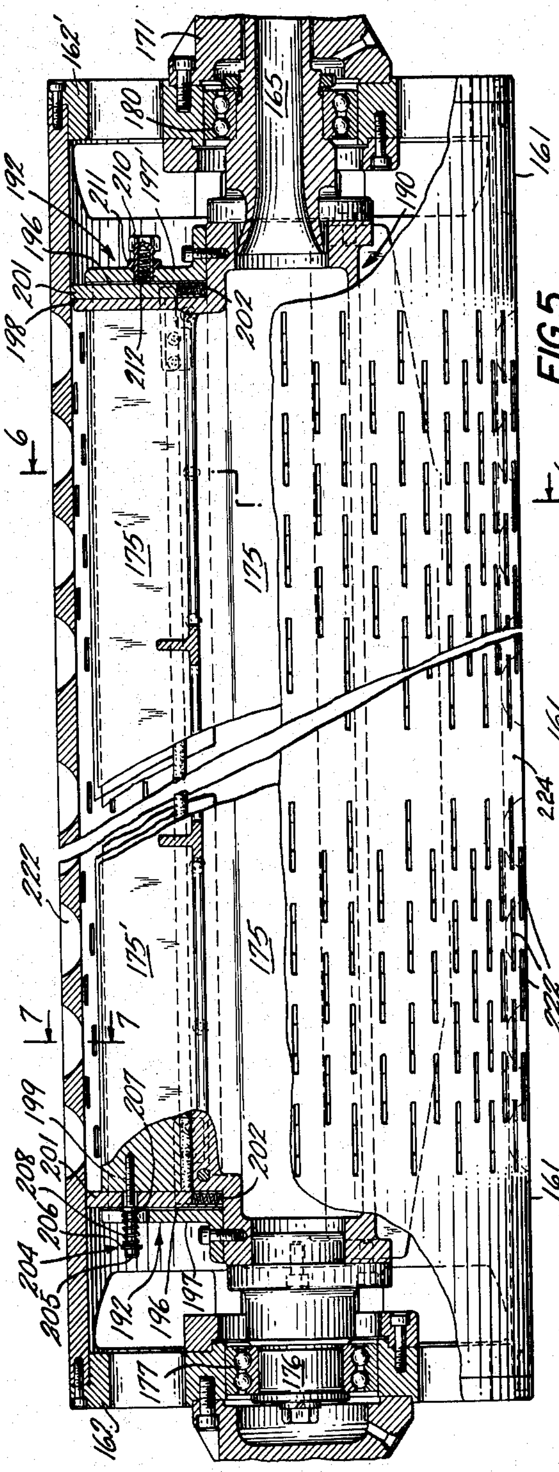

FIG.5.

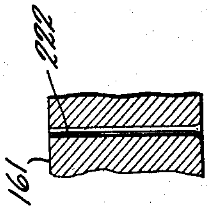

FIG.7.

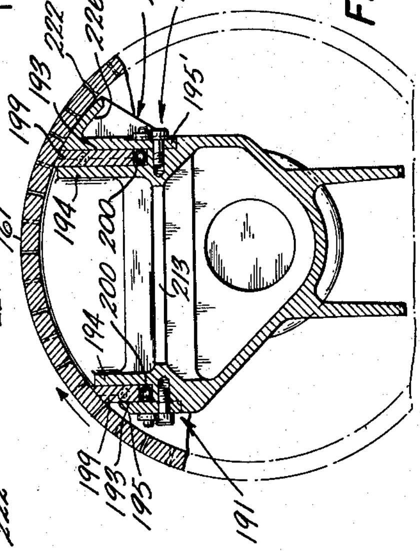

FIG.6.

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WEB DRYING APPARATUS

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Filed Oct. 16, 1958, Ser. No. 767,587
18 Claims. (Cl. 34—114)

This invention relates to methods and apparatus for drying rapidly moving webs.

This is a continuation-in-part of our copending application Serial No. 491,059, filed February 28, 1955 for "Web Drying Methods and Apparatus."

Difficulties have been encountered in the printing, paper, motion pictures and textile fields in connection with the rapid drying of a continuously moving web, particularly when such web travels at speeds in excess of 1000 feet per minute. At lower speeds, the use of heat drying has satisfied many drying requirements but as the speed of the web increases, the application of heat thereto must be proportionately increased to afford effective drying. However, such a heat increase often results in a scorched web, or alternatively, if this is to be avoided, a far longer run of the web for drying purposes than is desirable or, in many instances, possible. In addition, the necessary increase in heat may be so costly as to offset any advantages gained from the higher web speeds.

Considering, for example, the problems encountered in modern high speed printing methods, efficient inking of the rapidly moving web may now be performed up to the limiting speeds of the web material, about 2000 feet per minute. In addition, cutting and folding stations accommodate the rapidly moving web at its other end. Accordingly, such efficient operations on the moving web require greatly accelerated printing ink drying between the inking and the cutting and folding stations.

