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Importance of Rheology and Viscosity in Paper and Board Coating

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Abstract

Market demand for coated graphical paper has declined steady as a result of electronic media. However, other coated grades such as coated board and barrier coated packaging papers and specialties are forecasted with decent growth grades. Despite of the actual market situation the operational environment and coating functionalities are under continuous investigation. Flow properties i.e. rheology plays an important overall role in optimizing runnability and quality. This paper demonstrates the importance of rheology and viscosity in paper and board coating. A focus is in high shear viscosity that has been demonstrated to be in a critical parameter in coater runnability. Its importance will be discussed both from theoretical and practical standpoints. Furthermore, a new instrument for measuring high shear viscosity fast and easy will be discussed.

Keywords : High shear measurement, Rheological properties, Viscosity, Capillary viscometer, Coating color, Coater runnability

1. Introduction

Viscosity is the most important rheological property of coating color. Traditional ways to measure viscosity in paper industry are rotational viscometers (Brookfield, Paar, Hercules) and capillary viscometer (ACA). As coating colors are complex non-Newtonian fluids, their viscosity depends on shear rate[1]. At low shear rates the viscosity is structural due to surface chemistry whereas at high shear rate the structures are broken, and the viscosity is caused by hydrodynamic factors (**Fig. 1**). **Table 1** shows that different factors are governing the low and high shear viscosity and therefore it is not usually possible to draw conclusion about high shear rheology by measuring low shear region, or vice versa.

In the coating process, shear rates vary from zero to several millions s^{-1} and both surface chemistry and hydrodynamic factors are present as shown in **Fig. 2**. Surface chemistry (low shear viscosity) is important to understand the compatibility of various coating materials and is relevant for pumping and mixing steps. On the other hand, the hydrodynamic factors (high shear viscosity) are important for actual coating runnability as high shear rates are present in application and metering steps.

This paper focuses on the understanding of non-structural viscosity i.e. hydrodynamic viscosity and its influence on coater runnability and coating quality. The most important hydrodynamic factors in the coating color

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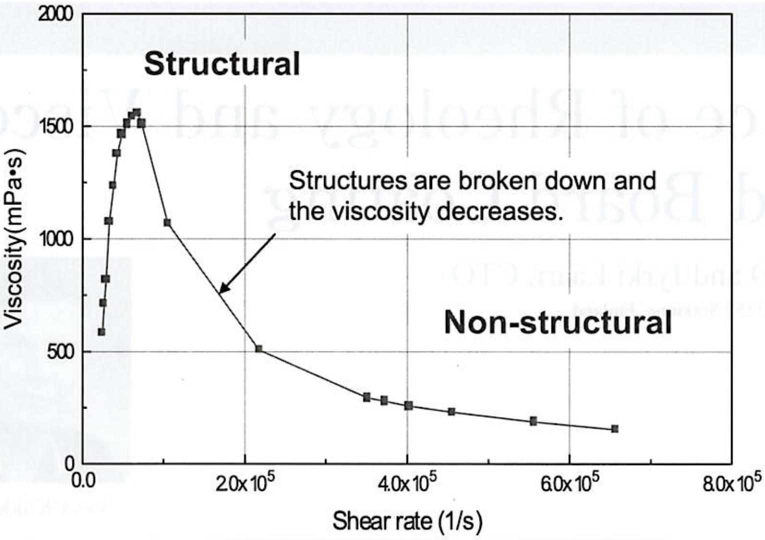

Fig. 1 Structural and non-structural viscosity.

