Formation of Films on Hatschek Machines

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Summary

The success of fibre cement manufactured by the Hatschek process is largely due its formation in thin paper like films that are placed one on the other until the desired sheet thickness is reached. Formation of the sheet by this means distributes the reinforcing fibres in two dimensions taking best advantage of the reinforcing fibres to increase the in-plane strength of the sheet. Thus the strength of sheets made in this fashion is approximately 50% greater than sheets formed to full thickness in one action in the filter press process.

Sheet formation on the Hatschek Machine occurs in 4 stages.

1. Initial formation of a filter layer on the surface of the sieve
2. Building of a very watery layer of fibre cement over the filter layer as the sieve rotates in contact with the slurry in the vat
3. Low intensity dewatering of the wet film as it transfers to the felt and
4. High intensity dewatering of the film as it passes through the nip of the accumulator roller.

This paper examines the second of these processes in detail. For fixed set-up of the vat, the thickness of the film formed during the passage of the sieve through the slurry is found to be proportional to the square root of the solids concentration of the slurry in the vat divided by the speed of the machine. Data from operating Hatschek machines is presented to demonstrate the validity of this relationship.

The significance of the relationship for control of sheet flatness and of the machine overall particularly with respect to sheet thickness is discussed

Introduction

The Hatschek machine was first developed for the production of asbestos cement in the 1890's when it was patented by the inventor, Ludwig Hatschek. The machine is still used in the same basic form today and although modern Hatschek machines are much more productive than the early models they would still be recognised by the inventor if he were alive today.

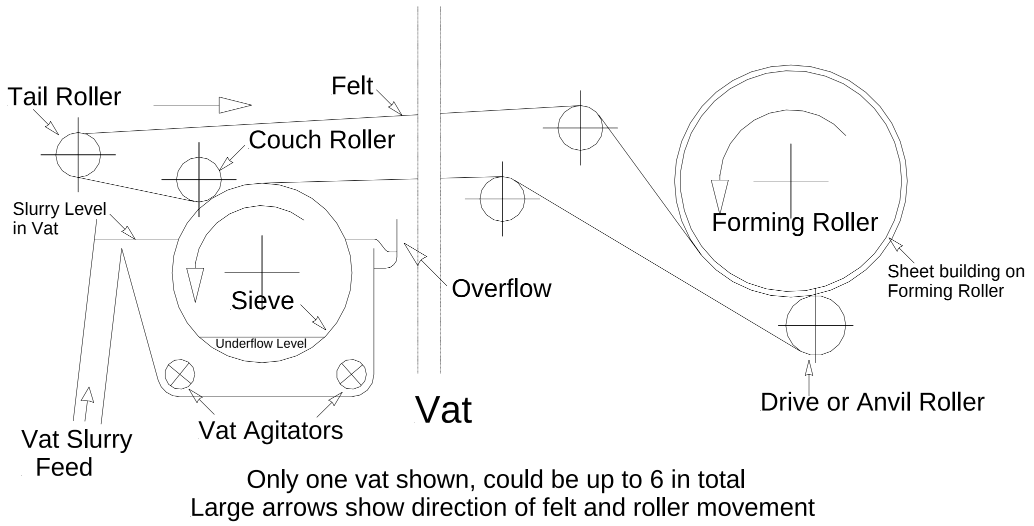


Figure 1: Schematic of Hatschek Machine showing principal components.

The fundamental part of the Hatschek machine consists of a vat in which a cylindrical sieve rotates in contact with a dilute water based slurry of fibres capable of forming a filtering film and mineral materials including Portland cement. (Figure 1) The sieve cylinder is mounted on an axle and driven by a continuous felt wrapped around the top of the sieve by a couch roller. The felt is threaded around a drive or anvil roller and a tail roller. The drive or anvil roller is pushed into hard contact with an accumulation roller.

Sheets are formed on the Hatschek machine as follows.

1. As the clean sieve is pulled under the slurry in the vat, water from the slurry runs through the sieve depositing a soft porous film of fibres and cement on the surface of the sieve.
2. The sieve carrying the film exiting the vat is brought into contact with the felt stretched tightly across the sieve. This removes much of the water from the film by forcing it back through the film. The solid film floats on this layer of water and is transferred to the felt partly in response to the effect of removal of water and partly because the felt has a greater affinity for the film than the sieve. (Figure 2)
3. The film is carried on the felt to an accumulator roll to which it is transferred by further removal of water at high pressure.
4. A sufficient number of films are wrapped on the accumulator roll to form a sheet of the desired thickness, the stack of films is then removed from the roller and laid out flat to form the sheet. The action of dewatering successive films in contact with each other under pressure is sufficient to bind the films together to form a contiguous solid sheet.

