WEB COATING APPARATUS

Filed Oct. 24, 1965 4 Sheets-Sheet 1

FIG. 4

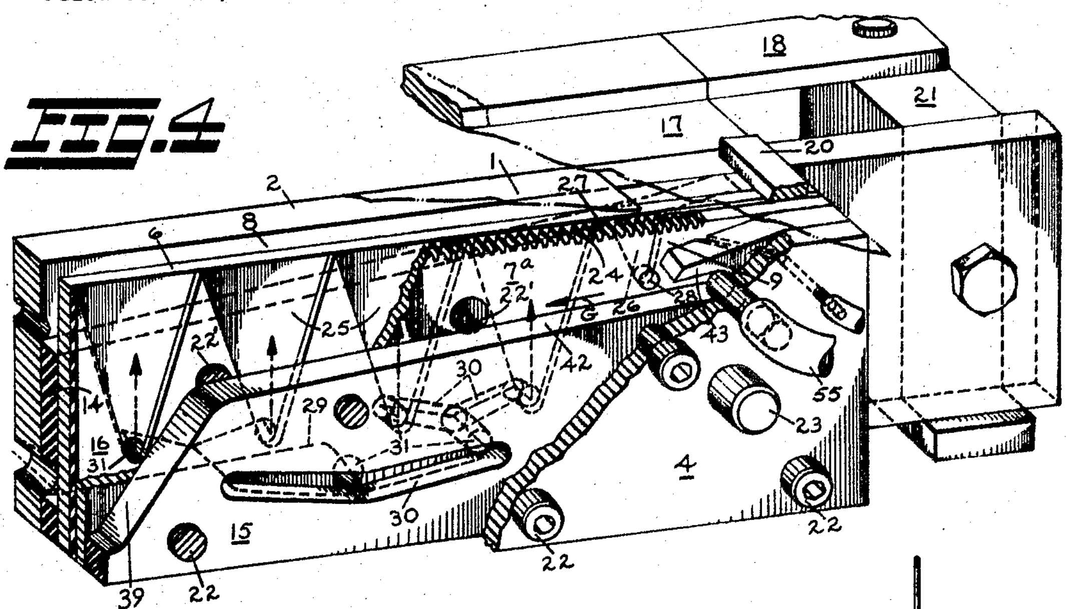


FIG. 1

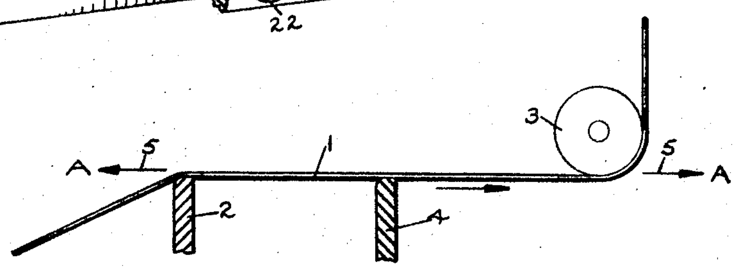


FIG. 2

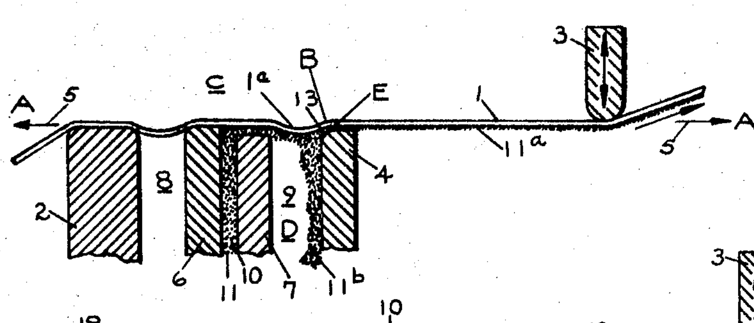
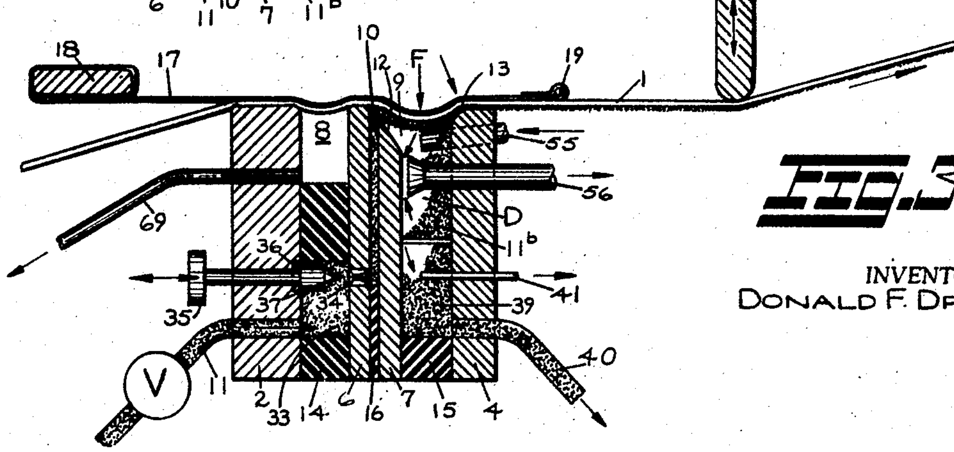


FIG. 3



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WEB COATING APPARATUS

Filed Oct. 24, 1965 4 Sheets-Sheet 2

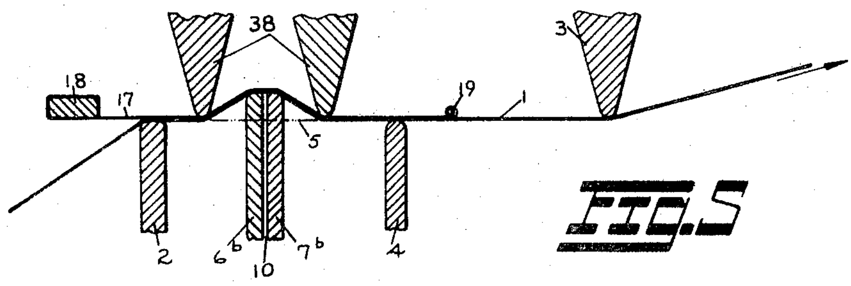


FIG. 5

FIG. 6

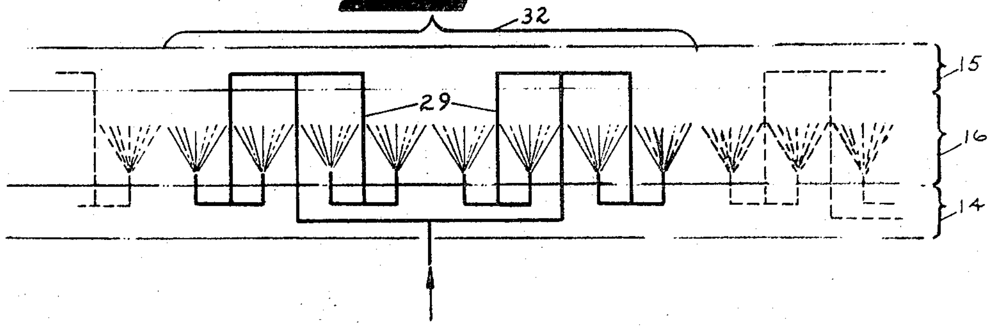


FIG. 7

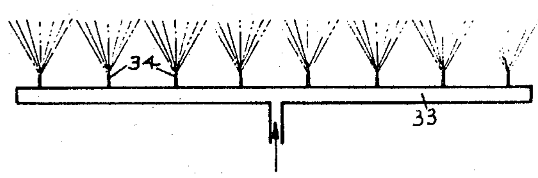
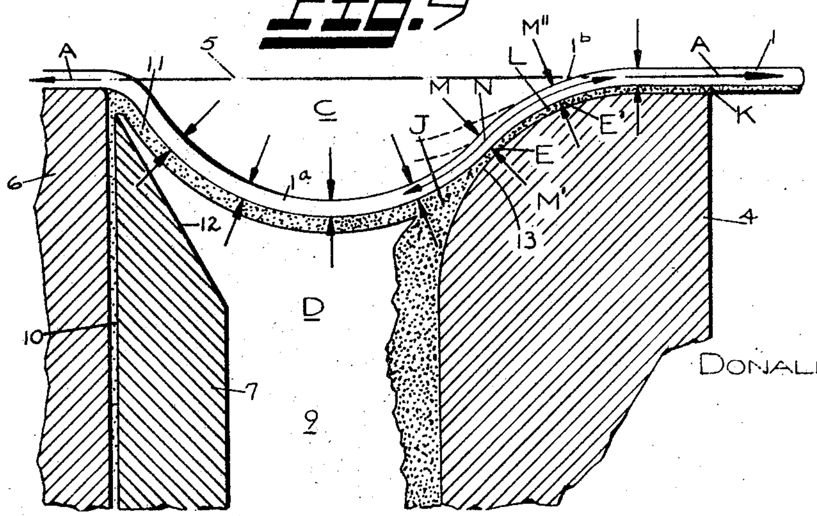


