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Monitoring the Growth and Removal of Cake Fouling Using Automated micro-Fluid Dynamic Gauging

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Introduction

Membrane fouling is the deposition of material on the membrane surface or within the membrane pores that usually results in increased pressure drops, reduced permeate flux and a reduction in product quality, while often being difficult and expensive to remove. The energy required to remove the deposits depends on the layers thickness and strength hence the importance of understanding of these properties.

This work presents a practical approach to study cake growth on microfiltration membranes. An automated micro-fluid dynamic gauging (AmFDG) technique [1] was used to track the thickness and strength of neutrally buoyant ballotini and *Lignoboost*™ softwood Kraft lignin cake layers formed on mixed cellulose ester membranes of 0.2 μm nominal pore size. The ballotini are mono-dispersed glass spheres of ~10 µm diameter and lignin is a substance which has earlier been found to be relatively self-adhesive [2]. The membrane performance is monitored by recording changes to the permeate flux whilst the foulant cake properties are monitored through the use of AmFDG to measure both the thickness and strength. Using this data it is possible to infer how fouling phenomena at the surface of the membrane and in a growing cake fouling layer on top influence flux decline.

Automated micro-Fluid Dynamic Gauging

Fluid Dynamic Gauging (FDG) is a non-contact proximity technique for studying soft films deposited on surfaces in situ [1]. The key elements are depicted in Fig. 1(a). A constant suction flow is set up between the fluid near the surface (1) and the discharge end of the gauge (2), so that fluid flows into the nozzle. Experiments have shown that the stresses imposed by the suction flow on the deposit were significant at low *h*, tending to remove the deposit from the steel surface. Knowledge of these stresses would therefore afford a method for determining the shearing yield strength of the deposit. The shear force produced by FDG can be quantified using computational fluid dynamics (CFD) allowing strength of the deposit to be calculated.

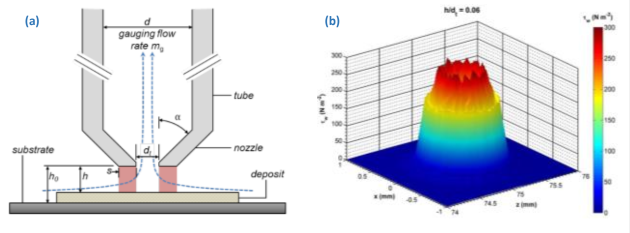
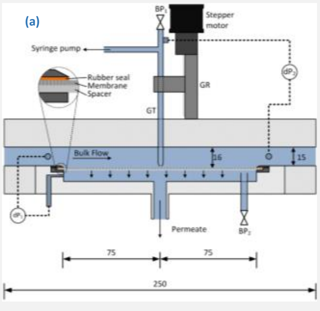


Fig. 1: (a) Schematic of FDG gauge. The tip of the nozzle is suspended at a known height h_0 from a substrate, and its height above the surface of a deposit can be inferred from the pressure drop across the gauge. The area shaded red indicates the region of interest where thickness and strength measurements are made. **(b)** 3D CFD surface plots of shear stress, τ_w, on the membrane surface at $h/d_t = 0.06$.

A schematic of the AmFDG apparatus is shown in Fig. 2(a). The main body of the test section was made from polycarbonate, and contained a single square channel of 15 mm cross-section through which the feed suspension flowed over the membrane. The resulting filtration cell was a 150 mm long channel, 15 mm wide by 16 mm high, with a membrane at the bottom surface. The gauge was positioned directly in the centre of the duct. The automated operation of FDG has been described in detail elsewhere [1]. All data are registered by LabVIEW™ 2010 Visual Interface (VI). The different parts of the membrane cassette is pictured in Fig. 2(b). The membrane was mounted between a rubber seal and stainless steel mesh spacer, clasped tightly within a stainless steel frame to form a cassette with a 15 × 150 mm porous surface.