The factors involved in preventing satisfactory drying of the rapidly moving inked web are, among others, the nature of the solvents employed in the normally used heat-set inks and the phenomena of the boundary layer of air which follows the web. The solvents generally employed in the heat-set inks are kerosene fractions which, accordingly, are relatively high boiling point liquids with low vapor pressures. Therefore, once the solvents are raised out of the ink film on the web, they tend readily and rapidly to condense if not immediately removed therefrom.

Concerning the layer of air, termed the boundary layer, clinging closely to the moving web, such boundary layer exhibits an increasing tenacity against efforts to remove it with increasing speed of the web. This boundary layer, if undisturbed, soon becomes saturated with solvent greatly inhibiting the rate of evaporation from the ink film below it. It will be readily understood that the solution to the drying problem must be concerned with the removal of this solvent laden boundary layer of air.

In discussing removal of the boundary layer of air, it will be understood that such language, while commonly employed in this art, may be misleading. There is always a layer of air at the web surface, the so-called removed boundary layer being a saturated layer of air that is immediately replaced by unsaturated air to aid solvent evaporation.

Attempts have been made to remove the boundary layer from the web by a jet of air directed against the direction of web travel. However, this method has not proven satisfactory since the jet of air, directed against the web, entrains cool air and such cooling effect greatly hinders solvent evaporation. Further, it is almost impossible to get a knifing action with such an air jet because the air issuing from an orifice tends to bell out and rapidly lose its velocity. Also, directed as it must be against the web direction, the jet tends to form eddies adjacent to the web having an unpredictable behavior.

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In view of the above, it will be evident that to provide for the satisfactory drying of a rapidly moving printed web, a significant fraction of the solvent must initially be raised out of the ink film by heat. Subsequently, the solvent laden boundary layer of air clinging to the web must be removed by some means to permit enough solvent to evaporate from the ink film to leave it substantially dry. In addition, some type of system must be provided to exhaust the removed boundary layer of air containing the raised solvent, to preclude condensation of the vapor on the web.

Accordingly, it is an object of the present invention to provide for the effective drying of a moving element carried by a cylindrical surface.

It is another object of the invention to provide for the removal of the solvent laden boundary layer of air clinging to a rapidly moving web.

It is a further object of the invention effectively to dry a rapidly moving inked and heated web by removing the solvent laden boundary layer therefrom.

It is yet another object of the invention to provide a drying station on a rapidly moving web for removing the solvent laden boundary layer of air therefrom.

It is yet a further object of the invention to provide a plurality of drying stations having the above characteristics along a rapidly moving web.

These and further objects of the present invention are accomplished by providing a blade adjacent to and extending longitudinally along a roll carrying a heated rapidly moving web. Convergent and divergent sections at the inlet and outlet sides of the web are formed by the blade. A hood, directly communicating with the convergent section, encloses the web at the initial web drying station.

Means including an exhaust system produces a differential pressure across the blade, between the convergent and divergent sections, to induce air flow between the blade and the roll, in the direction of web movement. The passage configuration thus formed between the blade and web is such as to cause a rapid acceleration of the air flow in the convergent section reaching a maximum velocity at a neckdown point that is sufficient to insure turbulent flow. As the roll curves sharply away from the main path of air flow, complete separation of the clinging solvent-laden turbulent boundary layer of air from the web is induced. Such separated air is removed immediately and permanently from the region of separation by the main flow of high velocity air which carries such solvent-laden air into the exhaust system. A counter flow of air along the web is provided to assist in flowing the solvent-laden air into the exhaust.

A further feature of the invention resides in the provision of vacuum rolls, under the blades if desired, to prevent web flutter due to the turbulence and lift produced by the high velocity air flow by controlling web tautness throughout the drying process.

These and further objects and advantages of the present invention will be more readily understood when the following description is read in connection with the accompanying drawings in which:

FIGURE 1 is a side elevation, partially in section, of apparatus for drying a rapidly moving web constructed in accordance with the present invention;

FIGURE 2 is a view in perspective, partially broken away, of a drying unit employed in the web drier illustrated in FIGURE 1;

FIGURE 3 is a fragmentary side elevation of the apparatus of FIGURE 1 illustrating in some detail the mounting of a blade utilized in such apparatus;

FIGURE 4 is a schematic diagram useful in explaining the principles of operation of the present invention;

FIGURE 5 is a longitudinal section of a vacuum roll that may be used in the drier of FIGURE 1;

FIGURE 6 is a transverse section of the vacuum roll illustrated in FIGURE 5 taken along the view line 6—6 looking in the direction of the arrows; and

FIGURE 7 is an enlarged sectional view of a slot in the vacuum roll of FIGURE 5 taken along the view line 6—6 looking in the direction of the arrows.

Although the present invention will be described in connection with inked paper webs, it will be understood that the drying principles set forth may be equally well applied to other rapidly moving webs or other elements supported by rolls such, for example, as paper, motion picture film, printing plates, textiles and coated material of any nature.

Referring to an illustrative embodiment of the invention with particular reference to FIGURE 1, a rapidly moving web **10**, newly inked at a printing station (not shown), travels in the direction indicated by the arrows over a vacuum roll **9** and rolls **11**, **12**, **13** and **14** to direction shifting rolls **15**, **16** and **17**, and then over rolls **18** and **19**. The rolls **9** and **11** to **19**, inclusive, are supported by any conventional structure (not shown) on the side frames **20** of the web drier. In addition, suitable means (not shown) may be provided for rotating the rolls **9** and **11** to **19** to drive the web **10**, in accordance with conventional practices in this art.