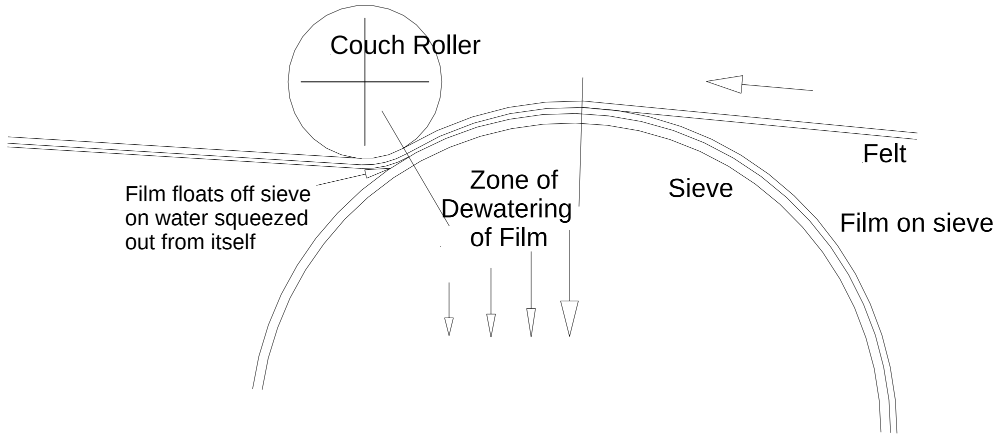


Figure 2: Primary dewatering of the film on removal from sieve

The purpose of this paper is to examine the first of these processes in detail and to determine those machine parameters that determine the rate at which films can be built.

As may be anticipated from the structure of the Hatschek machine, it is not possible to measure the thickness of films as they are deposited on the sieve within the vat of the operating machine. Nor is it easy to measure the thickness of the soft film on the sieve in the gap between the water and the point where the felt comes in contact with it. Nor is it easy to measure the thickness of the film being conveyed on the felt to the accumulations roller. Thus the average thickness of the film must be inferred from the thickness of the final sheet divided by the number of films that make it up.

Experience with secondary compression after sheet formation tells us that it is possible to alter the pore structure of formed sheets. One would therefore infer that the formation pressure in the nip of the drive and the calendar rolls influences the thickness of the final sheet and the apparent thickness of the films that are formed in the vat. However, it will be seen from what follows that dewatering of the films within the Hatschek machine during the transfer of the film from the sieve to the felt has negligible effect on the final dry film thickness. It will also be seen that although the sheet thickness is affected by nip pressure at the forming roll, the effect is small. Nip pressure may also be ignored with little loss of accuracy when only the primary effects on rate of film formation are considered.

It may also be noted that modern Hatschek machines combine 4 or more vats in series to increase productivity. The results reported below are from runs on a 4-vat machine with two or more vats running simultaneously. Thus to derive a theory of film deposition, it was necessary to assume that the conditions in each vat were identical. Despite these assumptions, it will be shown that an accurate prediction of film thickness can be made from a combination of set up and operating conditions within the machine.

Detailed Mechanism of Film Formation

The general mechanism of film formation is by filtration. A cylindrical sieve is rotated in contact with a slurry of fibres and non-fibrous materials, a film forms and is continuously stripped from the sieve as it emerges from the sieve vat. Formation of the film takes place as follows

1. A filter layer of fibres forms on the surface of the sieve within a short distance the immersion of the sieve into the water.
2. The film continues to build up on the sieve but now contains a lower proportion of fibres and a greater proportion of the non-fibrous materials.
3. The film is dewatered and stripped from the sieve on to the felt driving the sieve.

It may be noted that the position of formation of the filter layer (in 1 above) depends on the mode of operation of the Hatschek Machine fibre orientation screw. Two possibilities exist,

1. The fibre orientation screw runs counter to the sieve direction and throws the slurry onto the sieve above the immersion point. In this case most of the formation of the filter layer occurs before the sieve enters the slurry.
2. The fibres orientation screw runs in the same direction as the sieve that may be fitted with a rubber flap extending 50 mm or so beneath the surface of the slurry. In this case the formation of the filter layer takes place just below the rubber flap.

Materials

The feed to a Hatschek machine is a slurry of fibres, Portland Cement and finely ground minerals in water.

Fibres: Asbestos fibres were used in the original formulations and indeed asbestos containing fibre cement is still made today. In later times asbestos was supplemented and more recently has been totally replaced with cellulose fibres of various kinds. It is also common to use various synthetic fibres capable of providing specific properties to the final product. In this paper we will concentrate on modern cellulose based composites as these are of more abiding interest.

Cellulose fibres may be up to 4 mm in length depending on the wood species used. The commonly used wood fibres are less than 3 mm. Cellulose fibres may vary in diameter but their diameter variation is small from species to species is typically around 40 µm.

No matter what is the source of the fibres, filter film formation is dependent on their hydraulic properties.

Non Fibrous Materials: The specific materials used in addition to Portland Cement in modern fibre cement depend on the properties intended in the final product. There are two main categories of cellulose fibre cement - low temperature cured (commonly known as air cured) and high temperature or autoclave cured. Air cured formulations will usually contain large amounts of Portland cement combined with very finely divided materials such as clays, Silica fume, ground limestone or fly ash. Autoclaved formulations will normally contain finely ground silica with other finely ground minerals and lesser quantities of cement all.

With the exception of clays and silica fume that may have particles size of 2 µm or less, non-fibrous materials typically average around 50 µm in diameter the same size as Portland Cement. This is important in the formation of films.