Table 1 Governing factors in low and high shear viscosity

Surface chemistry dominates in low shear viscosity	**Hydrodynamics dominate in high shear viscosity**
- Van der Waals	- Particle size
- Electrostatic Repulsion/Attraction	- Distribution of Particle size
- Steric Factors	- Shape of Particles
	- Viscosity of Water Phase
	- Solid Fraction
Can be measured with Brookfield, Anton Paar and Hercules rheometers	*Can be measured with capillary viscometer*

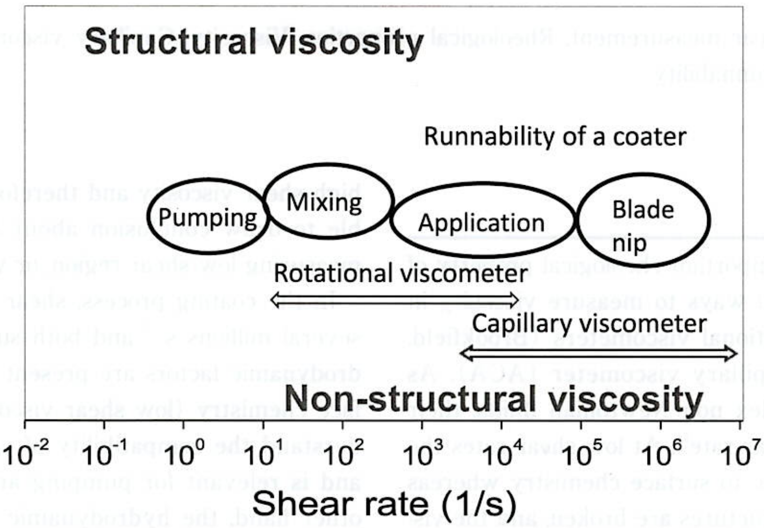

Fig. 2 Shear rate in viscosity measurement to simulate the real coating process condition.

are :

- Solids content (i.e. volume fraction of particles)
- Particles size
- Particle size distribution
- Shape of the particles
- Viscosity of continuous (water) phase

Capillary viscometer reaches shear rate up to 1,000,000 s^{-1} and is the typical way to measure hydrodynamic viscosity since shear rate limit of rotational viscometers (like Haake or Hercules) is about 40,000 s^{-1}. Principle of capillary viscometer is to measure pressure difference between the ends of the capillary and volumetric flow rate through it. In capillary viscometer fresh sample flows through the capillary continually, and therefore shear heating is not a significant problem. So far, the challenge had been the complexity of measurement. Required sample size had been quite large (1-2 liters), washing and cleaning of the device had been complicated and the overall time of one measurement had been too much for measuring each coating batch or continuously in the process. Therefore, capillary viscometers can be found nowadays mainly in research centers, training centers and universities.

ACA Systems Oy from Finland, the pioneer of capillary viscometer manufacturing, has developed a new device ACA AX-100 that is specially designed to measure viscosity of coating colors under hydrodynamic conditions fast and easy. The ACA viscosity (non-structural viscosity) is defined at the shear rate of 750,000 s^{-1}. The measuring principle has been proposed as a new standard method of TAPPI.

As the measurement of hydrodynamic viscosity has become easier than ever, it makes sense to review the industrial significance of the measurement. The experiments in this paper include a study of pigment particle size distribution, latex particle size and common natural thickeners and their influence on ACA viscosity and coating runnability.

2. Experimental

The reference coating color used in studies was 80 pts GCC (Hydrocarb 90 from Omya) 20 pts Clay (Hydragloss 90 from KaMin). In addition, 11 pts SB latex (DL 966) was used as a binder and 0.8 pts CMC (Finnfix 10 from CP Kelco) as a thickener. Solids content of the tested coating color was 65%. The experimental studies were performed in cooperation with a leading coated woodfree paper producer in Europe.

In the first series of experiments the GCC was replaced by narrow PSD PCC. The second series of experiments included the reference pigment formulation, but average latex particle size was varied between 0.1 μm and 0.2 μm. The last series of experiments demonstrated the difference between CMC and Starch as thickener.

Furthermore, a long-term mill scale investigation of ACA viscosity is described. The correlation between high ACA viscosity and blade lines is discussed in detail.

3. Results and Discussion

Fig. 3 below shows the high shear viscosity curve measured with ACA capillary viscometer. Substituting the GCC by narrow PSD PCC leads to a higher high shear viscosity.