A plurality of gas burners **21*a***, **21*b*** and **21*c*** supported in any desired manner (not shown), are positioned along and extend laterally across the web **10**. Pursuant to established practices, the burners **21*a*** to **21*c***, inclusive, are controlled in accordance with the speed of the moving web **10** to heat it to a predetermined temperature and to preclude scorching thereof.

A hood **21*d***, supported by angle bars **22**, is disposed around the moving web **10** and the gas burners **21*a*** to **21*c***, inclusive, in order to prevent cool air currents from interfering with a planned rise in temperature on the web **10**. The hood **21*d*** is constructed from top, bottom and side pieces **23** to **25**, respectively, formed from heat insulating material. The top **23** and sides **25** may be interiorly lined with a layer of aluminum foil **26**, although this has not proven necessary in many instances.

Upon reaching the end of the hood **21*d***, the rapidly moving web **10** encounters the roll **15** which carries it through a change in direction, shown here as a 90 degree turn.

A pair of brackets **27** are supported from the frames **20**, as best shown in FIGURES 1 and 3, by bolts **27*a*** in slots **27*b***. This permits longitudinal adjustment of the bracket **27** along the frames **20**. Obliquely positioned supporting arms **28** provided with transversely extending slots **29** carrying bolts **30** are welded to the brackets **27**. Threaded openings **31** receiving set screws **32** lead to the extremities of the slots **29**. It will be evident that adjustment of the bolts **30** in the slots **29** may be achieved by suitable rotation of the set screws **32**.

A blade **33**, obliquely suspended immediately above the roll **15**, includes a lateraly extending supporting plate **34** having its ends formed with a pair of busses **35** joined by reinforcing bars **36**. Threaded lateral openings **37** through the busses **35** receive the bolts **30**, which also pass through spacers **38** between the arms **28** and the blade **33**.

Fastened to the supporting plate **34** by a plurality of bolts **39** is a rectangularly shaped hollow chamber **40** formed with a flange **41** on the lower edge thereof, openings **42** and **43** being provided at both ends of the chamber **40**. A medium such as air may be circulated through the openings **42** and **43** to maintain the temperature of the lower surface of the blade **33** at a level precluding condensation thereon of solvent vapors from the web.

Each end of the blade **33** mounts a side shield **44** arcuately shaped to fit the roll **15** closely, as best shown in FIGURE 3, and fastened by suitable means such as brazing or welding to clamping brackets **44*a***. Each of the clamps **44*a*** extends laterally across the bottom of the blade **33** and is secured at one end to the supporting plate **34** by a foot **45** carrying set screws **46**, and at its other end to the flange **41** by a foot **47** carrying set screws **48**. In addition, an L–shaped bar **49**, fastened by bolts or rivets **50** to the flange **41**, provides for a continuation of the lower face of the blade **33** in the direction of web travel.

A plane surface adjacent to the roll **15** is provided by the blade **33**. It will be understood that the term blade as used herein refers to any structure forming an equivalent surface.

Referring to FIGURES 1 and 2, an angle bar **51** fastened to the frames **20** by appropriate structure (not shown) supports a rectangularly shaped exhaust chamber **52** joined thereto by means of hinges **53**. It will be apparent that this construction permits the exhaust chamber **52** to swing back about the angle bar **51**. A pair of angle bars **54** and **55** on the frames **20** are joined by bolts **55*a***. A further angle bar **56**, affixed to the upper edge of the exhaust chamber **52**, is clamped against the bar **54** by bolts **57** on the bar **55**.

The exhaust chamber **52** communicates with ducts (not shown) leading to suitable exhaust fans or pumps. This arrangement permits the pressure in the chamber **52** to be suitably decreased to perform functions explained in detail below.

To form an exhaust mouth **58** in the exhaust chamber **52**, adjacent rectangular portions **58*a*** and **58*b*** are cut from the top and one side thereof adjacent to the roll **15**, such portions extending from one end of the chamber **52** to a position adjacent to one end of the roll **15**. A lower lip **59** for the exhaust mouth **58**, angled toward the roll **15**, is secured by bolts **60** to coincide laterally with the cut away portion **58*b***. To complete the exhaust mouth **58**, the L–shaped piece **49** extends into the cut away portion **58*a***, as shown in FIGURES 1 and 2, and a sealer strip **61**, adjustably mounted by bolts **62** in slots **63** on top of the exhaust chamber **52**, may be positioned to abut the plate **49**.

The roll **15**, the blade **33**, the exhaust chamber **52** and associated mechanism form what will be termed a drying station for the web **10**. It will be understood that any number of stations necessary to dry the rapidly moving web **10** satisfactorily may be employed along its path. In FIGURE 1, a web drying system utilizes three drying stations along the rapidly moving web **10**, the first station being described above, the second station being associated with the roll **16** and the third station with the roll **17**. The web **10**, after leaving the first drying station, encounters the rolls **16** and **17** which carry it through further changes in direction and complete the drying process.