Formation of the Filter Layer

Typical sieve apertures are around 0.4mm (400 μm) and clearly the non-fibrous material is significantly smaller than the sieve apertures and so would wash through the sieve. Fibres on the other hand are able to bridge the wires of the sieve although any fibre presenting perpendicular to the sieve surface could also pass lengthwise through it. Entrapment of the non-fibrous materials therefore depends on the formation of a filter layer of fibres on the surface of the sieve. Fibres of this filter layer can be clearly seen on the front face of fibre cement sheets formed in an overflow Hatschek machine, although this is not so clear in sheets formed on a machine with static or non-overflow vats. (Fig 3)

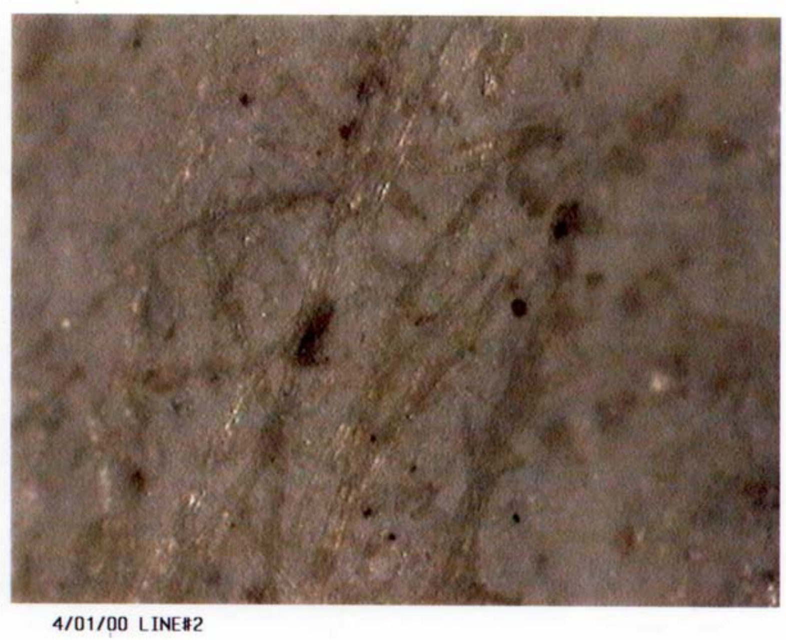


Figure 3 a – Top surface of Fibre cement from an overflow machine

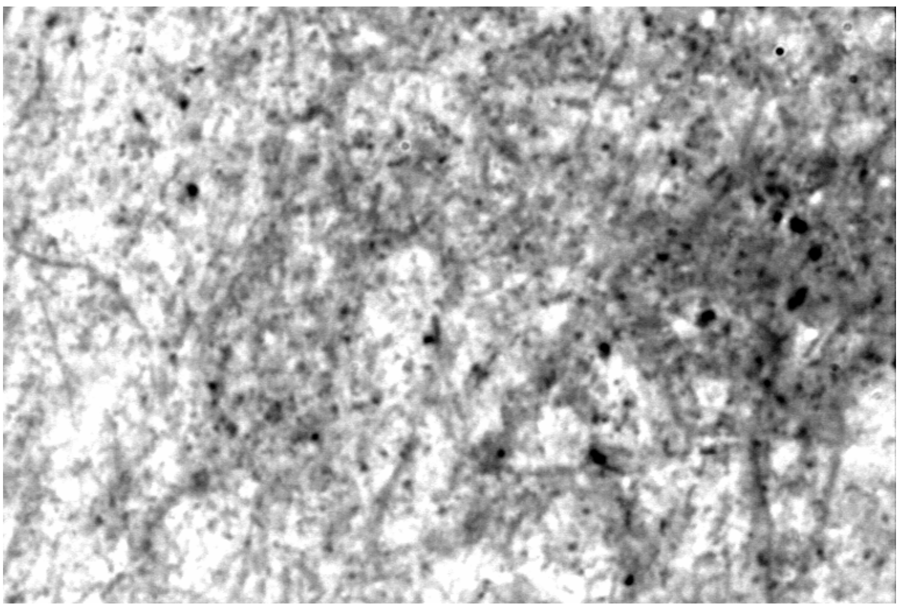


Figure 3 b - Top surface of Fibre cement from a static tub machine

The efficiency with which this filter layer traps the non-fibrous material depends on the conformation of the fibre and treatment of the raw fibre to reduce its effective diameter is necessary. This is done by a process of refining where the fibre is crushed without cutting. Refining has the effect of disrupting the internal structure of the fibre thus making it more flexible, while raising fine fibrils from its surface that reduce its hydraulic radius and provide a means by which other fibres can be entangled with each other. Some species of wood fibre also split and can be expanded to form a fine network. The result is that the cellulose fibre after refining has the ability to form a network of fine fibres capable of trapping at least the larger non-fibrous particles. This forms an initial filter layer on the surface of the sieve and allows the formation of the film.

It should be noted that refining of synthetic fibres commonly used in air cured formulations is not usually possible. Synthetic fibres have an homogenous structure and refining would cut them rather than develop their surfaces. Refining of wood derived cellulose is only possible because of the complex internal structure of the wood fibre that is able to absorb and dissipate the energy of refining without cutting or damaging the fibre. Thus air-cured formulations contain a minimal amount of cellulose for film formation purposes even though this may not contribute much to the final mechanical properties of the fibre cement.

Once formed, the filter layer commences to trap the non-fibrous particles and they in turn block up the spaces between the fibres. Thus the pore size of the film rapidly reduces and the finest non-fibrous particles are trapped in the film.