FIG. 9



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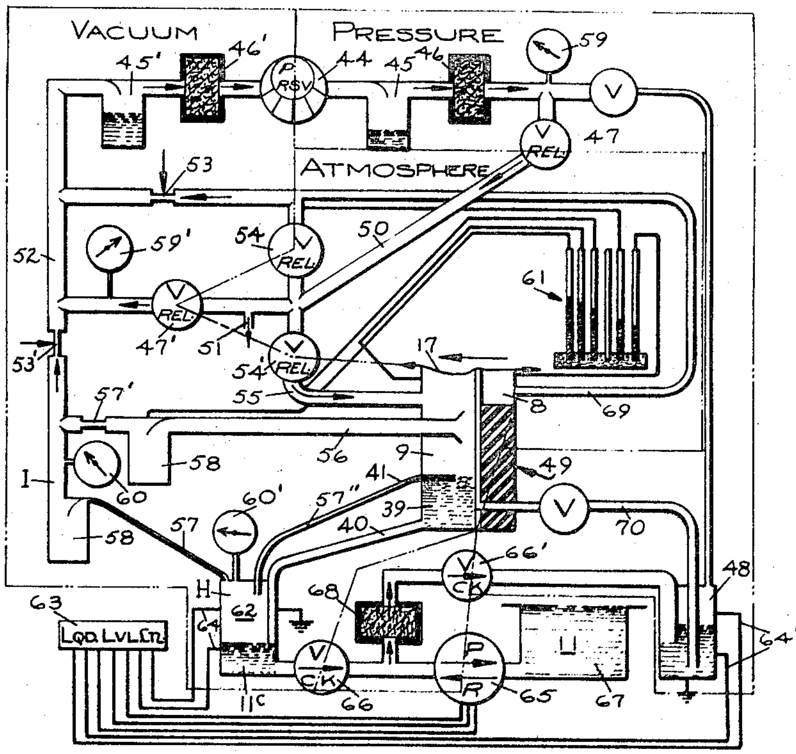

FIG. 8

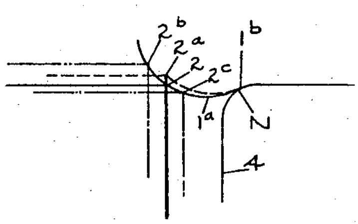

FIG. 11

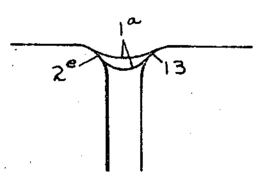

FIG. 12

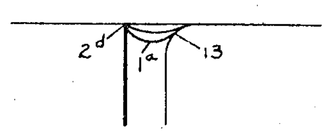

FIG. 13

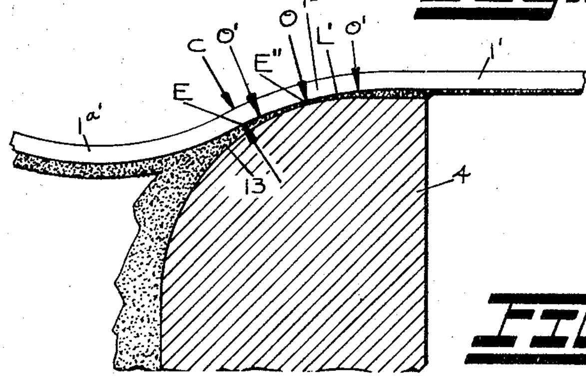

FIG. 10

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WEB COATING APPARATUS

Filed Oct. 24, 1965 4 Sheets-Sheet 4

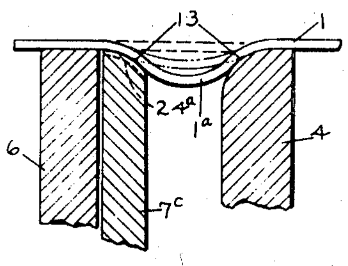

FIG. 14

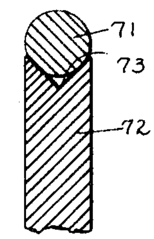

FIG. 15

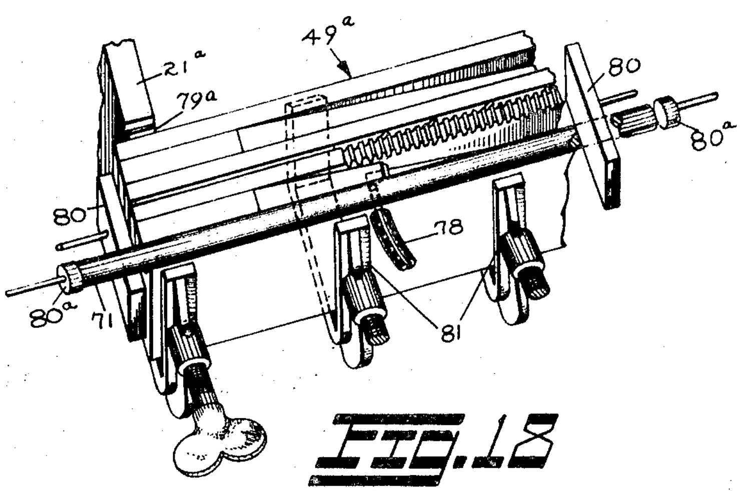

FIG. 18

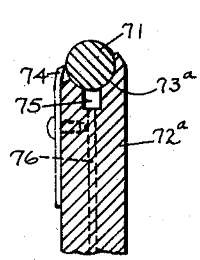

FIG. 16

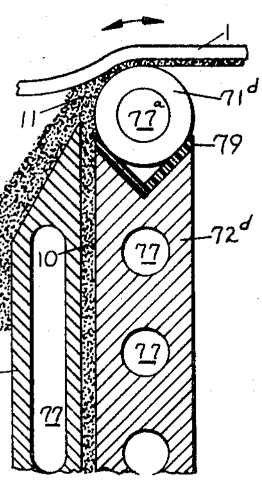

FIG. 17

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United States Patent Office 3,470,848 Patented Oct. 7, 1969

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3,470,848
WEB COATING APPARATUS
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Filed Oct. 24, 1965, Ser. No. 504,405
Int. Cl. B05c 3/02, 3/00
U.S. Cl. 118—410 24 Claims

ABSTRACT OF THE DISCLOSURE

Coating apparatus essentially for paper and film, comprising a fountain and a vacuous chamber communicative with a doctoring means wherein the coating thickness is controlled as a function of subatmospheric pressure, the effect of web tension nullified by positioning adjacent web supports in planar relationship to the doctoring means. Ancillary features include pliant membranous sealing of web and chamber(s), fountaining and liquid distributing techniques, separate withdrawal of excess liquid and gaseous substances, pressure differential means for inducing penetration, application of heat-liquifiable compositions, rod doctoring, margining and stripping techniques, and means for precise control of net and superficial coating weights.