The roll **16** may comprise a conventional water cooled roll in order to initiate cooling of the residual ink film to room temperature, if the ink film is based on thermoplastic resins or other materials requiring such cooling. The roll **17** may comprise a vacuum roll and cooperate with the vacuum roll **9** to insure adequate tensioning of the web **10** under the blades **33** and **33′** to prevent web flutter at the drying stations.

Other suitable tensioning devices may be substituted for the vacuum roll **9** such as a reel or other device exerting drag on the web. If desired, a suitable take-up reel or other device exerting a constant tension on the web **10** downstream of the drying stations may be used to replace the vacuum roll **17**. Since the drying stations associated with the rolls **16** and **17** are similar in many respects to that at the roll **15**, similar elements will be designated by primed reference numerals.

In each of the second and third drying stations, brackets **27′**, secured to the frames **20** by bolts **27*a*′**, are fastened to a blade **33′**, which may be identical to the blade **33** or may lack the chamber **40** as shown. Supporting arms **28'** suitably position a plate **34'** adjacent to the roll by means of bolts **30'**. Side shields **44'**, functioning for the same purpose as the shields **44** but slightly different in configuration due to the position of the blade **33'** with respect to the roll **16** or **17** are secured by means of a clamp **44a'** to the plate **34'**. In addition, an L-shaped plate **49'** effectively extends the face of the plate **34'** into an exhaust mouth **58'**. The exhaust aperture **58'** is further defined by a lower lip **59'** and leads into an exhaust chamber **52'** supported by angle bars **64** and **65** which are joined by angles **66** and **67**, respectively, to lower frame members **20b**, joined by blocks **20a** to the frame **20**. An adjustably mounted sealing strip **61'** abuts the extension plate **49'**. It will be apparent that the elements in the second and third drying stations corresponding to those found in the first station differ therefrom because of mechanical design considerations.

In examining a typical operation of the present invention, it will be helpful to state the nature of the problems involved in drying heat set inks printed on rapidly moving webs. At the outset, it should be understood that it is a simple matter to provide sufficient heat to raise the solvent from the ink film into the air immediately adjacent to the web. However, normal air will not hold the desired quantities of these relatively high boiling point and low vapor pressure solvents. Therefore, heated air is preferably provided along the web and as soon as this air becomes saturated with solvent, it must, if effective drying is to be accomplished, be removed from the vicinity of the web to permit further solvent evaporation. However, prior to the present invention, little success has been experienced in attempting to remove the so-called boundary layer of solvent laden air from a rapidly moving web. This boundary layer clings with great tenacity to the moving web and its saturated condition greatly inhibits the rate of evaporation of solvent from the ink film beneath it. In summary, the solvent saturated boundary layer of air must be removed effectively from the rapidly moving web to permit further drying of the ink and to prevent condensation of the solvent further along the line of web travel.

Examining the diagrammatic drawing of FIGURE 4, the roll **15** is illustrated together with the blade **33** and the exhaust mouth **58**. Before the rapidly moving web **10** engages the roll **15**, it has been heated to vaporize the solvent found in the ink film. The gas mixture pressure in the burners **21a**, **21b** and **21c** will, of course, be increased as the web speed is raised in order to heat the web **10** sufficiently to perform this function. As mentioned above, the solvent vapor will saturate the boundary layer of air clinging to the moving web **10**.

Due primarily to the vacuum found in the exhaust chamber **52**, a high velocity stream of air, identified by the arrows **68**, will flow into a converging section A formed by the blade **33** and a portion of the web **10** supported by the roll **15**. The provision of a constricted portion or throat B, formed by the necking down of the blade **33** to the roll **15**, will greatly accelerate the air stream **68**. The maximum air velocity will be reached in the neckdown B and its magnitude may be controlled by adjustment of the vacuum in the exhaust chamber **52** to insure that Reynolds number for the flow at point B exceeds a critical value established by well known fluid dynamic principles. In one structure embodying the principles of the invention, the critical Reynolds number has been determined to be 5000, and the drier has been operated at 6000 as a safety factor. The boundary layer will accordingly change from laminar to turbulent flow about at point B and thus facilitate its subsequent separation from the web surface when subjected to a sufficiently large pressure drop perpendicular to the web surface.

Turbulence is a function of the quantity known as Reynolds number which is expressed as

$$\text{Reynolds No.} = \frac{V \times L}{v}$$

where:

V=av. stream velocity in ft./sec.

L=representative linear dimension in feet (L is height of neckdown)

v=kinematic viscosity (a temperature and pressure function)

$$v = \frac{3.84\times10^{-3}+1.42\times10^{-5}\times T(°\text{F.})+1.27\times10^{-8}\times T(°\text{F.})^2}{\text{Abs. static pressure (in inches } H_g)}$$

It is apparent from the above formula that turbulence is a function of dimension, air speed, temperature and pressure (which together define the viscosity of the air.) Appropriate steps are taken to control the elements that contribute to the critical Reynolds number to provide turbulence which results in mixing and an attack on the stagnant boundary layer.