The film therefore has a structure with a fibre rich face on the sieve and a relatively fibre poor back surface. This structure is the same in all films and is maintained after formation in the final product due to the fact that the film is reinforced with fibre. The fibre prevents the film from deforming during the stresses of manufacture. Thus although a small amount of finer material may be displaced from its place of deposition deeper into the film this will be small and the proportion of solids of different sizes in different places in the film will remain consistent.

Theory of Filtration applied to the formation of Films on the Hatschek Machine

Filtration theory assumes that the filter medium (the sieve in this case) has the same permeability and properties as the resulting filter cake, (the film in this case). In other words it ignores the formation of the filter layer for the sake of simplicity. This is justified in this and the more general case because it is normal practice to coat the filter cloth in say a plate and frame filter with fine material such as Diatomaceous Earth to provide an initial barrier on which the filtrate will collect.

Adopting the same approach and assuming that the cake is incompressible under the conditions of formation Coulson and Richardson [i]provide the following expression.

$$\frac{1}{A}\cdot\frac{dV}{dt}=\frac{\Delta P}{r\mu\,\ell} \qquad (1)$$

where

ℓ = *cake thickness* (*the thickness of the film*)

μ = *slurry viscosity*

ΔP = *Pressure Drop across the film*

A = *Area of the Cake*

$r=\frac{5\cdot(1-e)^2\cdot S^2}{e^3}$ *the specific resistance of the Cake*

S = *the Specific Surface of the Particles*

e = *the void ratio of the cake*

V = *volume of filtrate*

t = *time*

This expression relates the amount of liquid being filtered in unit time per unit area of filter medium to the pressure drop, the filter cake thickness and the properties of the slurry being filtered. However we are interested in the rate of formation of the film or the rate of formation of the filter cake. We therefore rearrange this expression realising first that for constant solids concentration of the feed to the sieve we may related the volume of the cake to the volume of the filtrate by the following expression.

$$v=\frac{JV\rho}{(1-J)(1-e)\rho_s-Je\rho} \qquad (2)$$

where

J = *the solids content of the feed slurry*

ρ = *the density of water*

ρ_s = *the density of the solids in the slurry*

and *the other variables are as described in Equation 1*

Using v we can write

$$\ell=\frac{vV}{A} \qquad \& \qquad dV=\frac{A\cdot d\ell}{v}$$

Therefore by substitution in 1we obtain the following differential equation (3) relating film thickness with time.

$$\ell\cdot d\ell=\frac{v\cdot\Delta P\cdot dt}{r\cdot\mu} \qquad (3a)$$

Integration of 3 will allow us to estimate the film thickness at any time under the conditions within the machine. To translate this into machine conditions we need to relate time in contact with the slurry to machine operating conditions. We do this by realising that for a felt speed (s) and sieve radius (R) we may write for some arbitrary angle (2)

$$t = \frac{R \cdot \theta}{s} \qquad \textit{whence} \qquad dt = \frac{R}{s} \cdot d\theta$$

$$\textit{and} \qquad \ell \cdot d\ell = \frac{v}{r \cdot \mu} \cdot \frac{R}{s} \cdot \Delta P \cdot d\theta \qquad \textit{(3b)}$$

Equation 3b now relates the development of film thickness to operating conditions within the machine specifically felt speed and sieve radius with Pressure drop across the film and properties of the feed slurry and the film.

If the pressure drop across the film were constant, then the calculation of film thickness would be easily calculable from 3b. However it is evident that the pressure drop across the film varies with the position in the vat so this complicates the analysis.