CROSS REFERENCES TO RELATED APPLICATIONS

Applications bearing Ser. Nos. 504,406 and 504,445 filed concurrently herewith on Oct. 24, 1965, disclose subject matter stemming from and/or related in part to this application.

This invention relates to apparatus for coating continuous webs of flexible material, such as paper, film and the like, and more particularly is directed toward improvements therein by means of which spreading force may be more reliably and uniformly applied oppositionally to a doctoring element.

The use of variously shaped blades, stationary bars and rotating rods is old and well established in the coating art. In such apparatus, the coating weight is established by equilibrating opposing forces, viz.: fluid pressure within the coating composition and the occluding force applied thereto. The first named is a complex involving rheology of the composition, web speed, impingement profile, laminar friction and upstream pressure proximate the coating nip; the latter I designate as spreading force. In traditional knife coating apparatus the occluding force is developed tangentially by the tensioned web into which the doctoring element is deflectively interposed and thereagainst the web force radially applied to the coating composition, in consequence whereof the maintenance of constant tension becomes a primary requisite for uniformity of applied coating weight. The problems associated with perfect tensioning, including sheet malformation with resultant deviations crossweb, impose serious limitations upon attempts at precision coating by the use of such apparatus, precluding therefrom those applications in which simple averaging of specific coating weights is unacceptable.

I am not alone in recognizing this problem, as attest McGladrey and Rhodes in their Patent No. 2,354,033, issued July 18, 1944, and contemporaneously with my efforts, Kohler in his Patent No. 3,113,884, issued Dec. 10, 1963.

In my invention, spreading force is developed controllably by differential pressure operative against the web. This is accomplished by maintenance of subatmospheric pressure within a coating enclosure of which the downweb boundary comprises the doctoring element, over which the web and a deposited layer of coating composition are drawn and against which they are impinged by external atmospheric pressure, the net force of such impingement being the excess of external over internal pressure exerted against the web and thereby applied directly to the impacting composition and thus causing its flow through the nip to be meteredly restricted. By positioning the doctoring element in planar, rather than deflective, tensional engagement with the web, tension is sinally nullified as a primary factor affecting coat weight, since it will be apparent that by so positioning the operative surface of the doctoring element relative to the tensionally-spanned plane of the traveling web, the perpendicularly applied force is infinitely advantaged over that of web tension. It further will be apparent that in the described arrangement, the subatmospheric pressure differential enters the fluid pressure calculation deductively by reducing upstream pressure of the composition at its point of entry into the impingement nip, from which absolute level the fluid pressure is impactively increased to unity (one atmosphere) by the other elements in the fluid side of the equation.

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With the foregoing in mind, the immediate and impelling object of the invention is the elimination of web tension as a dominant factor affecting coat weight.

The objectives deriving directly therefrom include the simplicity of manometer-controllable uniformity of coating deposits, precision coating of greatly diverse product on relatively inexpensive and uncomplicated apparatus, and a broad range of versatility with respect to web structure, speed and width, composition type and viscosity, and coating weight.

A number of physical advantages of this type of apparatus will be readily apparent, including thereamong full enclosure of the complete fluid system, elimination of integral coating tanks and evaporative contact with external air, and extreme compactness. It is significant that precision coating can be achieved with minimal structural involvement, demanding only linear perfection in its web-contacting face relative to the following web support and sufficient internal rigidity to prevent chattering, there being no significant operational stresses perpendicular to the plane of the web. Thus, one of the important objectives of the invention is its minimal requirement of space and structure, and thereby its permissive insertion into a machine line unobtrusively, which often may be accomplished without relocation of existing facilities.

A most significant objective which is related to compactness concerns the predetermination of production behavior on laboratory apparatus insofar as the spreading of the coating per se is concerned, it being relatively simple to duplicate precisely in narrow width every essential factor directly pertaining thereto.

Operationally, the achieved objectives permit facile cleanup, reduction in startup problems associated with intermittent operation, and unattended handling of web splices and most imperfections, there being no mechanical constriction of web flow across the face of the coater.

Another object is to induce penetration of the surface coating into a semiporous web and to control the depth thereof.

Still another object is to provide simple distributive means for fountaining the coating composition uniformly crossweb, including therein means for margin definition and stripping, permitting the spreading of dissimilar compositions either in spaced relationship or abutted.

A further objective comprises significant contribution toward minimizing air bubble entrainment in coating compositions and the deleterious effects thereof.

Additionally it will be recognized that the invention is ideally adaptable to the application of heat-liquifiable compositions and the use of diverse types of doctoring elements.

A further object is adaptation of the teachings herein disclosed to plural treatments of such webs in instant sequence, including thereamong chemical treatment and impregnation either throughout or controllable in depth, high-solids filling of cavitous surfaces and laminar wet-on-wet surface coatings. These are more fully described in my accompanying application, which is first above identified.

Another object is further adaptation of the differential pressure technique to squeegees and other types of doctoring elements against a coating roller or a rigidly supported web, the said applications being more fully described in my second above identified application.

A better understanding of the invention will be aided by reference to the accompanying drawings in which

FIGURE 1 is a schematic illustration of the basic principle.

FIGURE 2 is a medial part section of the basic coater elements in operative position against a traveling web.

FIGURE 3 is a detailed medial section of a similar coater.

FIGURE 4 is a perspective view of a portion of a coating apparatus with parts broken away.

FIGURE 5 is a schematic showing of a pressurized fountain.

FIGURES 6 and 7 diagram branching and orificed distribution systems.

FIGURE 8 diagrams fluid circuitry usable in practicing the invention.

FIGURES 9 and 10 are greatly enlarged sections of the coating nip, by means of which specific elements of behavior are more fully explained.

FIGURES 11 to 13 are schematic illustrations connected with critique.

FIGURE 14 is a part section showing a rounded fountaining element.

FIGURES 15 and 16 are part sections showing rotatable rods as doctoring elements.

FIGURE 17 is a medial part section incorporating ducts for heat transfer fluids.

FIGURE 18 shows the application of one form of electrical heating of the several coater elements.

FIGURE 1 illustrates schematically the stated principle utilized by the present invention, indicating a traveling web **1** tension A spanned between upweb **2** and downweb **3** supports and therebetween a doctoring element **4** positioned nondeflectively against the web **1** so as not to alter the tensional plane **5** of the web. It will be apparent that in such positional relationship, vertical force B perpendicularly applied to the web **1** and transmitted therethrough against the doctoring element **4** is infinitely advantaged over that of the horizontal tension A and thereby the effect of linear tension is sinally nullified with respect to web impingement against the doctoring element.

FIGURE 2 shows this basic principle applied to the working face of a simple coater of which the basic elements comprise four rectangular bars or plate sections **2, 6, 7, 4**, each being in spaced and parallel vertical relationship to those adjacent, over which assembly passes the traveling web **1**. Vacuum chambers **8, 9** occupy the indicated spaces between the elements upweb **2, 6** and downweb **7, 4** respectively; similarly feeding channel **10** is developed between the intermediate plate sections **6, 7**. In this medial section the leading upweb bar **2** serves as the principal supporting and machine-spanning member, to which the other elements are bolted or clamped. The traveling web **1** traverses the face of the coater, held in pressure differential contact with the top edges of the several elements by the adjacently positioned vacuum chambers **8, 9**. The incoming flow of coating composition **11** is forced through the feeding channel **10**, fountained upon the traveling web **1** and thence carried into metering contact with the radius **13** of the doctoring element **4**. The differential pressure between the outside atmosphere C and that extant D in the vacuous coating chamber **9** applies external force B to the web as it moves across the doctoring element **4**, thus providing a uniformly constant spreading force oppositionally to the doctoring radius **13** and therebetween meters E a smooth and even coating **11*a*** on the under surface of the traveling web **1** and removes the excess coating composition **11*b***, which cascades down the inboard face of the last downweb bar **4** and is thence collected and drawn out from the bottom of the vacuum coating chamber **9**. The traveling web **1** is oppositely supported downweb from the coater by a vertically adjustable stationary bar **3** or by a roller, positioned in accordance with the aforestated principle.

