Calculation of filter cake thickness under conditions of dewatering under shear

Jerker Jäder and Lars Järnström

Department of Chemical Engineering, Karlstad University, SE-651 88 Karlstad, Sweden

ABSTRACT

Three paper coating colours of increasing CMC content were investigated by means of a controlled shear stress rheometer and an immobilization cell.

Assuming Newtonian behaviour in the investigated shear rate region, an apparent filter cake height may be calculated at any time during dewatering of the coating colour.

INTRODUCTION

In the paper coating process, dewatering of the coating colour occurs continuously, but to varying extents from application to the paper up to the final drying. At some periods during this process, pressure pulses in the application nip and at the metering station reinforce dewatering. It is the length of these pulses rather than their magnitude that determine the extent to which dewatering occurs[1]. Regardless of whether the dewatering process is looked upon as a thickening or as a filtration mechanism, there is an immobilized layer of coating colour being formed in the surface of the base sheet. Lohmander[2] using an NMR-technique has investigated a thick layer of coating colour and found that after pressure dewatering, the uppermost part of this layer has a solids content similar to the initial value and that there is a solidity profile within the layer

A problem of considerable importance in the field of paper surface treatment has been the measurement of dewatering and of the height of the filter cake thus formed. Several different methods have been proposed for measuring dewatering of coating colours[3,4].

The BASF immobilization cell, which was first described by Willenbacher et al.[5] has been presented as a tool for achieving information concerning the dewatering of coating colours in terms of the time needed to reach immobilization solids.

In this study, using the immobilization cell in a plate–plate geometry in which the normal forces are kept constant during dewatering enables the qualitative monitoring of the height of the filter cake being formed at any time during the process.

EXPERIMENTAL METHODS

In the present case, three calcium carbonate based coating colours of similar solids content but different and increasing levels of thickener were used. The pigment used was Hydrocarb-90, supplied by Omya AB, the CMC Finnfix5, supplied by Noviant CMC Oy and the latex DPL950, supplied by Dow Sverige AB. The three coating colours are called A1, A2 and A3, respectively. The total amount of latex and CMC added was similar for all colours. Recipes are presented in Table 1 along with the results from characterization by the ceramic plate[6] and

Table 1. Recipes and characteristics of the three coating colours used

Coating colour	Pigment	Latex [pph*]	CMC [pph*]	Initial solids content [% by mass]	Dewatering by ÅA-GWR [kg/m^2]	Immobilization solids (ceramic plate method) [% by mass]
A1	$CaCO_3$	9	1	60 %	147.6	88.71
A2	$CaCO_3$	8	2	60 %	111.2	88.82
A3	$CaCO_3$	7	3	60 %	85.49	89.10

*pph = parts (by mass) per hundred parts of dry pigment.

ÅA–GWR[3] methods. As a further means of colour characterization, flow curves were made, which are presented in Fig. 1.

For the rheological measurements, the immobilization cell was used in a Paar Physica UDS controlled shear stress rheometer (Anton Paar, Graz, Austria).

In this experimental set-up, a hydrophobic Teflon filter was chosen as base sheet in order to prevent spontaneous dewatering of the coating colour prior to applying the vacuum from beneath the filter. As the normal forces are set to a constant value during measurement, the vacuum driven dewatering of the coating colour causes the upper rheometer plate to move downwards.

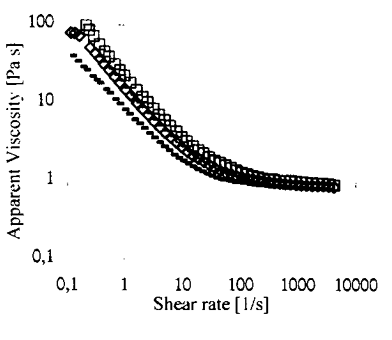

Figure 1. Flow curves of coating colours A1 (bars), A2 (diamonds) and A3 (squares) at 25 °C.

