Practical Problems Associated With Blade Coaters

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ABSTRACT:- An attempt has been made to use the already developed mathematical model which is based on various mechanical forces holding the blade against the web and fluid dynamic forces caused by the flow of coating formulation through the nip between the blade and the web for design estimation and prediction. The various parameters like speed, coater variables, blade properties, wet film thickness and coating color viscosity have been taken into account. It is indicated that there are certain problems observed during operation of blade coaters like stagnation, consequent streaking and stalagmite. The mechanisms involved are normally obscure and often ignored by the practicing engineers during design stage and evaluation. These problems have been tackled until now by the industry using trial and error method. With the help of the above models these problems have been critically examined in this paper. An attempt has also been made to reexamine the already developed model and to alleviate the above practical difficulties both from manufacturer's angle and as well as mathematical stand point. Due to brevity of space, some of the models are described in brief.

KEY WORDS:- Coating, Trailing Blade Coater, Mathematical models, Blade nip, Streaking, Stagnation, Stalagmite.

INTRODUCTION

Coating is mainly used for increasing gloss and brightness. Various kinds of coating formulations have been made for specific end uses. For the same type of base paper and for the same kind of coating formulations the control of coat weight/thickness and evenness are basically dependent on coating mechanism and hydrodynamic characteristics of coating color.

The coating mechanism in turn depends on the type of coaters to be used for the application. Various kinds of coaters are Cast coaters, Brush coaters, Air knife coaters, Blade coaters, Roll coaters and Extrusion coaters. All the above coaters have specific applications and possess both advantages and disadvantages. Leaving aside the Extrusion coaters, used for polymer application, the blade and roll coaters have predominant usage in the industry. Between the blade and the roll coaters the blade coaters have lot of flexibility in operation and are compatible with high speed paper machines. They are one of the most important devices for producing high quality coated papers. But the mechanism of coating through Blade coaters is not properly understood as complex hydrodynamic theory is necessary for the design, development and prediction of performance in INSITU conditions.

Various engineers have developed many models to relate the variables like coating weight, coating color, the base sheet properties and the operating conditions of the coaters. Before

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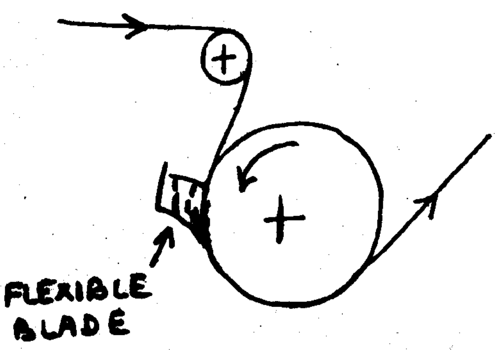
discussing the models and their interpretation for use of practicing engineers, it is worthwhile to describe the trailing blade coater at a glance with its geometric configuration. The various problems encountered in practice are scratching, stagnation, streaking, stalagmite formation, blade bleeding and blade splitting. These problems can be circumvented if proper understanding about the mechanism is known. In fact these can be alleviated by controlling various parameters lumped together.

TRAILING BLADE COATER:

.The trailing blade coater consists of a soft rubber covered roll (around 0.6 diameter) and a closely fitted trough. The leading edge of trough is a flexible steel doctor blade. The paper is led in to color trough with backside in close contact with rubber roll as shown in the figure(1). and it emerges from the color trough at a nip between the flexible blade and the rubber backing roll. The blade is forced against the backup roll with sufficient pressure to cause the free edge of the blade to deflect as the web travels downward past the blade (1, 2). The mechanism of action by a trailing blade coater is shown in fig. (2). The function is self explanatory. Advantages of Trailing Blade Coater are:

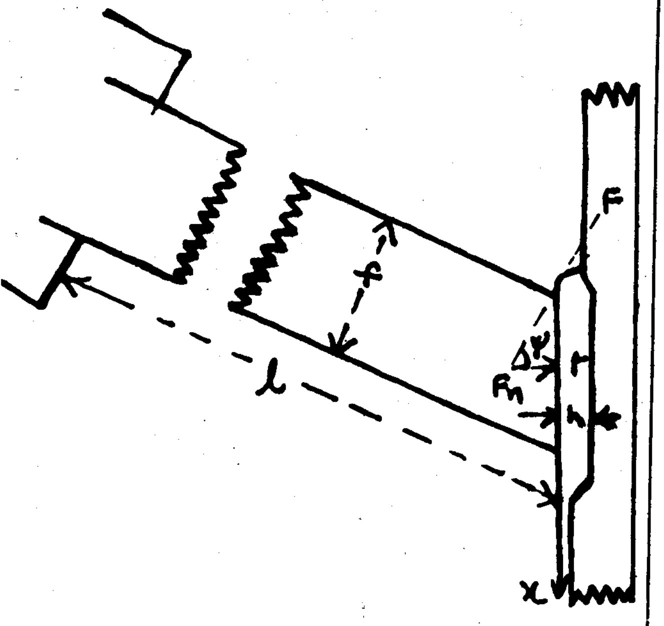
1. In this coater metering, application and smoothening of the coating formulation are accomplished simultaneously.
2. It can be operated at speeds greater than 450 m/min.

Fig- 1.



A TYPICAL SKETCH FOR THE ACTION OF TRAILING BLADE COATER (RICE-BARTON MAKE)

Fig. 2



SCHEMATIC VIEW OF COATING NIP

3. It can handle a wide solids content range and also a wide viscosity range (Viscosity of about 10,000 cps is preferred to prevent leakage around the end dams).
4. It does not involve transfer of coating from one roll to another, so there is no tendency to throw droplets of coating from the roll surfaces. Also it is free of roll patterning.
5. Both off and on machine coating operations are possible.

It is important at this stage to give typical formulations used for blade coating (Table 1)

Trailing Blade Coating Formulations (1)

Table-1

(Bread wrap, Carton sealers, Box board and Publication paper)

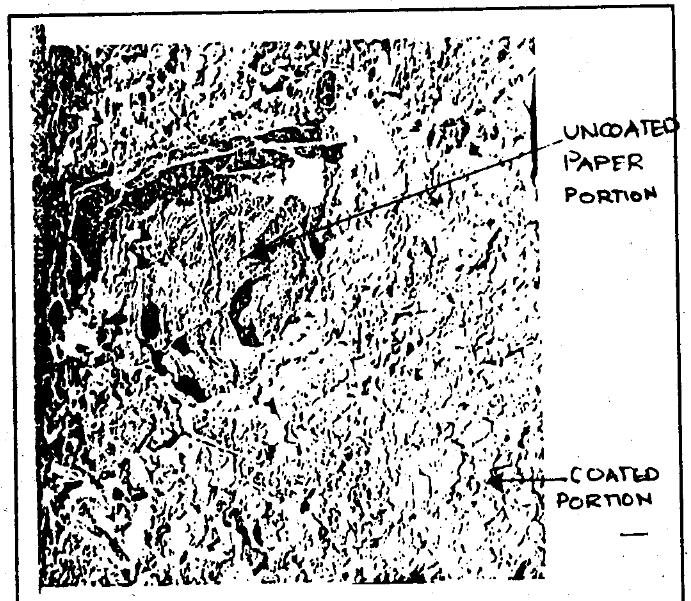
Pigment	Parts by weight			
Titanium dioxide	100	20	6	-
Clay Coating grade	-	80	94	90
Calcium Carbonate ppt.	-	-	-	10
Dispersants etc.	----------as needed--------			
Binder				
Latex	12	15	15	-
Antifoamer, thickener etc.	--------as needed----------			
Starch	-	-	-	10
Total solids	60%	60%	63%	55%
Coating weight(gsm) one side only	4-8	4-8	24-34	-

Having ideas about the blade coating geometry and its functions, the mechanism is now attempted in the following paragraphs.

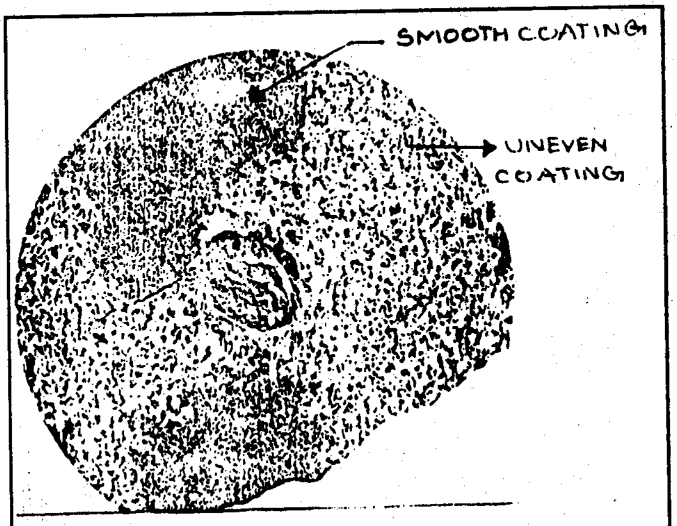
BASIC MECHANISMS IN BLADE COATING:

In order to gain some insight into the effects of machine speed, coater variables and coating viscosity on the type of coating applied, several models of blade coating process have been developed. Some of these are summarized below:

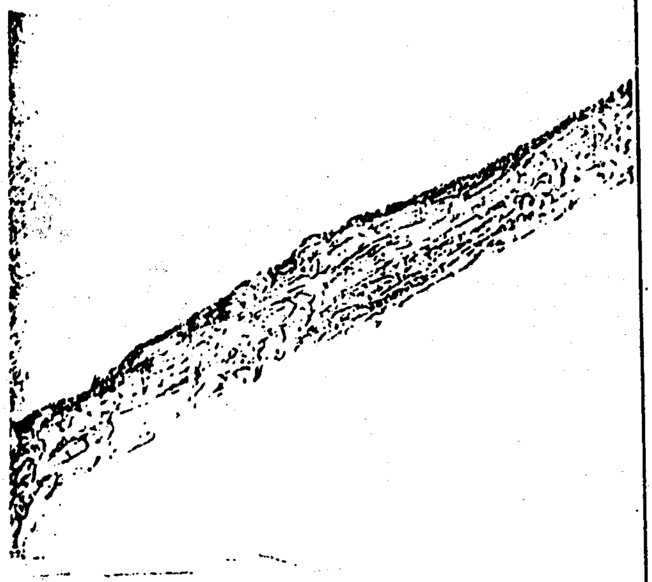
1. HUNGER'S MODEL: While the roll coaters, printing typecoaters or transfer coaters offer a premetered amount of coating to the raw stock which is transferred in a pressure nip, the blade coaters or trailing coaters apply an excess of coating to the raw stock. Blade coaters fill almost all surface voids, some of them to considerable depth. This coating is then metered by a metering device which will leave coating material in the lower portions of the web contour and remove it from the high elevations. In some cases the latter are scrapped completely bare of coating and sometimes, depending on the pressure, considerable scratch marks may be left on these fibers, caused either by the blade itself or by coating particles being trailed at great force over these areas (3). The imperfections and unevenness have been pictured through the photo micrographic views by Hunger in figures (3-6). It is reflected that there are considerable irregularities in many uncalendered papers indicating the possibilities of rejections. Therefore it is important to have a fresh look to the basics of the coating mechanism so that these problems can be effectively dealt with.



FIG(3) TYPICAL VIEWS OF IMPERFECTIONS OF COATED PAPERS (6



FIG(4) PICTORIAL REPRESENTATION OF UNEVENNESS OF COATING UNDER TRAILING BLADE COATER (6)



5) TRAILING BLADE COATED, UNCALENDERED PAPER(6)

FiG (6) EXAMPLES OF IN A TRAILING BLADE COATED UNCALENDERED PAPER (6)

2. BOHMER'S MODEL: It is concerned with the shear rates developed at the blade tip in a blade coater. It points out that the angle at the blade tip is nearly equal to the angle of the blade holder(4).

3. BLIESNER'S MODEL: It emphasizes that the basic controlling mechanism in blade coating is hydrodynamic in nature than viscoelastic. Thus, blade coater does an excellent job of filling in the surface voids to produce a level coated surface but is incapable of achieving complete coverage of the raw stock(5).

4. TURAI'S MODEL: Turai developed a mathematical model of blade coating process by equating the mechanical forces holding the blade against the web and the fluid dynamic forces caused by the flow of coating liquid through the nip formed between the blade and the web (6).

$$\theta = \frac{UWh}{2} - \frac{h^3 WtE\delta \cos\Psi \sin^2\Psi}{48\eta\ell^3}$$

It relates the volumetric flow rate to the machine speed, coater variables, blade properties, wet film thickness and coating viscosity. The model developed by Turai can be used effectively to eliminate streaking in blade coating process. There are various problems encountered during the operation of Blade Coaters such as specks, streaks, scratches, bubbles, curling, blocking, blackening, fish eyes etc. These are elaborately described by Kapoor(2). Some of the remedial measures have been explained. Still there exists some uncovered part of the problems which require much more understanding. These are streaking, stagnation, stalagmite formation, blade bleeding and blade splitting. In this investigation these are discussed in more detail.