Mill scale trials indicated a clear correlation between ACA viscosity and the blade loads. Furthermore, it was evident that when the ACA viscosity reaches a critical level or is beyond that, the formation of blade streaks and poor profiles occurs (**Fig. 4**). **Fig. 5** describes that the ACA viscosity is having a great correlation with blade loads whereas Brookfield viscosity is having no correlation at all. This is because ACA viscosity measures pure hydrodynamic behavior of the coating and simulates the conditions during metering phase of the coating process. Fig. 4 shows an example from a leading coated board producer. New coating recipe was developed and ran in a machine trial, but during the trial the runnability got poor and the trial had to be stopped mainly because of blade streak/lines. While Brookfield viscosity was adjusted to same level for both recipes, laboratory analysis showed 30-40% higher ACA viscosity compared to standard recipe. For future trials the customer decided to approve every new component first with AX-100 in order to avoid machine problems in advance.

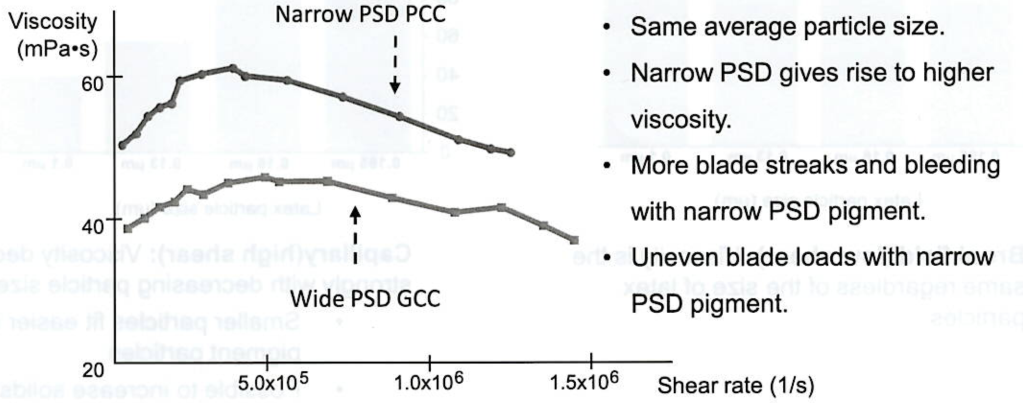

Fig. 3 Effect of filler particle size distribution (PSD) on viscosity (measured by ACA viscometer).

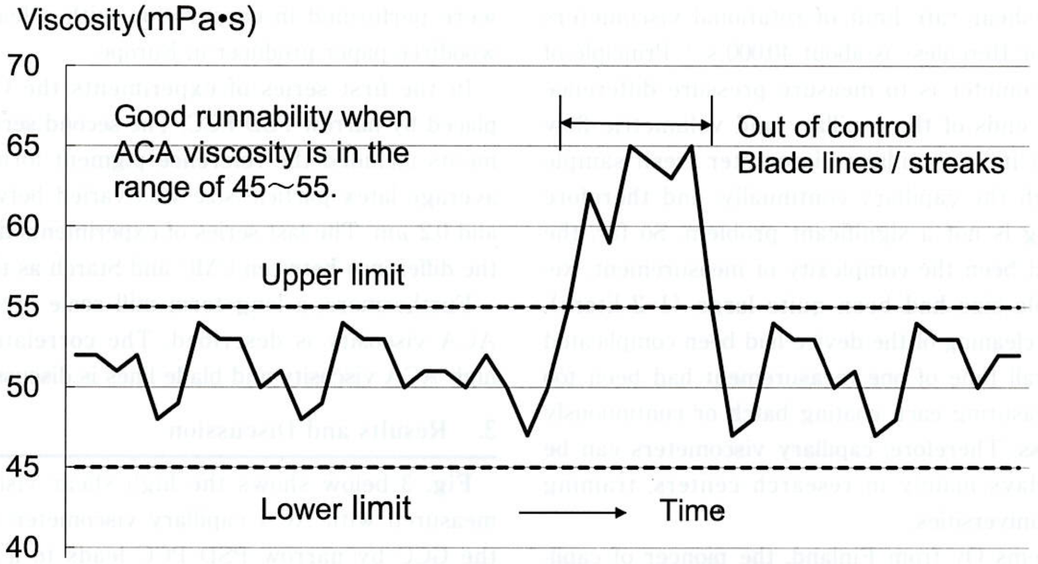

Fig. 4 Industrial example of ideal viscosity and deviation.