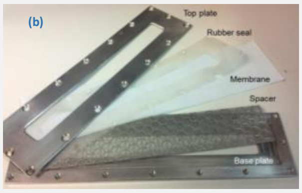


Fig. 2: (a) Schematic of AmFDG apparatus where dP_1 and dP_2 are pressure transducers, BP_1 and BP_2 are bleed points with pinch valves. GT is the gauge tube, GR is the linear guide rail from the stepper system and V7 is a needle valve used to control TMP. **(b)** components of the membrane cassette, which was screwed together tightly when used for filtrations [1].

Acknowledgements

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Results & Discussions

Ballotini (B)
0.02 vol% ballotini suspension was filtered

Lignin (L)
0.02 vol% lignin suspension was filtered

Ballotini + Lignin (M)
0.04 vol% of suspension equal volumes ballotini and lignin

Ballotini then Lignin (B->L)
0.02 vol% of ballotini suspension was filtered then 0.02 vol% lignin suspension was added

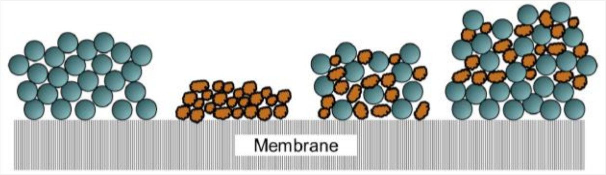

Fig. 3: Different types of filtration used in ballotini-lignin fouling studies.

Fig. 4(a) shows an image of the area just beneath the FDG gauge taken using an optical microscope after strength testing. An annular area of almost clean membrane is visible just beneath the nozzle rim. The size and shape of this region proved to be repeatable, and its alignment with the nozzle geometry is indicated in Fig. 4(b). This formation is similar to that seen for ballotini and the decrease in the quantity of material removed from the surface is in line with the shear stress profile in Fig. 1(b).

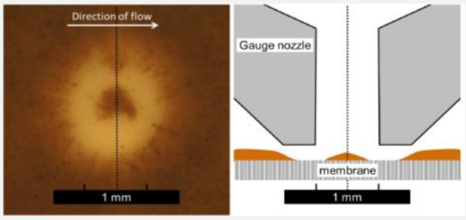

Fig. 4: (a) Magnified image of the eroded region of the lignin fouling (**L**) layer beneath the gauge nozzle, after 2000 s filtration at 50 mbar TMP. **(b)** Diagram representing a cross-section through this region where the geometry of the gauge nozzle is shown to scale directly above. Thickness of the fouling layer and membrane is not drawn to scale here.

Fig. 5 shows the flux decline curves for **B**, **M**, and **B->L** experiments. It is evident from the graph that **B** causes flux decline at a slower rate in comparison with **M** and **B->L**. The addition of inert ballotini particles, whether in the mixture or as a pre-fouling layer, did not result in any improvement to the flux performance. Fig. 6 shows that comparing bi-layered cakes formed by **B->L** experiments with the ones formed in **M** experiments indicated that in general, the former are harder to remove. Cakes formed from a single layer (**M**) appeared to be completely removed.

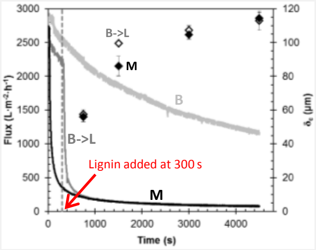

Fig. 5: Cake thickness (symbols) and flux (lines) against time for ballotini **B**, mixture **M** and ballotini then lignin **B->L**.

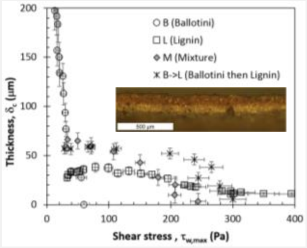

Fig. 6: Cake thickness against applied shear stress for ballotini **B**, lignin **L**, mixture **M** and ballotini then lignin **B->L**.

Conclusions

- AmFDG has been successfully used to track thickness and strength of cake layers in microfiltrations for mixed fouling systems of ideal (glass spheres) and non-ideal (lignin) suspensions in situ and in real time.
- No improvement to overall flux was observed as a result of adding ballotini to the lignin in the filtered suspension, but there appeared to be some reduction in the adhesive strength of the cake layer.
- The results from strength testing for bi-layer fouling opens up new possibilities for pre-treatment for membrane filtrations.

References

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