Normally, flow above the rapidly moving web **10** is laminar. Any attempt to diffuse solvent through this flow toward an exhaust system is opposed by the strong directional vector of the moving web. Laminar flow opposes mixing—the solvent tends to cling to the sheet, to stagnate in the boundary layer, and by its concentration there, preclude further evaporation from the hot ink film below it. Previous driers have attempted to overcome these problems by pouring in additional energy in the form of heat. But heat is dangerous for webs, expensive, and does little to offset the tendency of laminar flow to re-establish a saturated solvent-bearing layer on the web. Turbulence provides a powerful mixing action so that solvent is distributed uniformly above the web **10**. Such turbulence exists downstream from the neckdown line B to the lip **59** of the exhaust.

From the neckdown line B, the accelerated air stream passes into a divergent section or region C formed by the blade **33** and a portion of the web **10** supported by the roll **15**. In section C, the rapidly moving turbulent air flow **68** tends to follow a linear path along the blade **33** which produces the desired pressure gradient or lifting action which, with the breaking away of the web **10** from this path as it follows the roll **15**, induces separation of the solvent laden turbulent boundary layer of air at the surface of the web **10**. As shown by the small arrows **69** indicating separation in the divergent section C, the solvent laden air in the turbulent area is lifted and enters the main stream of air **68**, which carries it into the exhaust mouth **58**. In other words, separation results in a direct and violent attack on the boundary layer tending to peel it off and move it into the main line of air flow into the exhaust chamber.

In connection with boundary layer separation, the kinetic energy of the main air stream is reduced as it flows into the divergent section C since it encounters a rising pressure gradient. In addition, the kinetic energy of the boundary layer of air at the web surface, which has been at a much lower level than that of the main air stream due to frictional losses, drops to zero. Great shearing stresses are thus set up that induce separation of the solvent laden boundary layer from the web **10** and it is swept up into the main air stream and into the chamber **52**. The magnitude of these stresses is increased by virtue of the turbulent flow set up at the neckdown B and continuing into the divergent section C. In addition, the turbulent flow insures transverse mixing and a thinner boundary layer of air.

Boundary layer separation is initiated on the web surface in a region at which a tangent to the roll **15** makes an angle with the blade **33** exceeding about 3½ degree or, in other words, when the air stream sufficiently exceeds an angle of about 3½ degrees to a tangent to the roll **15** parallel to the blade **33**. Since this angle is determined by the diameter of the roll **15**, initiation of separation in the region C is a function of the roll diameter. Further along the roll **15** separation of the turbulent boundary layer increases until maximum separation is reached at a point at which a tangent to the roll makes an angle of about 35 to 40 degrees with the blade 33. Preferably the lip 59 extends to about such point of maximum separation to remove all of the separated air immediately from the web 10 and direct it into the exhaust chamber 52. The foregoing theoretical explanation should not be considered to limit the present invention to the exact angles set forth since the region at which separation is induced is not critical.

It is preferable to position the blade 33 so that the neckdown B occurs midway of the contact line along the web direction on the roll 15. This is true because the neckdown B is the point of maximum air velocity and therefore, it is also the point where the lift exerted upon the web 10 will be greatest. Since the web 10 must hug the roll 15 if the drying system is to operate efficiently, by providing the neckdown B substantially midway along the contact line, the lifting vector is opposed by the maximum vector of force on the web 10 acting towards the roll 15.

While a 90 degree wrap of the web on the rolls 15, 16 and 17 has been shown in FIGURE 1, a greater or lesser amount of wrap may be used to dry the web effectively without web flutter. In other words, if web speed and air velocity are increased, a greater wrap of the web 10 on the rolls would be preferred to oppose the higher lifting force at the neckdown B.

The lifting force at the neckdown B is also combated by the use of the supporting roll 15 since atmospheric pressure is not free to act on the underside of the web 10 at this critical point. In addition, the lifting force on the web 10 is also counteracted by suitably tensioning the web 10 by the use of vacuum rolls 9 and 17, or some equivalent devices, as pointed out heretofore. Such a taut web resists the lefting forces encountered under the divergent blades 33 and 33'.

If a vacuum roll is used under the blades 33 or 33', the reduced pressure created under the web 10 by the vacuum roll 17, for example, furnishes a pressure differential across the web that urges it against the roll in opposition to the lifting force of the turbulent boundary layer. Such arrangement also assists in preventing web flutter.

One type of vacuum roll assembly that may comprise the roll 9, or that may be used at the drying stations, is disclosed in U.S. application Serial No. 635,005, filed January 18, 1957, for "Apparatus for Tension Control." Referring to FIGURES 5 and 6, a cylindrical shell 161 is secured to end rings or plates 162 and 162' by threaded bolts. At one end of the shell 161 a hollow journal 171 is connected to a bearing (not illustrated) and through a center pipe 165 to a suitable source of vacuum. The center pipe 165 extends axially into a vacuum chamber enclosure indicated generally at 190 which includes a vacuum chamber 175 enclosed within the cylindrical shell 161. The end of the vacuum chamber 175 remote from the pipe 165 is closed by a plug 176 and supported in a bearing 177 mounted in the rotating end plate 162. A bearing 180 suitably mounted in the rotating end plate 162' surrounds the pipe 165.