STREAKING:

If the coating slurry loses water and the pigment concentration exceeds approximately 70%, the pigment will settle out of the slurry. The pigment particles may get lodged between the blade and the paper resulting in streaky coating. Streaks in a colored coating can be traced to insufficient mixing or to selective settling after mixing. Excessive viscosity, which results in an uneven flow of coating machine is also a possible source of this defect.

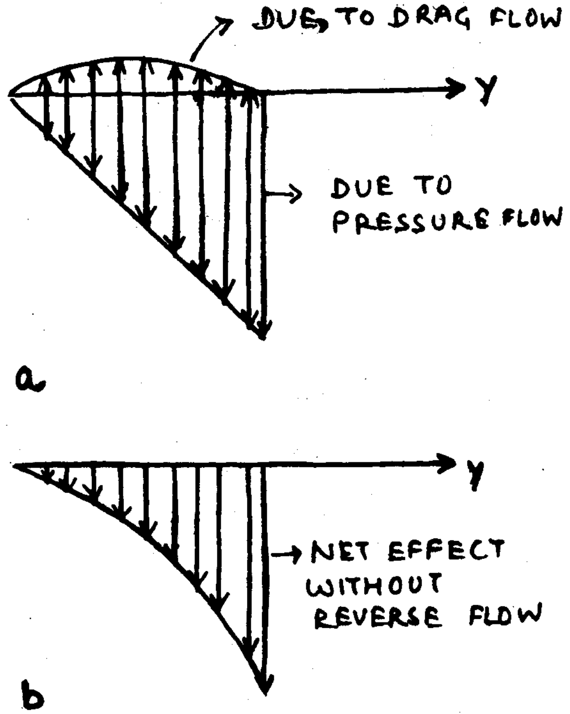
STAGNATION -COATING STREAKS:

According to mathematical model developed by Turai (6), the velocity of coating liquid in the nip is given by

$$u = \frac{U}{h} Y - \frac{dp}{dx}\frac{(hy-y^2)}{2\eta}$$

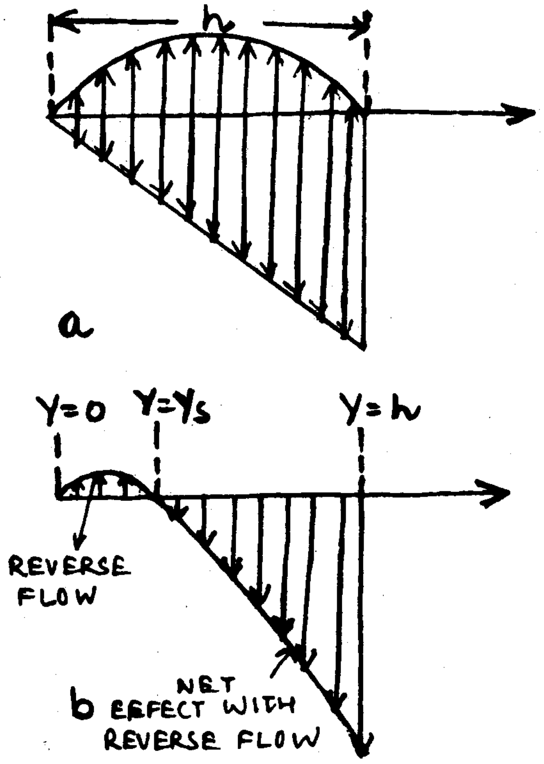
The first term represents the velocity component due to drag effect of the stationary blade (drag flow). The second term represents the velocity component due to the pressure gradient acting in the x direction (pressure flow). Fig.(7 & 8) show the velocity profiles on the xy plane in the channel of width h (figure 2) formed by the beveled edge of the blade and the web being coated, in case of the existence of a net reverse flow and when no net reverse flow exists.

At any point along y axis where the pressure flow exactly balances the drag flow, there will be a STAGNATION POINT and, corresponding to the whole width of the blade there will be a plane of stagnation in the channel in the xz plane. At the stagnation point the resultant velocity is u=0. For this condition to be satisfied the following Eq. holds



VELOCITY PROFILE ON XY PLANE
(WITHOUT REVERSE FLOW)

FIG.7.