It will be noted that as the web traverses each of the vacuous chambers it tends to deflect **1*a*** thereinto from its tensioned plane **5**, the extent of such deflection being a function of pressure differential (C–D) opposed by the web's tension A and inherent resistance to flexure. The effects of deflection and reverse curvature are more fully discussed later in this exposition, in connection with which it should be noted that inclusion of the upweb prevacuum chamber **8** is optional, and that it does not relate directly to the primary teaching of the present invention, its availability being advantageous, however, since it may be utilized for a number of useful purposes. Among these are included controllably additive web tension at this point, contribution toward crossweb tentering, corrugation control and wrinkle removal, sealing the upweb contact **6** with the incoming flow of coating composition **11** especially when using fountaining means other than nonpressured delivery, removal of dislodgeable foreign matter from the surface to be coated, and partial removal of air clinging to the traveling web, thus preventing introduction of entrainable air into the coating composition from this potential source. Prerarification also may be utilized further to induce penetration of the coating composition into a porous or semiporous web and to control its added inducement independently of the absolute pressure maintained in the coating chamber **9** as described later in this disclosure.

By referral to FIGURE 3 which shows the center section of the apparatus suggested by the previous figure, all the drawings herewith included being similarly referenced, it may be more easily understood that the vacuum chambers **8, 9** are sealed on three sides, and the respective pairs of adjacent coater elements **2, 6** and **7, 4** are spaced, by rubber sheeting **14, 15** or other gasketlike material of desired thickness. Similarly, feeding channel **10** is developed by a patterned insert **16** which spaces the intermediate, or fountaining, plate sections **6, 7** in parallel relationship. In addition to chamber development and shaping, a labyrinth of distributive, drain and air ducts may be incorporated within the several inserts **14, 15, 16** and made communicative by selective porting through the metal coater elements **2, 6, 7, 4**. This composite assembly is alignedly clamped together, thus forming a rigid machine-spanning unit.

Sealing of the top face of the coater, and coincidentally the top surface of a porous or semiporous web such as paper, may be accomplished by a pliant membrane **17** which trails downweb from its anchoring crossbar **18** as shown in FIGURES 3 and 4. This membrane overextends the width of the web and completes the top sealing of the vacuum chambers **8, 9**. It is preferable that the edges of the membrane make top surface planar contact with the several spacing inserts well outboard and generously spaced from the edges of the web and that the spacing inserts be fashioned to provide clearance for both the web and the membrane to deflect freely into the vacuous chambers. If the edges of the web instead were contacted by the spacing inserts, even the more pliant would tend to buckle over the doctoring element under the described conditions. Similarly the membrane would exert imperfect downward force against the web if it were planarly supported too close to the edges of the web.

Although such a membrane is not essential to practicing the generic teaching of the invention, since it is possible by other means to maintain a suitable level of subatmospheric pressure within the coating chamber **9**, its general use not only is highly advantageous but broadens the applicability of the teachings herein disclosed into useful areas in which they otherwise would tend to be less effective or from which they could be barred. Therefore the function of the membrane becomes essential if full benefit is to be gained from many of the herein teachings, especially those which pertain to the handling of porous and semiporous webs, since by no less simple means can the outer surface of a web be pliantly, transiently and reliably barriered.

Additionally, such a membrane may be utilized advantageously to provide a smoothing or tentering action against the web, it being especially useful for this purpose when handling exceedingly limp webs. Thin films, for example, often are badly distorted in winding and when spanned tensionally they tend to corrugate deviantly about the plane established by upweb and downweb supports. In coating such materials it is helpful that they be run at minimal tension, or at such tension level as to permit their being arcuately deflected as they traverse each of the vacuous chambers. By means of the resulting reverse curvature the web tends to be cylindrically perfected, thus mechanically nullifying the inclination of the web to corrugate in the immediate area of the doctoring nip, thereby permitting differential pressure to be the dominant determinate of spreading force and the web to be ideally tensioned rather than as might otherwise be dictated by control of coating weights. Nor is this teaching exclusive to such films, since many paper webs exhibit similar behavior, the differences being in frequency, extent and degree, and in the amount of corrugative spring force developable by such inclination and the degree of curvature required mechanically to negative it.

It further will be apparent that the degree to which the membrane itself is tensioned in the direction of the web flow, e.g., by frictional contact therewith, combined with its resistance to flexure in its own right, the extent of web deflection into the several vacuous chambers will be affected, by having isolated therefrom the downward vertical force F of external atmospheric pressure. Thus, by adequately tensioning the membrane and thereby preventing deflection into the vacuous coating chamber **9**, the web may be spanned nondeviantly from its tensional plane in strict accordance with the principle schematically illustrated in FIGURE 1, it being further evident that under such conditions the web would be so planarly positioned even though it were relatively nontentioned in its own right.

From the foregoing it will be apparent that the type of membrane most universally applicable should be pliant and somewhat distensible. Its capacity for rapid elastic cycling, however, usually must be somewhat limited in view of a tendency to chatter due to vacuum-induced frictioning against the traveling web surface, this being one means by which an exotic coated surface may be applied to the web. But when smooth coatings are desired it is advantageous that the membrane be slip finished in order to minimize its frictional coefficient, for which I have found a slip-finished well-plasticized vinyl sheeting to be well adapted. I also have discovered that the downweb trailing edge should be crossweb tensioned or stabilized whenever web deflection is tensionally permitted, since central deflection in combination with planarly-supported edges draws the downweb portion inboard and causes it to pucker over the doctoring element. Although this may be accomplished by oblique spring or rubberband attachment to the downweb corners, thereby tensioning the membrane both downstream and crossweb, I find it both effective and much more convenient to envelop a very light rod **19** in the trailing edge of the membrane, thereby preventing its being drawn toward the center of the web and permitting it to be freely positioned and drawn frictionally downweb by its measured affinity for the traveling web. I also have learned that edge clamps and other accouterments seem to be unnecessary when such a membrane has been properly attached to its upweb anchorage **18** and the top edge faces of the assembled coater offer smooth planar support. Such edge sealing may be aided, however, by application of viscous petrolatum or such as to contribute to vacuous sealing and lubricity, in addition to which I find it prudent to have available small bar magnets **20**, which may be used when necessary to perfect the edge seal in the manner illustrated.

FIGURE 4 shows a portion of a similar apparatus with parts broken away, indicating one of its machine mounting brackets **21** and some of its clamping bolts **22** for securing the assembly to the crossweb support member **6**. It will be noted that ground steel pins **23** may be included near each end of the assembly and used for perfecting alignment of its several members. It also will be noted that the downweb fountaining plate member **7*a*** has its top edge fluted **24**, the fluting forming multitudinous ducts through which the coating composition **11** may be frictionally drawn by the traveling web and flow-induced by the suction in the coating chamber **9**. By appropriate sizing of such ducts relative to flow rates, it will be apparent that such a fountain is capable either of nopressurable wet contact with the web as shown in the prior examples, or of being medianly pressurable thereagainst. The drawing also indicates the patterning of the fountaining insert **16** wherein distributing pockets **25** may be formed. An overflow well **26** is included at the web margin, into which a certain amount of coating composition may flow over the dam **27** and be drawn therefrom through the port **28** into the coating chamber **9**. Even though this type of overflow well is seldom necessary when the fountain is nonpressurized its use often is helpful since it tends to seal the traveling web to the dam **27** by means of its connection to the vacuous coating chamber. At times it also is helpful to bleed miniscule amounts of air into the well, especially when considerable drainage is involved and definitive margins are required.

It is preferable that the patterned insert **16** be relatively thin in order that the feed channel **10** may be somewhat flow restrictive, although it need not necessarily be segmentally pocketed. The development of upwardly extending portions, however, have been found useful in a number of respects, including their contribution to stability of the assembly and permitting bolt lockup **22′** of the fountaining plate sections **14, 15** to the main crossweb support **6** within the upper section of the assembly, thereby helping to secure perfect sealing among the several parts. It further will be evident that by the patterning illustrated, various coating widths may be accomplished with the use of a single insert simply by shutting off the flow of coating composition to the outboard pockets, each of the pennant-shaped segments being capable of serving as a marginal dam, especially when the top of the fountain is nonpressurized. Another interesting facet of establishing web contact at each of the divisional segments is that it may be used to appraise flow rates of the incoming composition relative to that which is being doctored on the traveling web, since at the point of marginal flow a tiny stripe will tend to occur on the coated web.