The vacuum chamber enclosure 190 consists of a pair of side walls 191 and two end walls 192. Longitudinal channels 193 are formed by upstanding flanges 194 and auxiliary plates 195 and 195' bolted to the enclosure as shown in FIGURE 6. The upstanding flanges 194 are formed integral with the chamber housing 190. Transverse channels 196 at the outer extremities of the walls 192 are formed by upstanding plates 197 and 197' (FIGURE 5) that are bolted to the vacuum chamber housing 190, and by the upstanding flanges 198 integral with the vacuum chamber housing 190.

Longitudinal sealing members 199 are mounted in the channels 193 and biased outwardly against and in frictional engagement with the inside surface of the cylindrical shell 161 by resilient tubes 200 mounted in the bottom of the respective channels. The biasing tubes preferably are formed of an age-resistant elastomeric material such as silicone rubber and, if necessary, may be inflated to produce the desired pressure for sealing the members 199 against the cylindrical shell 161. However, selection of tubing of the proper size and thickness makes it unnecessary to inflate those elements.

Lateral or transverse sealing members 201 are mounted in the end wall channels 196 and urged upwardly against the inside surface of the cylindrical shells by helical springs 202.

The longitudinal sealing members 199 and the transverse sealing members 201 are maintained in relatively air-tight contact with each other by adjustable spring screw units 204, two being located at each end of the chamber 175. The spring screw units 204, which include a threaded bolt 205 formed with a flanged head 206, pass through a washer 207, the plate 197 and the sealing element 201 without engaging those elements. Between the washer 207 and the head 206 is positioned a helical spring 208 acting on the washer 207 and the head 206 tends to pull the longitudinal sealing members 199 in an axial direction toward the lateral sealing members 201.

Shown at the opposite end of the vacuum chamber in FIGURE 5 is a bolt 210 threaded in the end plate 197 and provided with a lock nut 211. The bolt 210 is formed with a hollow cylindrical center using a helical spring 212 that presses against the lateral sealing member 201 thereby tending to maintain it in air-tight engagement with the flange 198. Several such bolts are provided at both ends of the vacuum chamber.

An upper vacuum chamber section 175' communicates with the central portion of the vacuum chamber 175 through apertures 213 best shown in FIGURE 6. A negative pressure may be maintained in the chambers 175 and 175' through the axial center pipe 165 and such negative pressure will be transmitted to slots 222 in the shell 161 to hold the web on the roll firmly against the outer surface of the shell 161.

The grooves 222 in the shell 161 are formed with an arcuate shape shown in FIGURES 5 and 7. Such grooves can be milled in the walls of the cylinder 161 by means of an 0.028" thick milling cutter resulting in a groove width of 0.028" to 0.013". A groove substantially wider permits the vacuum to mark the paper by pulling it inwardly. For processing heavier webs wider grooves may be used and, conversely, for lighter webs, narrower grooves may be used. In FIGURE 7 it may be observed that a sharp corner at the edge of the groove on the inside of the shell 161 is rounded off or chamfered to prevent damage to the sealing members 199. The edge of the groove on the outside edge of the periphery remains sharp as machined to assist in maintaining a firm hold on the web. The grooves in adjacent axial rolls are overlapped to obtain continuous coverage of the area of contact between the paper and the cylindrical surface.

To reduce noise originating from the successive sudden exposure of the slots 222 to atmospheric pressure, a structure designated generally at 225 (FIGURE 6) is provided. The longitudinal plate 195' extends upwardly almost to the inner surface of the cylindrical shell 161 and at that point is provided with a skirt 226 gradually tapering away from the inner cylindrical surface, moving in the direction of rotation of the shell. A wedge-like space is thereby formed between the skirt 226 and the shell 161 with the smallest clearance near the edge of the vacuum chamber. The structure described provides for gradual refilling of the evacuated slots, rather than a sudden refilling, with a consequent sudden reduction or even complete elimination of noise.

To maintain the tension of the web 10 to prevent web flutter under the blades 33 and 33', the vacuum roll may be controlled in two ways: (1) the vacuum may be maintained at a uniform level and the surface speed of the rolls **9** and **17** increased or decreased as desired by means of conventional variable speed devices driving the vacuum rolls or (2) the surface speed of the vacuum rolls may be constant and the vacuum varied. The first alternative (the control of the speed of the vacuum roll with constant vacuum) is preferred. In the second alternative (control of the vacuum) changing the vacuum varies the surface friction between the rolls and the web **10**, thereby permitting control of web tension.

With the above principles in mind, the illustrative embodiment of the invention shown in FIGURE 1 will be readily understood. The rapidly moving web **10** passes through the hood **21***d* where it is heated by the gas burners **21***a*, **21***b* and **21***c*. It should be noted that the hood **21***d*, being positioned adjacent to the blade **33** and side shields **44**, actually constitutes part of a single enclosure extending along the web into the exhaust chamber **52**. Thus, heated air provided by the burners **21***a*, **21***b* and **21***c*, increases the temperature of the air passing between the blade **33** and the web **10**. The heated air from the hood **21***d* and the heat radiated from the web **10** tend to heat the blade **33** which, together with the chamber **40**, prevents it from condensing solvent vapors.