VELOCITY PROFILE ON XY PLANE
(WITH REVERSE FLOW)

FIG.8.

$$\frac{U}{h} Y_s = \frac{dp}{dx} \frac{(hy_s - y_s^2)}{2\eta}, Y_s = -\left(\frac{2\eta U}{h(dp/dx)}\right) - h$$

The negative value of y indicates the non existence of a stagnation point within the nip. Hence

$$\frac{h^3 W t E \delta \cos \Psi \sin^2 \Psi}{48 \eta \ell^3} > \frac{UWh}{6}$$

The left side of the above inequality represents the pressure flow and the right side represents one third of the drag flow. Therefore condition for the existence of a stagnation point in the coating nip is that pressure flow be larger than one third of the drag flow. In order to avoid stagnation and consequent streaking, therefore is:

$$\frac{h^2 t E \cos \Psi \sin^2 \Psi}{U \eta \ell^3} < 8$$

The dimensionless expression on the left side of inequality is called the CRITICAL COATING NUMBER (6). Hence we need to regulate the coating conditions in such a manner that the critical coating number shall be less than 8.

EXPERIMENTAL VERIFICATION

Under the following machine and coating conditions, the model was tested for streaking problem.

$U = 5$ m/s, $W = 0.508$m, $t = 0.0508$ m, $\delta = 0.32 \times 10^{-2}$m, $E = 2.2 \times 10^9$ kg/m^2, $\Psi = 60^0$, $h = 1.74 \times 10^{-4}$m, $\eta = 1.1 \times 10^{-3}$ kgs/m^2

Therefore:

$$\frac{h^2 t E \delta \cos \Psi \sin^2 \Psi}{U \eta \ell^3} < 8$$

Predictions concerning the absence of streaks was confirmed from the data.

ELIMINATION OF STREAKING IN HIGH SPEED MACHINES

Research workers, Ortman and Donigian (7) have found coat weight variation in CD during high speed operation of roll blade coaters and named these variations as STREAKING. They expressed the variation as MD, high coat weight streaks which are typically a few mm wide. At high coating speeds the backing roll has a much greater effect on blade coating uniformly than had been recognized previously. Streaking appears to be related to rib pattern, originating at the divergence of the applicator/backing roll nip. The ribbed coating flow is proposed to cause an irregular pressure field with CD variations in the vicinity of the blade. When the pressure field variation are great enough to non uniformly deform the roll, non uniform coat weights pass underneath the blade, producing a streaky coating.(7)

Streaking can be eliminated by reducing CD variations in the coating approaching the blade, or by reducing the deformability of the backing roll. The irregularity of the pressure field immediately before the blade can be reduced by using a premetering device before the blade or by operating in a low angle mode. The deformability of the backing roll can be reduced by increasing the elastic modulus of the rubber roll. Varying the applicator gap changed the width and frequency of the streaking but did not eliminate streaking. Paper compressibility, due to its relatively high elastic modulus and low thickness, has less effect on coating non uniformities than the backing roll.

STALAGMITE PROBLEM:

Stalagmite is a rock constituted of solid particles of coating formulation, formed at the tip of the blade. Though engineers/ designers usually ignored this problem, Stalagmite is of paramount importance as far as the performance of blade