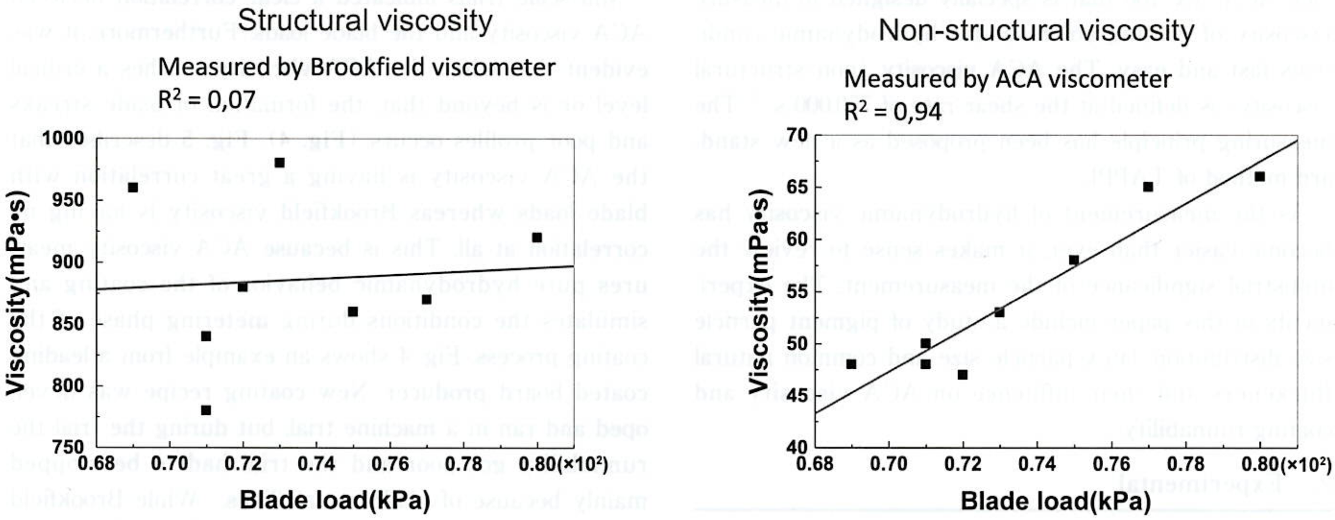

Fig. 5 Viscosity and blade load (runnability). Non-structural viscosity has a very high correlation with the actual coating process.