For measurement, a layer of 7.5 mL of coating colour was applied to the filter, after which the upper plate was lowered into measuring position, 2.39 mm above the filter surface. The rheological measurements began with a gentle pre-shear followed by a rest period to ensure similar amounts of structure within the coating colour at measuring. The measuring interval consisted of a rotational shearing at 100 s^{-1} at the beginning of which vacuum was applied. Shearing was stopped and the plate lifted up when viscosity started going towards infinity.

RESULTS AND DISCUSSION

The rheological measurements yielded graphs showing apparent viscosity (as given in rheometer software) and gap height, i.e. the distance from filter surface to the bottom surface of the upper rheometer plate are shown as functions of time. An example is given in Fig. 2.

In the initial experiments, the formation of a filter cake was visually detectable. In order to investigate this further, the material remaining on the upper plate after it has been lifted up was scraped off and analysed gravimetrically with respect to solids content. These results were compared with those obtained using the same technique for the whole coating colour layer and are presented in Fig. 3.

As can be seen from Fig. 3, the top layer does not differ much in solids content compared to the initial value, especially after short periods of time. With the use of NMR-technique, Lohmander[2] found that the uppermost parts of a thick coating colour layer has a constant solidity when subjected to static pressure dewatering.

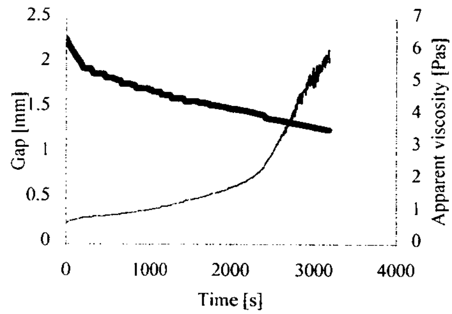

Figure 2. Gap height (thick line) and apparent viscosity (thin line) as functions of time for coating colour A2 at 100 s^{-1} and 25 °C.

The results in Fig. 3 show a small yet significant deviation, but in our experiments, there is no proof of film splitting occurring at the level of lowest solids content. In any case, there seems to exist a solidity profile also in these relatively thin layers.

Calculations of viscosity in a plate–plate geometry are based on the general equation

$$\tau(r) = \eta \dot{\gamma}(r) = r \frac{\eta \Omega}{H} \qquad (1)$$

where $\tau(r)$ is the shear stress at some radial position r, η the apparent viscosity, $\dot{\gamma}(r)$ the shear rate at the same position, Ω the angular velocity and H the gap height. In this, the viscosity is taken as a constant. Rearrangement of Eq. 1, allows calculation of gap height H for given values of r, Ω, η, and $\tau(r)$, Eq. 2.

$$H = r \frac{\Omega \eta}{\tau(r)} \qquad (2)$$

Assuming Newtonian behaviour in the investigated shear rate region, Eq. 2 shows that the gap height of the non-immobilized coating colour layer may be calculated, provided the required data are available. This gap height H then signifies an effective gap height of the coating colour volume that is actually being sheared.

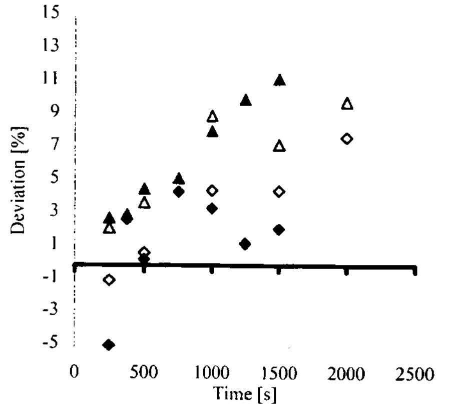

Figure 3. Deviation from gravimetrically determined initial solids content value of top layer (diamonds) and entire layer (triangles) for coating colours A1 (filled symbols) and A2 (open symbols)

Intuitively, one may assume that the measured torque is almost completely originating from the shear stress at the rim of the upper, rotating plate. Following this, r and $\tau(r)$ in Eq. 2 can be replaced by the upper plate radius R and measured shear stress, respectively. As a precaution, the crudity of this assumption was evaluated from similar measurements using an impermeable solid plate as base sheet and Eq. 3

$$r = \frac{\dot{\gamma} H}{\Omega} \quad (3)$$

The values for r thus obtained differed to a negligibly small extent from that of the upper plate radius and the error introduced upon making the replacement could likewise be neglected.

