Roll application of foam suspensions on a porous web

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In the production of tufted carpets and nonwovens, one process involves roll application of stable adhesive froths to bond fibers into a porous web. Adhesives are three-phase suspensions comprising inorganic filler and latex emulsion, a water phase with a synthetic thickener, and air. They are mechanically frothed to a density and typically have shear thinning rheology. The degree of penetration of the frothed adhesive into the porous web is a balance: too much penetration results in poor composite reinforcement and too little results in poor fiber coverage and binding. Figure 1 illustrates in a simplified manner the roll applicator, the web, the compound, and the penetration depth.

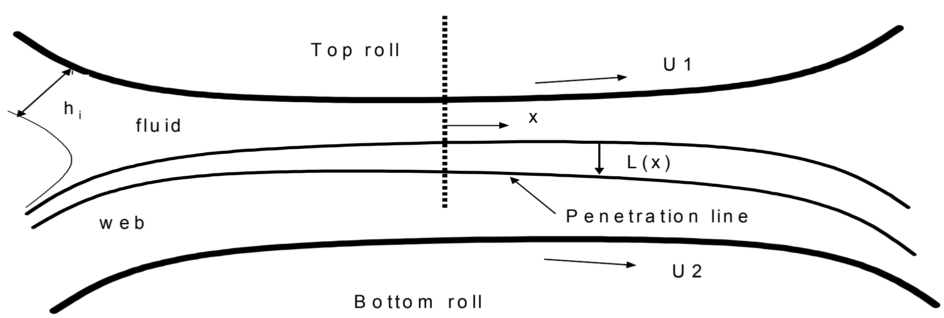


Figure 1. Enlargement of the applicator roll nip. L(x) is the depth of penetration into the porous web. A lubrication approximation to the flow field, accounting for penetration into the web as in Ninness et al. [1] gives:

$$\frac{dp}{dx} = 12\mu\left((U_1 - U_2)h(x)/2 + U_1 L_p(x)\varepsilon - U_1 * h_i\right)/h(x)^3 \qquad (1)$$

where P is pressure, μ is viscosity, $L_p(x)$ is the depth of penetration, ε is the void fraction of the web, and $h(x)$ is the gap between the rolls as a function of position; this gap is easy to calculate if the rolls do not deform given a gap between rolls and the curvature or diameter of the rolls. The top roll can be any speed relative to the web. The rate of penetration depends on the pressure field P in the nip and is given by the expression:

$$v_0 = \frac{P}{\mu\left[\frac{L_p}{K_p}\right]} \qquad (2)$$

K_p is the Darcy permeability coefficient of the web. The velocity above is the rate of change of penetration volume per unit area into the web or

$$v_0 = \frac{1}{\varepsilon}\frac{dL}{dt} \qquad (3)$$

where ε is the void fraction of the web.

The maximum shear rate at every x-position is calculated from the pressure gradient. It comes from a straight forward derivation from the momentum equation:

$$\gamma = \frac{\partial p}{\partial x}\frac{h(x)}{2\mu} + \frac{(U_1 - U_2)}{h(x)} \qquad (4)$$

One assumption to facilitate including shear thinning rheology in the model is that this shear rate can be used to calculate an approximate viscosity to use in the momentum balance. The power-law equation here is written as:

$$\mu = b\gamma^{c-1} \qquad (5)$$

One series of calculations were done to understand the amount of compression of the stable foam during this pressure buildup. The net result was that foam compression was not large for typical operating conditions.

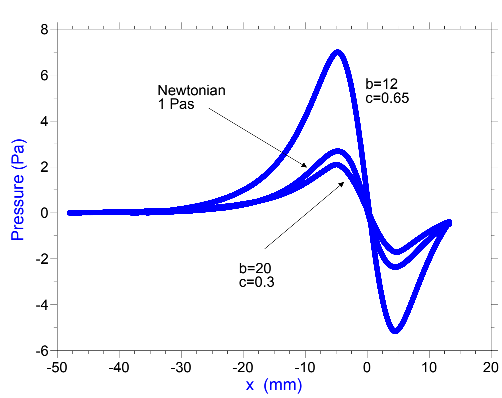
Tables 1 and 2 show typical values of the parameters in the model from practical experience and direct measurement of rheology. Figures 2 and 3 compare the model predictions of pressure, shear rates, and penetration for a Newtonian fluid and a power-law fluid for various cases. From empirical experience, the various compounds in Table 2 give different degrees of penetration upon application. Even though the non-penetrating foam generates higher pressures in the nip, the amount of penetration into the web is reduced because of the higher viscosity that resists penetration.