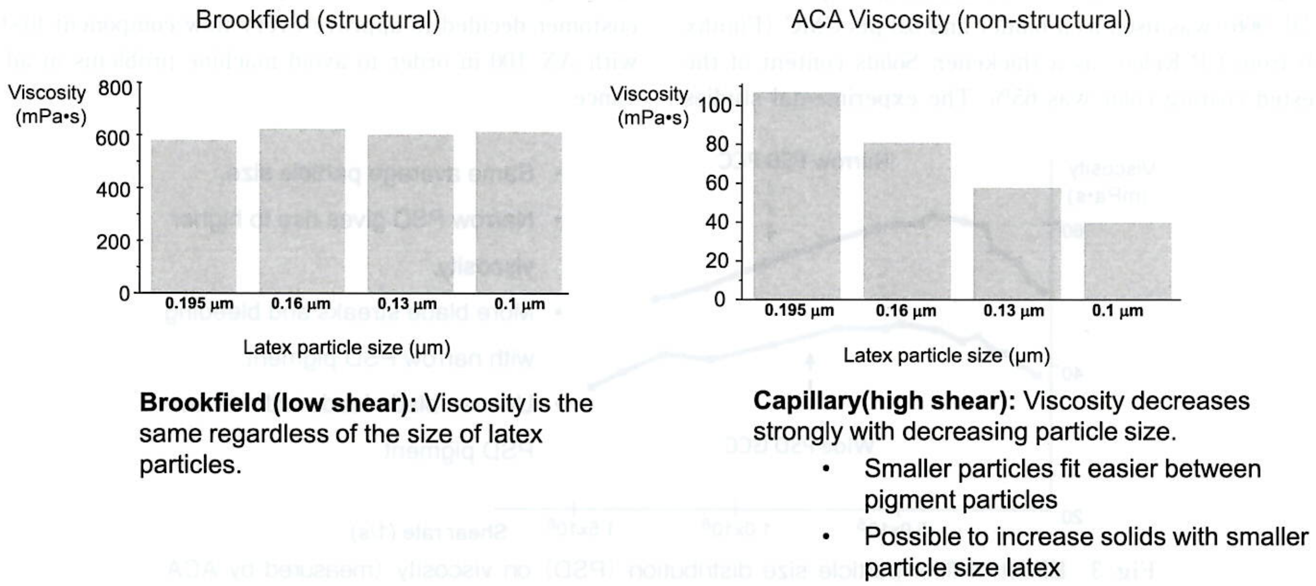

Fig. 6 Effect of latex particle size on viscosity.

Table 2 Effect of thickeners on viscosity

Property	Viscosity(mPa•s)		
	Without thickeners	CMC	Starch
Viscosity of water phase	1	3.5	8.3
Brookfield viscosity	100	1200	750
High shear viscosity	12	40	55

The experiment for latex particle size was performed again with the standard 80 pts GCC, 20 pts Clay, 11 pts latex, 0.8 pts CMC recipe (**Fig. 6**). The altering aspect in the experimental was a latex particle size. The used reference formulation contained a latex with 0.13 um particle size having ACA viscosity of 60 mPa•s. When particle size was increased to 0.20 um the ACA viscosity increased to 100 mPa•s. On the other hand, when the latex particle size was reduced to 0.1 um, the ACA viscosity dropped to a level of 40 mPa•s. Thus, it can be concluded that latex particle size has a big influence on coating color ACA viscosity. This can be explained by total particle packing i.e. smaller latex particles fit easier between pigment particles. Therefore, the flow properties of the particles are improved and viscosity decreases. Latex particle size optimization is a quick and relatively easy tool to increase solids content and optimize overall rheology. Of course, binding power, optical and printing properties needs to be considered at the same time.

In the experiment of thickeners, typical natural thickeners CMC and Starch were compared at the same dosage level in the standard recipe. Both structural (Brookfield) and non-structural (ACA) viscosities were measured. The results are shown in **Table 2**. CMC is clearly having higher Brookfield viscosity whereas starch despite having lower Brookfield viscosity is having higher high shear viscosity. CMC is typically absorbed on pigment surfaces due to its carboxyl groups, thus it tends to form strong structures. Starch, on the other hand, is thickening the water phase and not reacting as actively with particles as CMC. This phenomenon is clearly visible in the results. When measuring non-structural viscosity, the CMC structures are broken, but starch is more visible due to its ability to thicken the water phase. Therefore, results are consistent with the theory. In general, there are many types of rheological modifiers available and when testing their performance, it is important to understand both structural and non-structural sides of the viscosity.

4. Conclusion

Runnability problems at coater are very costly and they may originate either from base substrate, machine setups or from rheology. To understand rheology and using proper viscosity measurement technology it is possible to achieve significant cost savings and better coated paper quality. The new capillary measurement technology allows paper and board producers to manage the coating rheology better and eliminate rheological based coating problems. Also, the fundamental understanding of hydrodynamic viscosity enhances the runnability of functional coatings such us water-based barrier coatings or allows solids content increases and cost reduction of standard recipes. Because of novel technology, proper rheology management is today the easiest way to achieve significant cost savings and develop new value-added coated grades in the industry.

Reference

1) Esa Lehtinen : Papermaking Science and Technology, Book 11, Pigment Coating and Surface Sizing of Paper, 661, Gummerus Printing (2000)