As the web **10** travels over the roll **15**, the high velocity stream of air changes the solvent laden laminar boundary layer to a turbulent boundary layer at region B. Further along the web **10**, separation of the solvent laden turbulent boundary layer occurs, as explained above, in the divergent section C created by the blade **33** and a portion of the web **10** supported by the roll **15**. This results in the removal of the turbulent boundary layer from the web **10**, and it is immediately carried into the exhaust chamber **52** along with the stream of air as indicated by an arrow **70** in broken line in FIGURE 1. Additional solvent will now evaporate from the ink film since the restraining solvent laden boundary layer has been removed.

The positioning of the lower lip **59** on the mouth **58** assists in directing the solvent laden air into the chamber **52**, and a suitable exhaust system creating a negative pressure or vacuum in the chamber **52** also removes the solvent carrying air therefrom.

It should be understood that the precise clearance between the blade **33** and the roll **15** is not critical. However, it is preferably kept in excess of one-quarter inch to avoid trouble with pasters, air bubbles and wrinkles. In addition, with a very high capacity system, a smaller neckdown may choke the flow of high velocity air. In one embodiment of the invention, it was found that the neckdown dimensions could be varied from between three sixteenths to three-quarters inch without seriously impairing its operation. An exemplary clearance is about three eights to one-half inch.

In connection with the lower lip **59**, it is placed as close to the web **10** as possible, for example one-quarter inch, to permit the reduced pressure in the exhaust chamber **52** to act with maximum efficiency. Such reduced pressure also induces a reverse or counter air flow into the divergent section C between the lip **59** and the web **10** (FIGURE 4) which aids in promoting and maintaining boundary layer separation.

In a typical drying station, the aperture of the exhaust mouth **58** may measure about two inches across with a sixteen inch diameter roll **15**, these dimensions providing a sufficient area for separation of the boundary layer of air from the rapidly moving web **10** before the pickup of such air.

In applying the invention to the printing art where, for example, heat-set inks with solvents consisting of kerosene fractions with relatively high boiling points and low vapor pressure are employed and the ink film is based on thermoplastic resins, it has been found that one drying station is adequate to dry the rapidly moving web **10** at speeds of about 1000 feet per minute . Beyond that speed, it has been found that the solvent continues to rise from the web **10** beyond the drying station. Accordingly, at higher speeds second and third stations such as those shown in association with the rolls **16** and **17** may be provided. However, it is generally not necessary to heat the rapidly moving web between drying stations because as the speed of the web **10** increases, the cooling effect of the rapidly moving air in each drying unit is less pronounced and the heat level persists for a longer distance beyond that source. However, if the speed is greatly raised or for other reasons, it will be understood that further heating means may be employed within the scope of the present invention.

Examining the operation of the drying station employed in connection with the roll **16**, the rapidly moving web **10** passes under the blade **33'**. Due to the exhaust chamber **52'**, a high velocity air stream passes between the web **10** and the blade **33'** creating turbulence and separation of the solvent laden boundary layer as discussed in connection with the first drying station. The separated saturated air immediately passes into the chamber **52'** as shown by an arrow **70'** in broken line, and is subsequently exhausted therefrom. The rapidly moving web **10** is then advanced to the drying station at roll **17** for further drying and from there may be carried to a conventional cutting and folding station by the rolls **18** and **19**.

Rather than providing a roll at each drying station, two or more drying stations may be positioned adjacent to a larger roll around which the web **10** is wrapped to a greater extent than on the rolls **15**, **16** and **17**.

While the inventive methods and apparatus have been described as particularly advantageous in connection with high speed webs, such methods and apparatus are also useful in drying of rapidly moving webs traveling at somewhat slower speeds such as in gravure or aniline (flexigraphic printing) printing presses. In such instances, direct heating of the web may be eliminated in favor of heated air supplied to the convergent section formed by the roll and blade.

It will be evident that the principles of the above invention facilitate the effective drying of moving webs by aerodynamic means and at the same time, reduce the heat requirements previously rendering high speed drying impractical and uneconomical. Of course, the above-described embodiments of the invention are illustrative only and modifications thereof will occur to those skilled in the art. Therefore, the invention is not to be limited to the specific apparatus disclosed herein but is to be defined by the appended claims.

We claim:

1. A drying unit for a rapidly moving web comprising a roll adapted to support and change the direction of travel of the web, a blade extending longitudinally along at least a portion of the roll and positioned adjacent to a supported portion of the web to form with the web convergent and divergent sections joined by a throat, a pair of side shields mounted on the blade and conforming to the configuration of the roll for partially enclosing the convergent and divergent sections and the throat, means for creating a pressure differential across the blade to generate a high velocity flow of air through the throat in the direction of web travel, the air flow inducing turbulence and shearing and lifting forces at an area adjacent to the web in the divergent section, and means for immediately exhausting the air flow from the divergent section.

2. Apparatus as defined in claim 1, in which means are provided to induce a counter flow of air along the web into the divergent section.