Having established these relationships, the differences between apparent gap heights indicated on the instrument (i.e. distance upper plate – filter surface) and the effective gap heights calculated with Eq. 2 were taken as measures for the height of the immobilized layer at any time, see Fig. 4.

From the flow curves in Fig. 1 it can be seen that the viscosities of all three coating colours are approximately constant in the shear rate region between 100 and 1,000 s^{-1}. Therefore, if the assumption of a constant solidity of the uppermost part of the colour layer is valid, using Eq. 2 with a constant viscosity value would be a possible way to get information concerning the height of a filter cake formed under dynamic conditions.

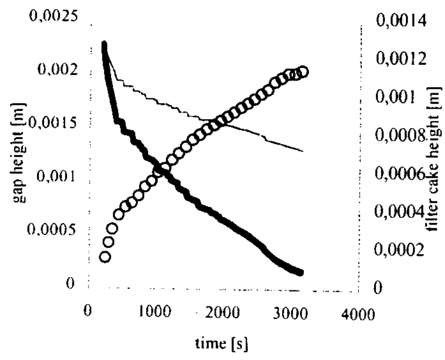

Figure 4. Graphic visualization of apparent gap height (thin line), effective gap height (thick line) and filter cake thickness (circles, secondary y-axis) for colour A2

Having come so far, the filter cake build-up for coating colours of different CMC-levels may be compared, fig 5.

As can be seen from Fig. 5, there is a significant difference in cake thickness between coating colour A1 on the one hand and coating colours A2 and A3 on the other. The highest values for filter cake thickness are obtained for A1, which may be explained in terms of the higher degree of dewatering achieved with a lower CMC-level. The colour layer is thus immobilized to a greater extent. A possible explanation for the small difference between colours A2 and A3 is that the build-up of a thinner filter cake for the highest CMC-level (A3) is counteracted by the less dense packing of material obtained with high levels of thickener. According to Sandås and Salminen[7], the ability of CMC-colours to trap some of the dispersing medium may be explained in terms of the elastic floc model proposed by Firth and Hunter[8,9].

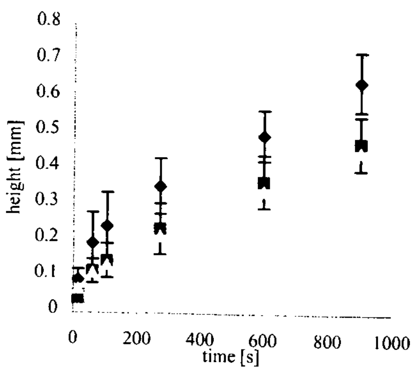

Figure 5. Filter cake thickness at different times during measurement. Results for coating colours A1 (diamonds), A2 (squares) and A3 (triangles).

In this manner, measurement of filter cake thickness under dynamic conditions is made possible. Of the assumptions inherent in the method, the one of constant solids content for the top layers seems to be the crudest. The crudity of this assumption is not evaluated here

CONCLUSIONS

In measuring the rheological properties of calcium carbonate based coating colours with the immobilization cell, it was clear that a filter cake consisting of immobilized solid material was formed on the Teflon filter base sheet.

From the definition of shear stress in a plate–plate geometry, a qualitative value for the thickness of the filter cake formed may be obtained. These calculations involve the assumptions of constant solids content of the uppermost layer and of Newtonian viscosity in the investigated shear rate region. Of these two assumptions, the one concerning constant solidity is not experimentally evaluated here. However, its validity is critical for these estimates of filter cake thickness. Therefore, future work with this model should involve a more thorough evaluation of the top layer solids content.

In the future, comparisons will be made between thickeners acting through different mechanisms, e.g. entanglements and association.

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