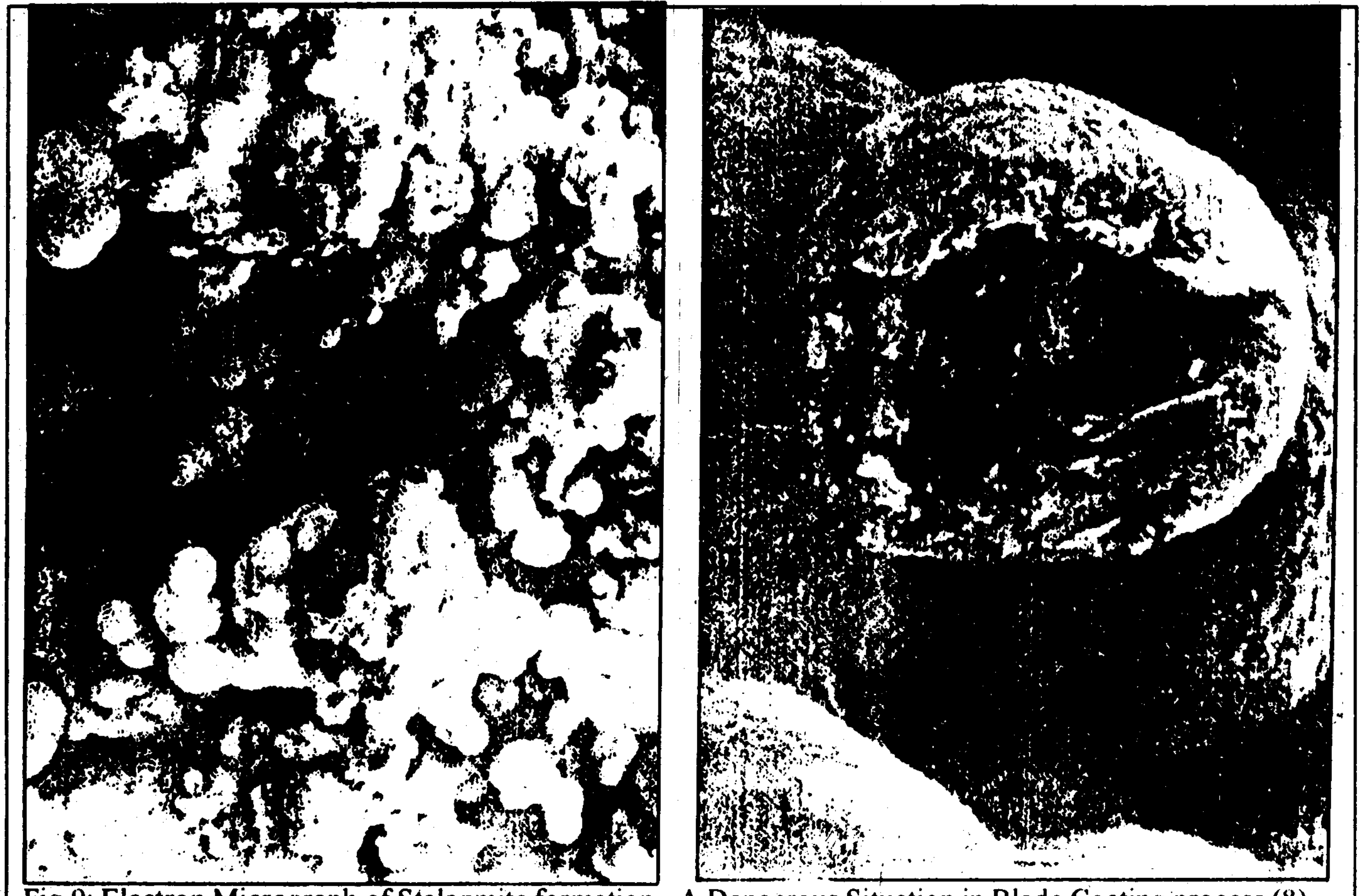


Fig.9: Electron Micrograph of Stalagmite formation - A Dangerous Situation in Blade Coating process (8).

STALAGMITE FORMATION

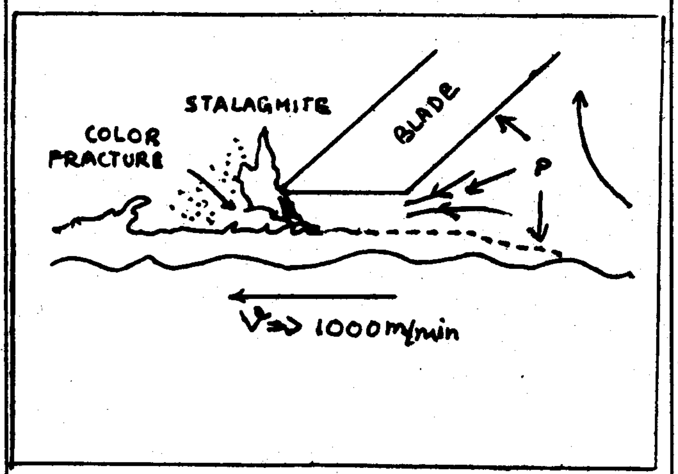


FIG.(10)

coaters is concerned. It occurs when the blade coaters are used with high speed machines. Stalagmite deposition varies in appearance from mill to mill and between machine and formulation. The contour view of Stalagmite formation as obtained by electron microscope is shown in fig.(9). The exact theory of formation and understanding is a complex phenomenon. However analysis of stalagmite deposits often show that there is an absence of fiber and debris within the stalagmite. Deposits often appearance on the upstream side of the blade after prolonged running times. The appears of stalagmite growth at the exit or downstream side of the blade with time has implicated these upstream deposits (fig.10).