FIGURE 4 suggests a branching sytem **29** for crossweb distribution of the coating composition utilizing the vacuum chamber inserts **14, 15** in which a series of divisibly branching ducts **30** may be formed in communicative relationship by porting **31** the intermediate plate sections **6, 7*a*** through which equal portions of the coating composition may flow into the pockets **25** patterned in the feed channel insert **16**. Such a system is flow diagrammed in FIGURE 6 in which the phantomed coordinate lines indicate the positioning of the ducts relative to the several inserts **14, 15, 16** and an eight-pocketed section **32** such as may be conveniently handled by the particular system illustrated. It will be apparent that a single branching system of this type may be extended to any desired power of 2, or that several systems may be used conjunctively end-to-end as indicated by the phantomed partial sections in the flow diagram.

FIGURE 7 diagrams an orifice distributive system in which the coating composition is maintained at relatively high pressure in a crossweb duct **33** which may be formed within the upweb insert **14**, from which the composition meterably flows through uniformly spaced orifices **34** in the upweb fountaining plate section **2**, the orifices preferably being precision-sized so as to maximize pressure drop thereacross, thereby causing their individual flow rates to be minimally influenced by small deviations in upstream pressure. This type of system is suggested in FIGURE 3 which includes a plunger **35** installed in the crossweb support bar **2** in alignment with each orifice **34**, the plunger being sealed with an O-ring **36** and including a forward protruding extension **37** so sized as to be thrustable through the orifice **34**. The primary purpose of the plunger as illustrated is to permit operational clearing of a plugged orifice, which can occur upon occasion even in well filtered systems. With slight modification it may also serve as a close-off valve, requiring means for locking the plunger in closed forward position and in some cases additional means for sealing the closure. In the form illustrated it will be apparent that the plunger is sealed at all times and that the fluid pressure in the duct **33** will force the plunger into its shown position. Alternatively, metering needle valve stems may be substituted for the plunger **35**, thereby permitting individual adjustment of flow rates either into segmented pockets **25** or distributively along the base of a common feeding channel **10**.

In the field of coating apparatus, definitive feeding apertures offer sizable advantages among which is included control of coating widths and edge margins. Although final margin definition occurs at the doctoring element, there being outboard from that established at the fountain, lateral flowout tends to be a function of the proportional excess of coating being removed, and therefore controllable by varying the amount of such excess by altering the flow rate at the fountain. By utilization of such means it will be apparent that a web may be coated full width even when using a lesser-widthed fountain, which in all cases is preferable and simply good operating practice since it contributes to efficient functioning and helps to avoid running difficulties associated with web edge imperfections by eliminating agglomeration of coating materials in areas where no useful purpose is served. Striping applications also can be reasonably definitively widthed by utilization of such technique, the plural application of which may necessitate precise orifice-balancing of flow rates and/or variable control of flow into each of the several fountain apertures. From this it follows quite logically, since the flow to individual pockets within the fountain may be separate and independent, that different coating compositions may be fed into alternate apertures and thence smoothed over a single doctoring element. In such applications it is preferable to minimize excess flow in order that lateral flowout along the doctoring radius and the quantity of drainage may be minimal especially if bicompositional admixing will constitute waste. In the case of immediately adjacent and intentionally contacting dissimilar compositions it is interesting to note that exceedingly little blending occurs on the coated web. This is due to the fact that web contact has been established by each coating composition and that the bulk of each composition is carried over the doctoring element undisturbed. Insofar as that portion which may be incorporated manipulatively into the rolling mass or bead, such mass is continuously fed with fresh compounds, and even though they may migrate laterally the adjacent compositions tend to abut rather than to intermix.

The described coating techniques are of particular interest with respect to bubble entrainment within the coating composition, whatever be its source. It is well known that air can be frictionally delivered into a rolling mass of liquid and incorporated cumulatively therein to such extent that the coating layer deposited therefrom includes myriad tiny air bubbles which can seriously affect both quantity and quality of coating. In order to minimize such accumulation excessive flows often are used, some twenty times the net consumption not being unusual. In the present invention I first provide upweb vacuous means as hereinbefore suggested by which the traveling web source of such entrainment may be minimized or eliminated, in addition to which it will be apparent that the upper or web-contacting portion of the upweb fountained composition passes frictionally through the impingement nip as hereinbefore suggested, only the excess composition being that which may indeed enter the rolling mass and become frictionally manipulated by the web-mentioned layer. It further is interesting to note that by subjecting the impingement nip to subatmospheric pressure, the coating laydown rather surprisingly contains no discernable bubbles when air-entrained compositions intentionally have been pressurably fed into the coater. This perhaps may be explained by the fact that the mechanical stability of the entrained air bubbles is so weakened by expansion and rarification that they are less capable of being drawn into the impingement wedge and there being reimpacted through the metering restriction.

Although the coating composition may be applied to the web by a variety of means, the fountaining technique is preferred in the instant invention since it adapts well to the suggested type of assembly, is readily meterable to desired flow rates and is capable of broad range in pressurization at the point of first web contact. The bead fountain **6, 7, 12** shown in FIGURE 3 exemplifies a perfect nonpressured application wherein the bead actually is subpressured at the vacuous level of the coating chamber **9**. At the opposite extreme, a full pressured fountain is schematically illustrated in FIGURE 5 wherein the fountaining section ***6b*, *7b*** is raised above the web plane **5**, mechanically deflected by overpositioned bars **38**, and thereby tensionally drawn over the fountainhead. It will be apparent that identical fountain behavior may be achieved below the web plane **5** instead of above in the manner illustrated. Pressurization of the fountainhead rather obviously is used either to spread an obstinate composition forcefully against the web or to induce penetration thereinto.

Penetration, however, does not necessarily require fountainhead presurization, but may be accomplished solely by means of rarification of web-entrained air and fluid pressure increase within the applied coating composition in contact therewith, such as may be made to occur in several steps if desired. For example, utilizing the assembly shown in FIGURE 3, if the prevacuum chamber **8** were maintained at 10 inches of water column subatmospheric and the coating chamber **9** at 5 inches, pressure differentials of 5 inches such as described would occur when the coating composition **11** first contacts the web **1** over the feeding channel **10** and again over the doctoring nip E in which the fluid pressure increases to one atmosphere. It further will be apparent that the total force available for the described purpose may be determined by the vacuous level of the upweb chamber **8** and thereby being unaffected by the specific level D of the downweb chamber **9**, although the two steps would be differently proportioned thereby. This is not to imply that there might be no differences in penetration in consequence of changing such proportions, in view of the dwell interval during which each of the differential pressure are operative between the fluid composition and the web-contained air, in connection with which it should be noted that it is possible to retain a measure of rarification of such air transiently downweb from the doctoring nip E by means of the vacuous attachment of the trailing portion of the membrane **17**. To those who are skilled in the art it will be apparent that pressurization of the fountain head **6***b*, **7***b* may be utilized further to induce instant penetration and thereby to eliminate or to minimize reliance upon dwell time which often is considered unavoidable in many coating and impregnating applications.

Referring again to FIGURES 3 and 4, it will be noted that the excess coating composition **11***b* is directed toward a central sump **39** and therefrom withdrawn by vacuum. While it is possible to size the drain **40** so generously as to permit drainage and maintain the desired gaseous vacuum level D within the coating chamber **9**, it is preferred to separate liquid and air flow therefrom so that the vacuous level D may be maintained constant and nonsurging in consequence of partial blockage of a multi-purposed drain by intermittent excesses of the more viscous fluid. The rate of liquid withdrawal should be adjustable so that the drain **40** is subject only to viscous flow, and therefore prevented from upsetting the equilibrium of the gaseous system. Some form of liquid level sensing therefor is advisable, one such method being illustrated wherein a sensing feedback **41** serves to alter the suction level operative against the drain **40** and thereby to regulate its rate of flow as a function of demand or liquid level in the sump **39**.