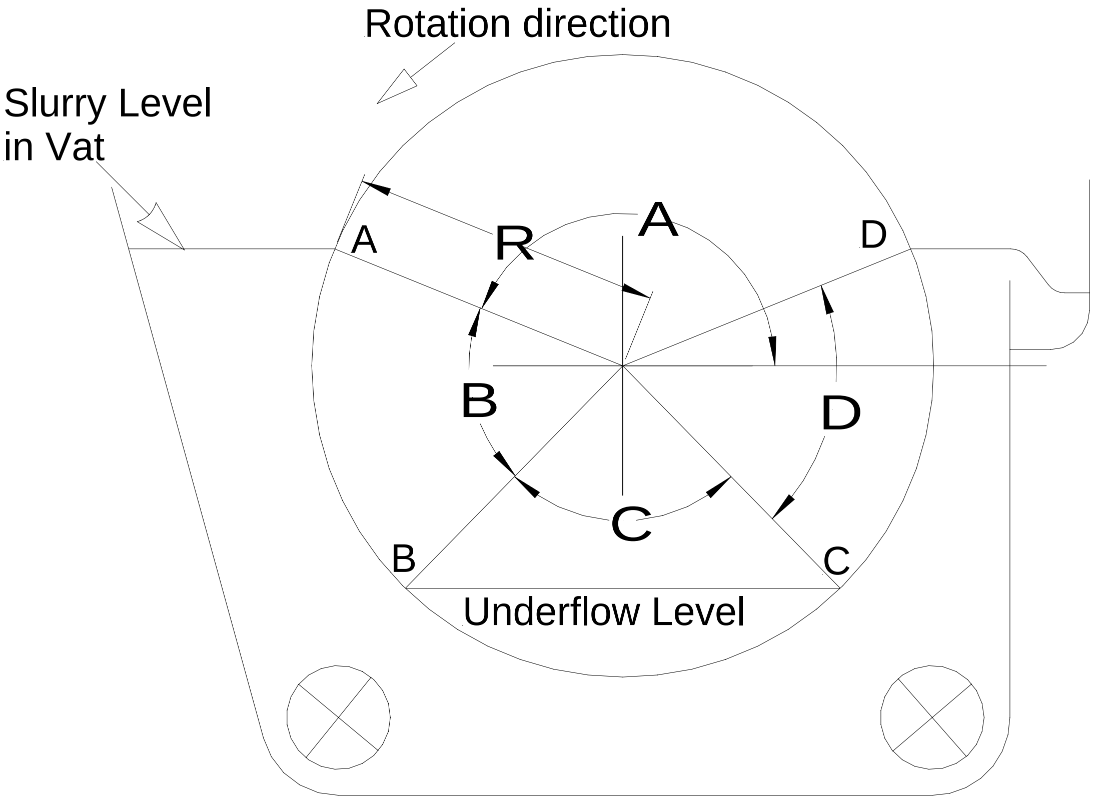


Figure 4: Section through a Hatschek Machine Vat

Consider figure 4 showing a typical Hatschek Machine vat where the sieve rotates anticlockwise. The sieve dips below the slurry level at A and emerges at D where in both cases the pressure drop *)P* across the sieve due to the slurry will be zero. From A to B the pressure rises to a maximum and from B to C it remains constant at that maximum. From C to D it falls again to zero.

For the portion of the sieve where it dips beneath the surface of the slurry, we may relate the pressure drop across the film in relation to position of the sieve with the equation 4 that follows. It should be noted that we have chosen to ignore the centrifugal force that is the result of rotation of the sieve. This will reduce the pressure drop that drives film formation and in the ultimate will cause the sloughing of the film from the sieve.

$$\Delta P = R \cdot g \cdot \rho_f \cdot (\sin\theta - \sin A) \qquad (4)$$

where

R = Radius of the sieve

g = acceleration due to gravity

ρ_f = density of the slurry feed

θ = angular position of the sieve

A = angle to zero the point of measurement of angle

Similar expressions can be used to determine the pressure for the remainder of the immersion of the sieve and the pressure drop across the sieve can be calculated.

The pressure drop across the sieve is illustrated in Figure 5 where pressure in Pa is shown for a typical sieve vat. It is assumed that the sieve diameter is1200mm, the underflow level is 200 mm above the invert of the sieve and the slurry level is 150 mm below the crown of the sieve.

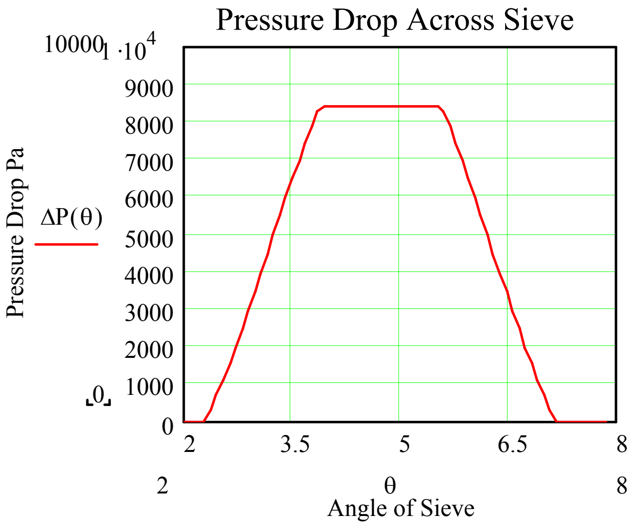


Figure 5 Pressure drop across a typical Hatschek Machine sieve due to slurry depth

It is seen that the pressure drop rises sinusoidally from zero at position A to the maximum at position B remains constant from B to C and falls sinusoidally again to zero at position D.

Having now determined the pressure relationship for the first section of the process we substitute for)P in equation 3b and integrate the differential equation over angle B to determine the film thickness at point B.

$$\ell \cdot d\ell = \frac{v}{r \cdot \mu} \cdot \frac{R}{s} \cdot R \cdot g \cdot \rho_f \cdot (\sin\theta - \sin A) \cdot d\theta$$

Integrating and simplifying this expression we obtain after substituting the limits of integration, the thickness of the film at B is given by.

$$\ell = \frac{1}{\sqrt{s}} \cdot \sqrt{\frac{2 \cdot v \cdot g \cdot \rho_f}{r \cdot \mu}} \cdot \sqrt{R^2 \cdot (\cos(B + A) - \cos A - B \cdot \sin A)} \qquad (5)$$

The right hand side of Equation 5 has been split into 3 components to illustrate the dependence of film thickness development on different factors. The first component ($\frac{1}{\sqrt{s}}$) contains the operating speed of the machine, the second ($\sqrt{\frac{2 \cdot v \cdot g \cdot \rho_f}{r \cdot \mu}}$) depends on the slurry and film properties entirely while the remaining component is a function only of the size and the set up of the machine.