Continuous vortex circulation in the upstream flow could generate the necessary long term shear for this to occur. The upstream deposits in itself is not a necessary condition for poor runnability, but it is probably a manifestation of the process which ultimately is likely to lead to yet another mechanism based on contamination in this case by large particles or aggregates.

The blade geometry and solid content in coating formulation play an important role in the formation of stalagmite. A simplistic view can be afforded by considering the pressure drop on the downstream side of a particle in a velocity field. Fig.(11) illustrates this effect for large clay platelets as the high velocity stream lines become compressed in the flow between the particles and the base paper. A resultant acceleration of the solid material to the low velocity boundary has the effect of raising the solid content in the color in contact with the blade. Cross sectional area of the particle presented to the flow is important factor in such a mechanism.

PHASE SEPERATION UPSTREAM & AT THE TIP

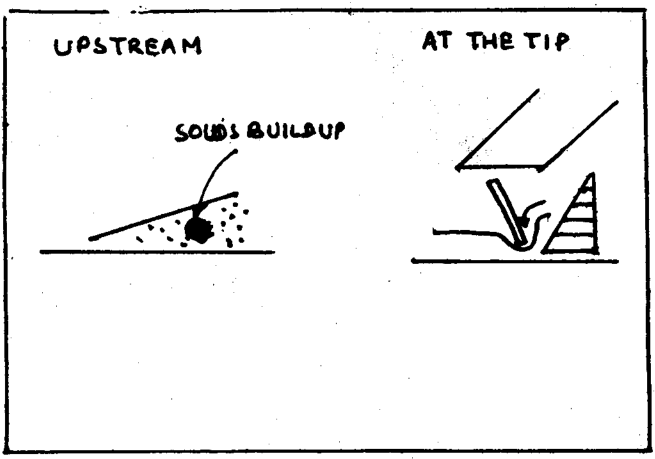


FIG.(11)

DIFFERENT TIP LENGTHS

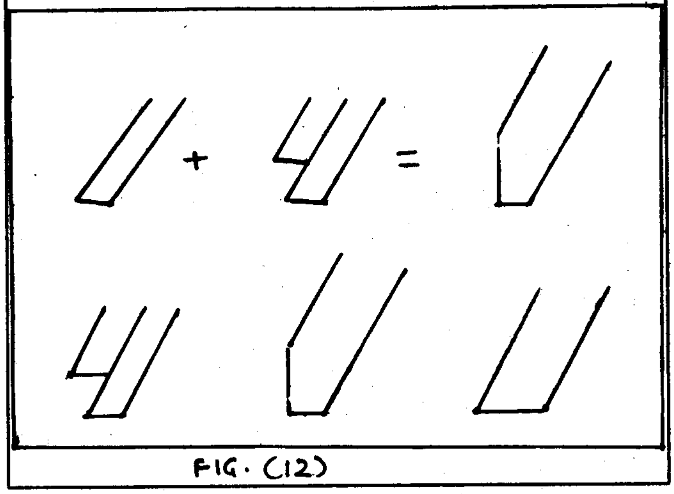
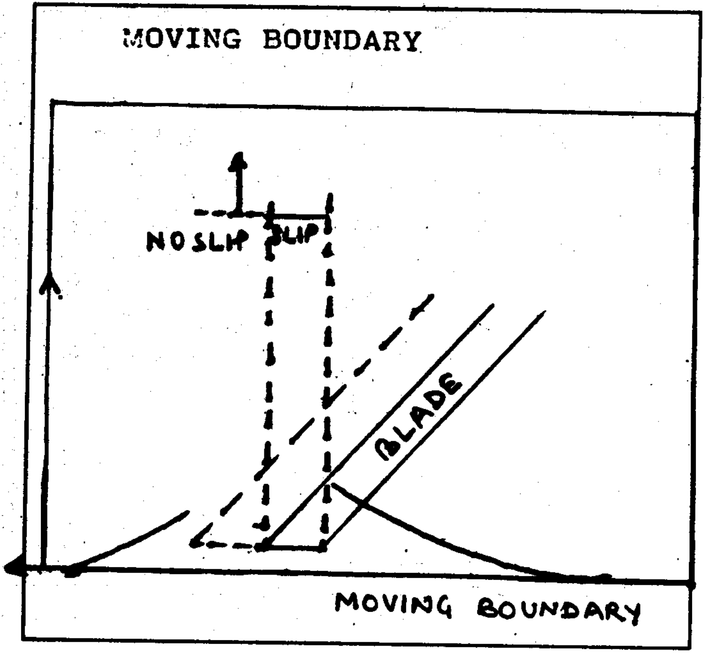