Although the described separation of liquid and gaseous flow permits maintenance of constant vacuous intensity within the coating chamber, a velocitied flow of air G through the coating chamber **9** has been found advantageous for use in propelling the excess coating composition **11***b* along the shelf **42** of the chamber-forming insert **15** toward the sump **39**, thereby providing effective inducement for such flow and permitting the chamber to be lesser depthed than would be required for gravitational flow along a more steeply inclined shelf. A plurality of drains, of course, may need to be incorporated in certain applications; but since each drain is likely to require individual control it is helpful that their number be minimal. It also is advisable to provide deflective means **43** as shown in FIGURE 4 for entry of the air G into the coating chamber **9** to prevent its turbulence at the point of injection from disturbing the applied coating layer ahead of the metering nip E.

The introduction of outside air, however, would tend to promote evaporation of volatile portions of the coating composition, even though the high velocitied air G under such conditions tends quickly to become saturate. For this reason I consider it advisable to introduce saturate air, which may be accomplished readily by recycling.

A system by which each of these elements may be accomplished and coordinated is illustrated in the flow diagram of FIGURE 8. Beginning with the vacuum pump **44**, air is delivered first through a reservoir or jar **45** and thence through a filter **46**, the output being pressurized if desired by the relief valve **47** and used to deliver coating composition **11** from its operative reservoir **48** to the coater assembly **49**. The volume flow of air passes the relief valve **47** into the supply duct **50** from which the accumulated excess of air exhausts through the open port **51**, thereby providing a nonpressured supply of saturate air for use within the recycling system.

Returning now to the supply duct **50**, that portion of air which recycles within the pumping system per se is drawn through the master vacuum relief valve **47′** into the duct **52** which comprises the primary vacuum source for each of the several operative systems, and thence through the jar **45′** and the input filter **46′** to the pump **44**. The jars **45, 45′** may serve either to collect condensate or to provide such gaseous volatiles as the air stream may absorb. Additionally a more effective humidifier may be inserted in the supply duct **50** or at other points in the various systems as might therein be required in order to provide fully saturate air under all operative conditions.

Vacuum for the upweb chamber **8** through connecting hose **69** is developed by cracking the needle valve **53**, the desired subatmospheric level being maintained by the relief valve **54**. A similar system **53′, 54′** would suffice for passing the high velocitied air G through the coating chamber **9** except that at least three connections would be required, the two input hoses **55** and the suction outlet **56**, all being sized adequately to pass the required volume of air, the input connections **55** being particularly significant in the illustrated arrangement since the downstream controlling relief valve **54′** must be relied upon to maintain constant level in the vacuous chamber **9**. Although this particular circuit as illustrated is identical in principle to that described, it differs with respect to its vacuum source I which is modulatingly integrated with the liquid drainage system and designed therefore to perfect their behavior. The illustrated circuitry was developed in order more effectively to stabilize the all-important metering of the coating in the impingement nip E under all operative conditions, including startup with an unfilled sump **39** and drain line **40**. At such time it will be apparent that three outlet vacuum lines connect to the coating chamber **9**, two being significantly sized and unobstructed with respect to air flow. As developed, the composite system is meterably vacuum-fed I through a single needle valve **53′** upstream from which are two fixed orifices **57, 57′**, one leading to the drainage system and the other to the gaseous circuit, an emergency trap **58** being inserted in each line as an additional precaution to prevent liquid from being passed into the primary valve and pump circuit. The restriction **57** in the drainage system as illustrated includes a section of very small hose which may be used either in lieu of, or in series combination with, a standard restrictive orifice. The liquid level control feedback **41** is similarly line-restricted **57″**, in addition to which it is orificed (not shown) at its liquid-contact point within the sump **39**. By so combining the liquid and gaseous circuits and origining their working vacuum outlets in a single meterable source **53′**, the operative suction I downstream from their individual restrictions **57, 57′** is widely variable. Thus when the drain line **40** is unrestricted by viscous flow, the operative suction I is quite low, from which level it raises into operative range as the drain line **40** develops restrictive flow. Thence the feedback serves to modulate the drainage suction H as a function of its flow being gaseous or liquid, and thereby causing rather sizable variation in suction H with only minor alteration of vacuum level I at the common source.

It will be noted that gauges **59, 59′** are provided within the pump circuit, and that vacuum gauges **60, 60′** indicate the operative levels H, I just described. In addition, a set of manometers **61** is provided for the less intense vacuous levels involved in the gaseous systems directly connected with the coater, by means of which its vacuous performance may be observed and the array of valving intelligently adjusted.

Returning to the drainage system, the effluent from the coater is drawn through the drain hose **40** into a sealed tank **62**, which may be relatively small-volumed if means are provided for periodic withdrawal of the drainage **11***c*. Such means as illustrated include a liquid level control **63** with connecting high and low sensors **64**, by means of which a reversible pump **65** is activated in such rotation as to draw the drainage **11***c* from the collecting tank **62** through the check valve **66** and thence returned into the main supply reservoir **67**, the return flow being stopped at a suitable level within the sealed tank **62**. A similar arrangement including sensors **64′** is provided for replenishing the supply of coating composition **11** in the operative reservoir **48**, the pump **65** being activatable in the opposite rotation so as to feed the coating material **11** from the main supply reservoir through an in-line filter **68** and the check valve **66'**. Thus by relatively simple means the coating operation may be made continuous, the operative tanks **48**, **62** so sized as to be conveniently proximate the coating operation and easily cleaned, and the filtering of the coating supply isolated from the operation while retaining most of the advantages of in-line filtering at the point of use, thereby lessening the likelihood of its causing interruption in the coating operation.

In traditional tension-opposed knife coating apparatus the precise configuration of the blade often is critical and comprises an art in itself. Although certain of the same rules apply to doctoring elements as used in the instant invention, their shaping seems to be less critical, except of course that their contours should be uniform from end to end and their positioning correct in relation to planar spanning **5** of the web. Even though enlargement of the upweb radius **13** inevitably shallows and lengthens the impingement wedge into which the coating composition impacts, thereby being more pressure-inducive and laying down a heavier coating, the amount of spreading force available and its controllable variability independently from web tension permits application of a very broad range of coat weights over a given radius. In addition I have discovered that the influence of impingement radius is much less than I had learned to expect in traditional knife-coating. This is accounted for by the fact that in web-tension-opposed spreaders, an increase in radius reduces radial pressure per unit of area in direct proportion, whereas the effect of wedge angle is of a considerably lower order.

Although the premise upon which the invention is based is patent and demonstrably supportable, certain aspects of its behavior deserve investigation, the explanation of which may be aided by reference to FIGURE 9 which is greatly enlarged and showing the web **1** being coated in deflective engagement with the doctoring element **4** and its immediate upweb support **6** against which the coating composition **11** is fountained by the beveled plate **7** nonpressurably upon the under surface of the traveling web. Metering restriction E occurs at the point where the inner surface of the web becomes tangent to its fluid pressure supported downweb radius **1*b***. The impingement portion J of the nip is upweb from this point, into which the coating composition is drawn by the traveling web and through which it is carried frictionally against its under surface, thence around the remaining radius **13** and thereafter crossing the flat surface of the doctoring element, at the terminus of which it will be noted that its thickness reduces K as the web departs therefrom. This reduction in thickness is indicative of frictional drag in fluid contact with the doctoring element, which it will be recalled was included in the formula originally suggested and therein designated as laminar friction. It will be recognized that this behavior is not greatly dissimilar to that of fluid flow through a pipe, except that in this instance the flow is motivated by frictional contact with the moving web. In the ideal example illustrated, the thickness of the described passage L is uniform and the web perfectly radiused around the doctoring element **13**. This phenomenon should persist even though the wrap angle around the doctoring radius were varied.