Of these components only the second requires further simplification to be useful to our arguments. The Hatschek machine uses dilute slurries and although they may vary significantly in solids content (typically around 3 to 5% by weight), their properties such as density and viscosity vary only by small amounts with these changes. The only problematical factor is v as defined above. It can be shown either by differentiation or by simple substitution that v is a linear function of solids content of the slurry to within one part in 1000 within the region of normal solids contents. Thus solids content (c) can be used as a proxy for v in the above expressions and equation 5 can be simplified into the following.

$$\ell = kR\sqrt{\frac{c}{s}} \qquad (5a)$$

The constant k in equation 5a encapsulates all of the other factors that relate to the slurry feed and the properties of the film that is formed.

Equations 5 and 5a deal only with formation of the film up to point B in figure 5. For a complete determination of film formation, it is necessary to include the contributions of sections B to C and C to D; however, it can be shown that these have the same general form as the first section. Although the pressure function is not a continuous function around the sieve we can concatenate the functions into one since the lower limit for integration of the film build function for Section B to C is the given by the integration of section A to B. Thus equation 5a represents a general equation that we can use empirically to determine the value of k and predict how film formation on the Hatschek machine is affected by changes in the operating conditions.

It will be seen that providing all other conditions remain the same equation 5a predicts

1. Large machines will produce thicker films.
2. Increasing the solids content will increase film thickness and
3. Increasing machine speed reduces film thickness while slowing the machine increases the film thickness.

It remains now to see how well equation 5 predicts film formation on an operating machine.

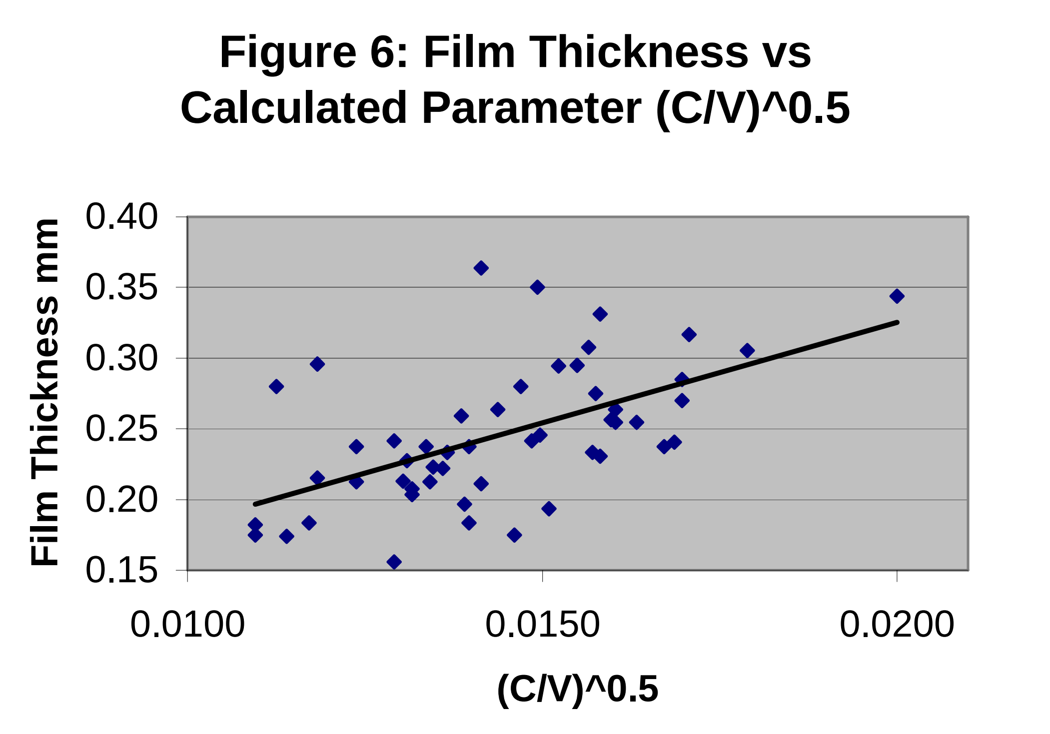
Experimental Results and Analysis

The following results were obtained during the commissioning of a 4-vat overflow Hatschek machine operating only 2 vats. Solids content was sampled from the overflow of the last vat at the time that the other parameters were recorded.

Table 1: Results of field trials from 4 vat Overflow type Hatschek machine; running 2 vats