FIG.(12)

Disordered platelets will pose a greater problem than either ordered, thin platelets or fine, spherical particles. The clear evidence that stalagmite growth may coexist in many cases with a satisfactory coating on the paper is perhaps the key to understanding the mechanism of blade bleeding. Blade bleeding is an apparent extrusion of coating color in solid content ranging from wet to dry. It is observed when there is high solid in conjunction with low blade angle (stiff blade mode) and high speed.



An optimum balance should be taken between solid content in coating formulation and blade geometry. It was observed that the tip length of the blade affects the runnability. So for optimizing the blade thickness first the speed differences were checked out by taking different tip lengths, (Fig. 12). On analysis it was found that with thicker blade the runnability was reduced markedly. For example, SPS at 63 wt% solids in an offset formulation of 11 pph SBR latex and 1 pph CMC had a maximum runnable speed reduction of 400 m/min. on going from the thinner to the thicker blade (0.3 mm and 0.54 mm).

By considering the greater tip length it was found that the probability of establishing a zero velocity boundary condition will be higher due to the increased residence times. The condition of slip/non slip [Fig (13)] will occur depending upon the relative velocity. The shorter the boundary contact length the less likely is the zero-velocity boundary condition to become established. Blade spitting or "fleas" leads to deposition of a discreet quantity of excess coating on the paper. A plug flow phenomenon in which the slippage at the blade boundary predominates at high speeds will prevent blade spitting to occur.

So by above analysis we see that the stalagmite formation or "beard" plays an important role in the reduction of runnability.

REMEDIAL SOLUTIONS:

1. If the blade is fitted at an angle which truly satisfy zero velocity boundary condition then blade wear will be reduced as the abrasive particles would not have any motion relative to the blade and would also make a bridge over the small gap between the blade and the base paper and contributing to the break down of idealized continuum flow.
2. Replacement of a worn blade or use of nonwetting material can eliminate bleeding i.e. an unwetted blade encourages boundary slippage and plug flow.
3. A low viscosity fluid medium is known to encourage phase separation at the flow boundary. Hence it will prevent vortex formation which is the root cause of stalagmite formation.

CONCLUSION:

Various aspects of blade coaters were analyzed. The remedial solutions of STREAKING were given with the help of a mathematical model. Stagnation should be avoided to alleviate streaks formation. Having seen the importance of blade coaters in high speed paper machines. the problem of STALAGMITE was discussed and the solutions were offered. Keeping these solutions in mind, the blade coaters can be used in an efficient manner.

LITERATURE CITED

1. Heiser E. J., Svensk Papperstidning, 389(12) : 61(1958)
2. Kapoor J., Coating Theory and Practicals , IPPTA Journal
3. Hunger G. K., Tappi 54(11): 1847 (1971)
4. Bohmer E., Svensk Papperstidning 70(2): 673 (Oct. 1967)
5. Bliesner W. C., Tappi 54(10): 1673 (1971)
6. Turai L. L., Tappi 54(8) : 1315 (1971)
7. Ortman B. J. and Donigian D. W., Tappi 1992 Coating Conference.
8. Patrick A. C. Gane, Philip McGenity and Philip

Watters, Tappi (1992) Pg. 61-73.

9. Williams A and Preston J S., Tappi 1990 Coating Conference Proceedings, Tappi Press Atlanta P.405.

NOMENCLATURE

η = Viscosity (kg/m.s.)
ρ = Density (kg/m^3)
P = Pressure (kg/m^2)
U = Constt. Velocity (m/s)
W = Width (m)
h = Depth (m)
Q = Volumetric Flow Rate (m^3/s.)
ℓ = Blade Extension (m)
E = Elastic Modulus (N/m^2)
t = Thickness of the Blade (m)
δ = Deflection (m)
Ψ = Angle formed by the Blade and by the Tangent to the Web (Degree)