It will be realized that the more deeply the web deflects **1*a*** into the vacuous chamber **9** the sharper or more abrupt the configuration of the impingement nip J becomes; and contrariwise, its configuration becomes increasingly pressure-inducive as the deflection diminishes. Thus, given a basic relationship between vacuous level and web flexibility, the deflection **1*a*** will then be determined by web tension A. Under such conditions we should anticipate a tendency for coating weight to increase somewhat with increases in tension, which in fact is precisely what does occur, except that such variations appear to be on the order of something less than 10% in total range between maximum and minimum tension levels when coating exceedingly limp film (which in this case was 1 mil Pliofilm) which has virtually no inherent capacity to cantilever the aperture. Since it would be impractical to handle such a web in the range of tensions applied in this testing program, and since the levels at which they can be run tend to be exceedingly critical due to their distensibility and lack of mechanical structure, it may be deduced that for all practical purposes the specific coating weight may be held to tolerances which heretofore have been considered improbable. The described tendency is opposite to that which occurs in traditional knife coating, being of exceedingly small order when contrasted thereto. The behavior is further interesting when applied to malformed webs wherein baggy portions of the web tend to be more deeply deflected and thereby more abruptly impinged into the nip J with lesser coat weight tending to result at the very points which normally become excessively coated in traditional equipment of the character described. When the teaching is applied to corrugated webs retaining elements of spring force in the corrugations, we again find a tendency for this apparatus to compensate.

Referring again to the illustration, it will be noted that the reverse arc **1*b*** of the web over the doctoring radius **13** and deflection **1*a*** into the vacuous chamber are equally mean radiused as shown. Thus the point of null-balance N in radial force M, M' in consequence of web tension A occurs at the intersection of the line connecting the respective centers of the described arcs, which heretofore has been described as the point of metering restriction E, in which the net fluid pressure must of necessity be unity, or one atmosphere, since there it is opposed independently by external pressure C. Observing the stress pattern more critically, it will be realized that immediately downweb from this point the radial force M'' exerted by the tensioned web A is applied additively to the external air pressure C surrounding it, so that the fluid contained in the arcuate passage L from such point to the downweb tangent must be pressured at a level in excess of one atmosphere. This would seem to comprise a secondary metering restriction E' which normally could be expected to lessen coating weight. Contrariwise it has been learned that under the stated conditions an increase in tension actually tends to increase coating weight as previously described, which effect has been attributed to the favorable alteration of the impingement wedge J. In support of this explanation, it seems probable that web friction so dominates forward impaction within the radial passage L as to prevent upstream transmission of the pressure increase counter to laminar flow. It is possible, however, that the secondary restriction E' in fact does influence the primary and controlling restriction E, in which event it could indeed account in part for the observed increase in coat weight.

It further will be noted that when the deflection **1*a*** is reduced, its radius is increased and the point of tangency between the reverse arcs **1*a***, **1*b*** moved downweb around the doctoring radius **13**. Due to the difference in radii of the reverse arcs, it will be realized that the oppositely directioned radial forces M, M' in consequence of web tension are unequal at this precise point, since the radial force is an inverse function of radius. In such instance, therefore, the point of null balance N must of necessity be proximate thereto but very slightly downstream, beyond which we again are faced with the conundrum of increased downstream pressure as just described.

It will be apparent that relative inflexibility of the web also could influence behavior in and about the doctoring element J, E, L, such a web **1'** as shown in FIGURE 10 tending to fulcrum over the doctoring radius **13** and thus to be more shallowly arcuate **1*b'*** so that its closest impingement occurs midway in its wrap angle with the fluid radial passage L' tapered therefrom both up- and downweb. Thus the combined external force is nonuniformly applied to the opposed fluid support L′, thereby increasing the combined force O at such point E″ and gradingly lessening it O′ outward therefrom. However the point of radial force null balance N still occurs at the point of tangency between the two reverse arcs **1***a*′, **1***b*′ and thus is capable of functioning as the primary metering restriction E in accordance with the original premise and in the light of the immediately preceding critique, the discussion on the secondary metering restriction E′ being especially pertinent. Since all except exceedingly light webs are likely to be endowed with measurable stiffness, the described behavior will tend to be present even though its theoretical effects are likely to be unnoticed.

In general, self-compensative behavior seems characteristic of the described coating technique, concerning which I often find explanation to be more difficult than execution. The need for dependence upon self-compensation in the above instance may be circumvented if necessary by increasing the radius of the doctoring element to that which the web will more readily accept, although it should be noted that microprecision in coating weights is more likely to be required on lesser base stocks such as films and very lightweight papers rather than on heavier materials where the tolerances generally are less critical. It also should be noted that whereas in traditional apparatus such increase in radius would likely demand a lower-viscositied composition, such would not necessarily be required with my invention in view of its pressure differential potential whereby greatly increased spreading force is easily obtainable. The extent of this available force will be more fully appreciated when contrasted with vacuous levels of only 1 to 10 inches of water column, which usually cover the normal range of commercial coat weights and viscosities, using doctoring radii from 1/16 to 1/4 inch.

Another imponderable which is only partially explained concerns the apparently critical positioning of the doctoring element relative to the plane of upweb and downweb supports, which is especially sensitive to nonparallelism between the web-contacting edges of the doctoring element and the immediate upweb support, as suggested by the schematic illustration in FIGURE 11, one end of the said support **2** being slightly higher **2***a*. The effect of this type of malpositioning has been demonstrated quite as infallibly as the basic noneffect of tensioning and the extent of web deflection into the vacuous chamber deviantly below the established support plane. The adverse effect of such malpositioning would be obvious if the web were high-tensioned and thus not permitted to deflect from the described plane, in seeming contradiction to my earlier statement concerning the sinal advantage of perpendicular force thereto, but understandable in view of the relative proximity of the upweb support and the doctoring element. The confusion therefore arises in connection with deflection of the web and the stress behavior when the web is reverse-arced in the manner described. If, as illustrated in FIGURE 11, the upweb support were raised **2***b* or lowered **2***c* and moved up or down web but so positioned as to continue the deflective arc **1***a* without change relative to the radius **1***b* over the doctoring element **4**, it would appear that the point of null balance N and the described behavior in and about the impingement nip and downweb there from would be unaltered. Logically, therefore, it may be presumed that parallelism of these two working edges is more important pragmatically than precision contact with the tensional plane **5** of the traveling web, thereby permitting the top or working face of the coater assembly to be planar rather than stepped in the manner illustrated in FIGURE 2, except for those elements which are purposefully positioned above or below the web plane such as the bead fountain **7, 12** in FIGURE 3 and the pressurized fountain **6***b*, **7***b* in FIGURE 5.

It also will be noted, by reference to FIGURE 13, that web deflection **1***a* is nonsymmetrical when supported upweb by a sharp cornered support **2***d* and a radiused doctoring element **13**. Perfection in this respect may be achieved by matching radii **2***e*, **13** as shown in FIGURE 12. FIGURE 14 details such an upweb support in the form of a downweb-radiused fountaining element **7***c*, the top edge being fluted **24***a* so as to provide precision web support in combination with fountaining.

I include these observations as a part of the herein teaching, including that which relates to my quandry and seems contradictory in the light of partial explanation which admittedly is inadequate and subject to correction, in the hope that others may be aided thereby in practicing the methods herein described and that in so doing they may contribute to better understanding and fuller explanation of the described phenomena.

Returning now to the subject of doctoring elements per se, it will be noted that only stationary elements have thus far been displayed and discussed. The rotating rod is equally prominent in this general field of application, variously sized, mounted and driven, and used in both polished and wire-wound forms. Although the use of rotating rods by no means is universal, they do possess certain advantages in many applications. It now becomes my purpose to show how this type of doctoring element may be incorporated usefully in the subject invention.

Although it should not be deemed impossible to design a supporting element for wire-wound rods and to seal them adequately for use in the type of apparatus herein described, their use would tend to be self-defeating when serving as a barrier between differential pressures due to the transverse ducts developed by the winding. This implied preference for polished rods, however, should not be construed as estoppal of the teachings of the instant invention to wire-wound rods nor to other types of doctoring elements whenever applicable.