Solids Content %	Felt Speed ft/min	#Revs per Sheet	Sheet Thick. mm	Film Thick. mm	(c/s)^0.5
3.0%	180	17	5.3	0.16	0.0129
2.6%	200	23	8.0	0.17	0.0114
3.2%	150	16	5.6	0.18	0.0146
2.4%	200	14	4.9	0.18	0.0110
1.8%	150	17	6.2	0.18	0.0110
2.4%	175	21	7.7	0.18	0.0117
3.9%	200	21	7.7	0.18	0.0140
5.4%	237	15	8.7	0.19	0.0151
2.9%	150	14	5.5	0.20	0.0139
2.6%	150	14	5.7	0.20	0.0132
2.6%	150	13	5.4	0.21	0.0132
4.0%	200	18	7.6	0.21	0.0141
2.7%	150	12	5.1	0.21	0.0134
2.3%	150	12	5.1	0.21	0.0124
3.4%	200	19	8.1	0.21	0.0130
2.1%	150	13	5.6	0.22	0.0118
3.7%	200	18	8.0	0.22	0.0136
2.9%	160	13	5.8	0.22	0.0135
2.4%	140	11	5.0	0.23	0.0131
5.1%	204	18	8.3	0.23	0.0158
2.8%	150	12	5.6	0.23	0.0137
2.8%	150	12	5.6	0.23	0.0137
3.7%	150	12	5.6	0.23	0.0157
3.9%	200	16	7.6	0.24	0.0140
5.7%	204	16	7.6	0.24	0.0167
2.5%	140	12	5.7	0.24	0.0134
2.3%	150	12	5.7	0.24	0.0124
5.8%	204	16	7.7	0.24	0.0169
2.5%	150	12	5.8	0.24	0.0129
4.3%	195	12	5.8	0.24	0.0148
2.8%	125	11	5.4	0.25	0.0150
4.0%	150	11	5.6	0.25	0.0163
4.5%	175	11	5.6	0.25	0.0160
5.1%	200	16	8.2	0.26	0.0160
2.4%	125	11	5.7	0.26	0.0139
3.1%	150	11	5.8	0.26	0.0144
5.4%	210	11	5.8	0.26	0.0160
3.6%	125	10	5.4	0.27	0.0170
3.1%	125	10	5.5	0.28	0.0157
2.7%	125	10	5.6	0.28	0.0147
1.9%	150	10	5.6	0.28	0.0113
3.6%	125	10	5.7	0.29	0.0170
2.9%	125	9	5.3	0.29	0.0152
3.0%	125	10	5.9	0.30	0.0155
2.1%	150	12	7.1	0.30	0.0118
4.0%	125	9	5.5	0.31	0.0179
5.0%	204	13	8.0	0.31	0.0157
5.1%	175	9	5.7	0.32	0.0171
2.5%	100	8	5.3	0.33	0.0158
4.0%	100	8	5.5	0.34	0.0200
2.9%	130	8	5.6	0.35	0.0149
4.0%	200	11	8.0	0.36	0.0141

The last column of the above table contains a calculated parameter $\sqrt{\frac{c}{s}}$. Since all of the other parameters were fixed during the operation of the Hatschek machine this parameter should be linearly related to the film thickness according to equation 5a and this has been investigated graphically and by means of a regression and analysis of variance. Figure 6 is a graph of film thickness the calculated parameter.



The analysis of variance of the linear regression line is shown in Table 2 below.

Table 2: ANOVA on Regression of Film Thickness vs $(C/V)^{1/2}$

Regression Statistics	
Multiple R	0.5648
R Square	0.3190
Adjusted R Square	0.3054
Standard Error	0.0403
Observations	52

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.0380	0.0380	23.4192	1.29142E-05
Residual	50	0.0811	0.0016		
Total	51	0.1191			

	Regression Coefficients
Intercept	0.0405
X Variable 1	14.2495

The ANOVA shows that there is a significant correlation between the calculated parameter and the film thickness but that the regression only explains 30% of the variation. The intercept of the regression with the x-axis corresponds well with the prediction of zero film thickness with zero parameter. There is however considerable scatter within the results.

Discussion of Results

It should be realised that the results are drawn from an operating machine that was at the time being commissioned. Sampling of solids content of the vats was problematical and usually represented only grab samples from one spot in the vat and sometimes more than one of the operating vats. Thus in many cases there was a necessary presumption that the solids content of one vat was representative of the solids content of the entire vat and in other cases there was a presumption that the solids content of each vat was the same as in other vats. In addition there is an error associated with the determination of the solids content of the sample. Both factors contribute to errors in the measurement of the operating parameters and thus to the scatter of results above.

In addition it was necessary to estimate the film thickness from the thickness of the green sheet as measured on the run-off conveyor. Such measurements are also variable and subject to error and thus some of the scatter of the results could be attributed to the error in thickness measurement. It must be said though that errors of thickness measurement were not large.

Of more significance however was the fact the loading of the anvil roller against the forming roller was not constant. Although compaction of the void system of the green sheet is not greatly affected by the pressure of the anvil roller there is still an effect and greater anvil roller pressure will result in a greater compaction of the sheet and an apparently thinner film. This will also contribute to the scatter of results in the above analysis. A simplistic analysis of the results taking this into account did not prove fruitful and although information about anvil roller loads was available it has not been included in the results above.

The above analysis assumes that the solids content of the feed remains constant during its passage through the vat. In fact this is not true and it is found that in an overflow system the water content in the feed is different from the water content of the overflow. Indeed there is a systematic difference in the particle size distribution of the feed and the overflow. Larger particles such as the fibres are almost entirely retained on the film while the proportion of finer particles retained in the film compared to the proportion passing the sieve lessens as the particles become finer. Thus the total solids content of the overflow may be around 6% compared to 3% in the feed and the fibre content in the feed will be around 6% of the total solids to produce 8% fibre in the final product. This arises from the fact that the formation of the initial filter layer with pore diameters less than that of the smallest solid particle takes a finite time. Clearly even at this minimum pore diameter water can still drain through the film and so its retention is less than the solids and the solids content of the slurry will rise.

Thus the above analysis will always be approximate and a more accurate analysis should take into account the retention of each individual particle size separately. Nevertheless it appears that initial solid content of the feed slurry is a useful approximation to predict film formation rate and the performance of the sieve.