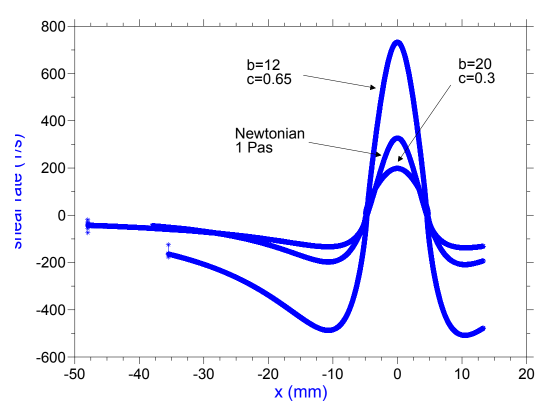
Table 1. Parameters used in calculations.

Parameter	symbol	Value
Top roll velocity	U_1	0.25 m/s
Bottom roll velocity	U_2	0.25 m/s
Roll radius	R	0.1 m
Compound coated thickness	h_i	1 mm
Web void fraction	ε	0.5
Web permeability	K_p	10^{-10} m^2

Table 2. Power-law parameters for the experimental compounds.

	b (Pas $s^{(1-c)}$)	c
Compound 1	3	0.75
Compound 3	9	0.63
Surfactant A	12	0.65
Surfactant B	20	0.3
Surfactant C	12	0.65





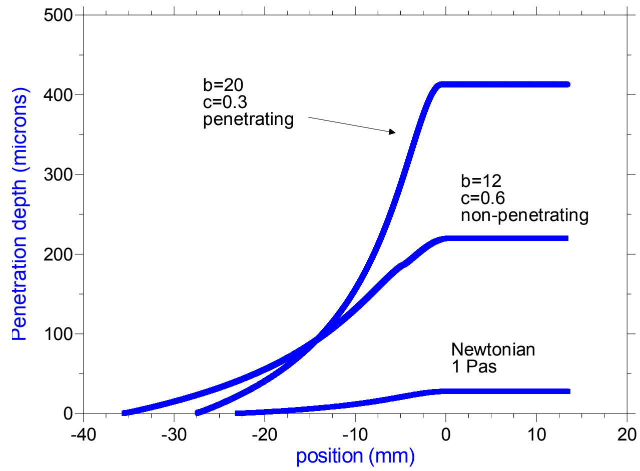


Figure 2. Model predictions of pressure, shear rate (previous page), and penetration for a Newtonian fluid and two shear thinning fluids.

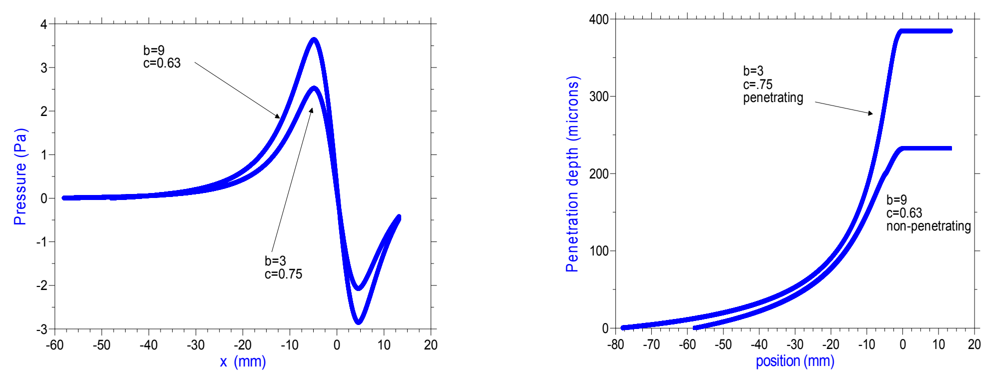


Figure 7. Pressure profile (left) and penetration (right) predictions of the model for shear thinning parameters given that represents foam compounds 1 and 3.

The model qualitatively predicts the difference between the penetrating (compound 1) and non-penetrating (compound 3) compounds, even with the simplified method to include shear thinning. The model seems to pick up the key physics of the process and should help guide the development of new compounds in terms of rheology.

1. Ninness, B., Bousfield, D.W., and Triantafillopoulos, N.G, "Fluid Dynamics Model of the Film-Fed Nip with a Porous Web", Proceeding of the TAPPI Coating Conference, pp. 515-530, TAPPI Press, Atlanta, GA (1998).