FIGURE 15 shows a rotatable polished rod **71** capable of functioning as a doctoring element, supported by a V-grooved bar **72**, the assembly shown in this medial part section being a simple and interchangeable substitution for the radiused stationary element **4, 13** shown in preceding views. The doctoring rod **71** may be power-rotated in either direction, or with suitable friction arrangement it may be repositioned from time to time as the operation may require. If desired, the rod may be held securely in its socket **73** by the use of clips or drawn down magnetically or by means of vacuum. Effective sealing at either end may be fashioned quite simply and held in place by lockup of the complete assembly or by other suitable means.

FIGURE 16 shows a more sophisticate support **72***a* for a rotatable rod **71** including a scraper **74** and a bearing socket **73***a*. A lengthwise groove **75** is provided, into which a lubricant may be supplied through a duct **76**. Wicking or other capillaried material may be inserted in the groove **75** in order that lubricant may be applied sparsely and uniformly to the surface of the rotating rod **71**. Although superbly applicable to the present invention, its utility involves a complex of elements and therefore is described more fully in the two accompanying applications for U.S. patent previously identified.

The surface coating apparatus herein described is adaptable to the application of heated compositions. The heating of the coater may be accomplished by any suitable means, one of which is illustrated in FIGURE 17 showing a composite fountaining and doctoring part assembly in which the basic plate elements **7***d*, **72***d* include ducts **77** into which steam may be injected or through which a heat transfer fluid may be passed, thereby maintaining suitable temperature for the flow of coating composition **11** through the feeding channel **10** and into beading contact with the rotatable doctoring rod **71***d*, the coating composition **11** pressurably delivered by means of a heated supply line **78** (FIG. 18). The doctoring rod

71*d* may be tubular, thereby forming a separate duct 77*a* and capable of being heated therethrough independently of the basic plate elements 7*d*, 72*d*, the rod's supporting socket being insulated 79 so as to permit the rod 71*d* to be differentially temperatured either higher or lower than that at which the support 72*d* is maintained. By such temperature differential means it will be apparent that the final spreading viscosity of the coating composition 11 may be transiently modified advantageously, e.g., by the use of such temperature as might be injurious if maintained for a longer interval.

FIGURE 18 shows a coater assembly being heated by electrical resistivity, low voltage current being passed through each of the basic metallic elements between electrodes 80. Insulated 79*a* machine brackets 21*a* support the ends of the assembly 49*a* and together with a number of clamps 81 lock the ends of the assembly together. It will be noted that the included doctoring rod 71 similarly as in the preceding example may be insulated and differentially heated, for which purpose individual electrodes 80*a* are provided, this electrical circuit being supplied independently with suitable voltage. Similarly, each of the coater elements may be independently supplied and thus individually temperature controlled, thereby permitting their being differently thicknessed, compositioned and temperatured if desired. Other forms of electrical heating of course may be used, these including induction, dielectric or standard resistance elements, each being capable of zoning and selective temperatures and therefore well adapted to the purposes herein described. It also will be apparent that the coater may be jacketed.

I claim:

1. An apparatus for applying a liquid composition to one surface of a traveling web of paper and metering the superficial thickness of said composition to effect a finished coating, said apparatus comprising, and in concatenate combination, a fountain to dispense said composition conjunctly with said surface, a doctoring means to meter said thickness, a coating chamber having an upweb and a downweb boundary to support said web, said doctoring means comprising said downweb boundary, and vacuous means coactive with said cotaing chamber to effect impaction between said web and doctoring means, and wherein web support means are positioned unobstructedly up- and downweb from, and aligned coactively in a common plane with, said doctoring means, whereby when said web is transited between said support means it will be drawn vacuously into metering relationship with said doctoring means and the superficial coating thickness controlled as a function of subatmospheric pressure independently of web tension.

2. The coating apparatus as described in claim **1**, including pliant membranous means overlying said chamber and adapted to be conjunct transiently with the other surface of said web.

3. The coating apparatus as described in claim **1**, wherein said apparatus comprises an assembly including elongate flat metal members substantially juxtaposed in spaced parallel plane relationship with compression-sealable inserts interposed thereamong, said inserts patterned to contour said fountain and chamber respectively, each of which is boundaried up- and downweb by adjacent said members.

4. The coating apparatus in accordance with claim **3**, including separate withdrawal means for liquid effluent and gaseous exhaust from said chamber.

5. The coating apparatus in accordance with claim **3**, including a distributive duct system patterned in said inserts coactively with communicative porting of said members.

6. The coating apparatus as claimed in claim **5**, including parallel orificed flow means for distributing said composition uniformly.

7. The coating apparatus as described in claim **1**, wherein said fountain includes an upweb and a downweb boundary to support said web, and wherein said downweb boundary of said fountain has a fluted edge to form multitudinous parallel flow ducts conjunct with said surface.

8. The coating apparatus as described in claim **1**, wherein said fountain includes a plurality of discrete pockets to conjoin said surface individually.

9. The coating apparatus in accordance with claim **8**, including means for injecting a plurality of liquid substances selectively into said pockets.

10. The coating apparatus in accordance with claim **8**, wherein one said pocket is non-dispensing and includes drainage communication with said chamber to withdraw adjacent fountain dispensation from a conjuct portion of said surface, thereby to perfect margin definition of said coating.

11. The coating apparatus as described in claim **1**, wherein said fountain is adapted to conjoin said composition nonimpactively upon said surface.

12. The coating apparatus in accordance with claim **11**, wherein said fountain is positioned contiguous said doctoring means.

13. The coating apparatus as described in claim **1**, including a discrete prevacuum chamber positioned upweb from said fountain to communicate vacuously with said surface.

14. The coating apparatus in accordance with claim **13**, wherein said fountain is adapted to conjoin said composition impactively against said surface.

15. The coating apparatus as claimed in claim **14**, including superposed external means to support said web proximate said fountain.

16. The coating apparatus as described in claim **1**, wherein said doctoring means comprises a rotatable rod.

17. The coating apparatus in accordance with claim **16**, including means for heating said rod and for controlling the temperature thereof.

18. In a coating apparatus for applying a fluid substance to a traveling web of paper, said apparatus comprising means for conjoining said substance with one surface of said web, a chamber having upweb and downweb boundaries conjunct with said surface, and means for occluding external air from said chamber, the improvement in said occluding means which comprises, and in combination, a pliant membrane overlying said chamber and adapted to be conjunct transiently with the other surface of said web.

19. In a coating apparatus for applying a liquid composition to a traveling web of paper, said apparatus including a doctoring element to remove an excess of said composition applied to said web, said element conjunct with a chamber, one boundary of which comprises said element, into which chamber said excess can cascade, and wherein said chamber is adapted to be maintained vacuous by gaseous exhaust, the improvement therein which includes, and in combination, a sump toward which said excess can drain laterally, said sump comprising an integral part of said chamber, and separate but cooperable means for withdrawal of said excess from said sump as liquid effluent and gaseous exhaust from said chamber.

20. The combination as claimed in claim **19**, including velocitied air flow means for inducing lateral flow of said excess toward said sump.

21. The combination as claimed in claim **19**, including recycling means for supplying substantially saturate air to said chamber.

22. In an apparatus for dispensing a distributed flow of liquid composition, said apparatus comprising an elongate fountain having an extrusion nip and a pressurable supply chamber, the improvement in said fountain comprising, and in combination, a plurality of precision orifices interposed between said chamber and said nip, said orifices sized and contoured restrictively to effect a significant pressure drop thereacross relative to contiguous downstream pressure and concurrent variation in fluid pressure within said chamber, said orifices preferably aligned, spaced uniformly and sized identically, thereby to effect minimal influence upon the comparative concurrent flow through individual orifices by fluid pressure deviations up- or downstream therefrom.

23. The combination as claimed in claim **22**, wherein said fountain includes a plurality of flow compartments interposed between said orifices and said nip, each said compartment being discrete to a downstream position proximate said nip.

24. The combination as claimed in claim **22**, including reciprocative plunger means for clearing said orifices.

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