Implications for machine operation of Overflow Hatschek Machines

Obtaining uniform film and sheet thickness is a well-known problem with all Hatschek machines. It is common for much of the commissioning of new machines to be devoted to achieving uniform film thickness and levelness. Another relevant observation is that the overflow of Hatschek machine is apparently uniform on average as indicated by fluctuations of depth of the overflow. Fluctuations are usually small thus the flow rate does not vary much across the width of the sieve. This observation when combined with the above analysis offers an explanation for the consistent variation in sheet thickness.

It is apparent that flow in the tub of a Hatschek machine is laminar thus any variation of the solids content of the feed at the inlet to the tub will persist during its passage around the tub to the overflow. Thus if there is a persistent low spot or high spot in the sheet thickness this is explained by a low or high solids content respectively in the feed to the tub at specific spots. Generally the high or low spot is associated with some persistent disturbance in the level of the feed to the tub. If for example, there is a high spot in the feed with standing waves in the surface of the feed trough then it is common to find that the sheet will be thin where the standing waves in the feed is high and thick where they are at a minimum. This can be explained by segregation in the feed caused by vortices in the feed trough; these result in patterns in the solid content of the feed and variations in film thickness.

Sheets consistently thicker at one side compared to the other are the result of a gradient in the feed solids content from one side of the machine to the other. Such gradients often occur when the machine is fed from one side only which results in a different solids content at one side of the machine compared to the other. Usually the thicker side is closer to the feed because the water tends to separate from the solids and these concentrated closer to the entry to the tub.

It is therefore critically important that a uniform feed is made to the full width of each tub and that this is maintained throughout the operation of the machine. The most common solution to this problem is to use “fishtail” shaped distribution pipes that have a narrow included angle. This ensures that there is no segregation of the solids in the feed and a uniform distribution of solids is maintained across the sieve. It is not uncommon for tubs to be fitted with two or more fishtail feeders to feed half or a lesser fraction of the width of the tub.

It is also clear that where the film thickness of the sheet is varying it can be brought under control by varying the speed of the machine. Equation 5a shows that the film thickness varies with the reciprocal of the square root of the speed of the machine. Thus a temporary change in the solids content of the feed due to a disturbance in the feed to the machine can be compensated with a change in the speed of the machine. Thus if there is an increase in the solids content the machine should be speeded up to compensate and contrarily a decrease in the solids content in the feed can be compensated by a decrease in the machine speed.

It would seem that the productivity of the machine could be significantly enhanced by simultaneously increasing its speed and the feed solids. There are however limits to the solids content that can be used in the tub. Two factors are controlling-

- increased viscosity of the feed that increases resistance experienced by the sieve as it rotates in the tub and
- flocculation of the feed that prevents the formation of smooth films.

The increase in the viscosity of the feed results from an increase in the solids content of the slurry. This slows the rate of formation of the film as shown in equations 1 through 5 and increases the friction that the sieve experiences. If the resistance increases too much then the sieve in a conventionally felt driven sieve may slip. This causes uneven film formation because the section of the sieve that is immersed when the sieve stops will develop a thicker film. When the sieve starts again the next section of film will be thinner and it will prove extremely difficult to obtain uniformly thick sheets.

Of equal importance is the increase in the flocculation of the feed at higher solids contents. This results from the "crowding" of the particles of together particularly the fibres that become entangled. The fibres in turn trap other particles in their interstices in irregular lumps. Thus it is not possible to form smooth uniform films and the appearance and the other properties of the sheets are compromised.

Thus there are limitations to the solids content of feed slurries before formation or operational problems occur within the Hatschek machines. Thus the predictions of the equations break down under extreme conditions because the assumptions of uniformity within the slurry no longer apply.

Comparison with Static Vat Machines

Figure 3 shows that the surface of sheets formed in a static vat machine are somewhat different. This is due to the use of flocculants in static vat machines. Flocculants are chemicals that are added to bind the fibres to the other particles. Flocculants bind the fine particles to each other and to the fibres thus reducing the amount of fine material that passes through the film into the underflow. Reducing this recirculating load is the primary reason for introduction of flocculant but it also has the effect of changing the way in which the filter layer forms. The cement and other particles effectively coat the fibres while still in suspension thus the filter layer contains considerably more fine material and the fibres are not so clearly apparent on the surface of the fibre cement. It can be inferred that fibre cement formed on a static machine should be somewhat more uniform than on an overflow machine.

Fibre cement formed on these machines usually has significantly higher inter-laminar bond than for an overflow machine. This is a result of the coating of the fibres that means that adjoining layers are bonded by cement-cement bonds not fibre to cement as with and overflow machine.

Future Work

Although this paper has presented a reasonable model of the formation of film on the overflow Hatschek machine a more detailed comparison of the overflow and the static vat machine should be quite revealing. In particular the detail of the formation of the filter layer and a detailed investigation of the differences between the two types of filter layers should show ways to better control the properties of the fibre cement.

This paper has also indicated that although the model of film formation is a useful approximation, a more accurate model could be derived if the partition of the material between the overflow, the underflow and the film were to be taken into account. It would appear that there is a systematic effect of particle size on the relationship between the retained and the passing material. Thus a detailed investigation of this relationship along with the development of a model of film formation should be a fruitful field of investigation.

The development of such models should provide a means to form better quality films and better fibre cement products and to improve the productivity of Hatschek machines.

References:

[i] "Chemical Engineering" Second Edition, 1968, Pergamon Press, Volume 2, Chapter 2, Filtration. J.M.Coulson and J.F.Richardson