3. Apparatus as defined in claim 1, wherein the pressure differential creating means comprises the exhaust means.

4. Apparatus as defined in claim 1, wherein the roll comprises a vacuum roll to prevent web flutter under the blade.

5. Apparatus for drying a rapidly moving web comprising a roll adapted to support and change the direction of travel of the web, a blade extending longitudinally along at least a portion of the roll and positioned adjacent to a supported portion of the web to form with the web convergent and divergent sections joined by a throat, a pair of side shields conforming to the configuration of the roll for partially enclosing the convergent and divergent sections, means for at least partially enclosing a portion of the web leading to the roll, said enclosure means communicating with the convergent section defined by the blade, the roll, and the shields, means in said enclosure means for heating the rapidly moving web, means for creating a pressure differential across the blade to generate a high velocity flow of air through the throat in the direction of web travel, the air flow inducing turbulence and shearing and lifting forces at an area adjacent to the web in the divergent section, and means for immediately exhausting the air flow from the divergent section.

6. Apparatus as defined in claim 5, in which means are provided to induce a counter flow of air along the web into the divergent section.

7. Apparatus as defined in claim 5, wherein the pressure differential creating means comprises the exhaust means.

8. Apparatus as defined in claim 5, in which means are provided for cooling the blade.

9. A system for drying a rapidly moving web comprising a plurality of drying stations along the web, each of the drying stations including; a roll adapted to support and change the direction of travel of the web, a blade extending longitudinally along at least a portion of the roll and positioned adjacent to a supported portion of the web to form with the web convergent and divergent sections joined by a throat, a pair of side shields mounted on the blade and conforming to the configuration of the roll for partially enclosing the convergent and divergent sections, means for creating a pressure differential across the blade to generate a high velocity flow of air through the throat in the direction of web travel, the air flow inducing turbulence and shearing and lifting forces at an area adjacent to the web in the divergent section, and means for immediately exhausting the air stream from the divergent section; means for at least partially enclosing a portion of the web leading to the initial station, said enclosure means communicating with the convergent section defined by the blade, the roll, and the shields found in the initial station, and means in said enclosure means for heating the rapidly moving web.

10. A drying unit for a rapidly moving web comprising a roll adapted to support and change the direction of travel of the web, a blade extending longitudinally along at least a portion of the roll and positioned adjacent to a roll supported portion of the web to form with the web convergent and divergent sections joined by a throat, said throat being between the blade and the roll supported portion of the web, means to create a sufficient pressure differential across the throat formed by the blade to flow air through the throat in the direction of web travel tangentially to the web to provide a turbulent boundary layer on the web flowing in the direction of web travel and to separate the turbulent boundary layer from the web at a region in the divergent section, and means adjacent to and downstream from the roll and blade to exhaust immediately the separated turbulent boundary layer from the region of separation between the blade and the web.

11. Apparatus as defined in claim 10, wherein the exhaust means comprises a chamber having a mouth communicating with the divergent section, a lip forming one wall of the mouth extending into close proximity with the web, and means to couple the chamber to a vacuum source to create said pressure differential and exhaust the separated turbulent boundary layer.

12. Apparatus as defined in claim 11, wherein the lip is positioned to create a counter flow of air along the web into the divergent section between the lip and the web.

13. Apparatus for drying a rapidly moving web comprising a roll adapted to support and change the direction of travel of the web, a blade extending longitudinally along at least a portion of the roll and positioned adjacent to a roll supported portion of the web to form with the web convergent and divergent sections joined by a throat, said throat being between the blade and the roll supported portion of the web, means to heat the web prior to its passage over the roll, means to create a sufficient pressure differential across the throat formed by the blade to flow air through the throat in the direction of web travel tangentially to the web to provide a turbulent boundary layer on the web flowing in the direction of web travel and to separate the turbulent boundary layer from the web at a region in the divergent section, and means adjacent to and downstream from the roll and the blade to exhaust immediately the separated turbulent boundary layer from the region of separation in the divergent section.

14. Apparatus as defined in claim 13, in which means are provided for varying the blade temperature.

15. Apparatus as defined in claim 13, in which is provided means to engage the web upstream and downstream of the roll to maintain the web in tension and hold it against the roll in opposition to the lifting force of the turbulent boundary layer.

16. Apparatus to dry a wet surface comprising a roll adapted to support the wet surface concentric with at least a portion of the roll and to move the wet surface in a desired direction, a blade extending longitudinally along the roll to form with the wet surface convergent and divergent sections joined by a throat, said throat being between the blade and the wet surface, means to create a sufficient pressure differential across the throat formed by the blade to flow air through the throat in the direction of travel of the wet surface and tangentially to the wet surface to provide a turbulent boundary layer of air on the wet surface flowing in the direction of movement of the surface and to separate the tubulent boundary layer from the surface at a region in the divergent section, and means communicating with and downstream from the divergent section to exhaust immediately the separated turbulent boundary layer from the region of separation in the divergent section.

17. Apparatus as defined in claim 16, in which means are provided to heat the air prior to its flow into the throat between the blade and the roll.

18. Apparatus as defined in claim 10, in which is provided means to engage the web upstream and downstream of the roll to maintain the web in tension and hold it against the roll in opposition to the lifting force of the turbulent boundary layer.

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