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The Physics of Coal Liquid Slurry Atomization
Contract Number: DE-FG22PC92152

Technical Report

In this reporting period, the major objective of the research was to develop a technique for measuring the extensional viscosity of coal -water slurries. The Extensional properties of the suspending solutions (water + additives) and the slurries (coal + water + additives) are determined using the breakup of droplets in the drip mode. Photographic visualization of the breakup of viscoelastic materials in the drip mode has shown that these materials exhibit completely different breakup patterns when contrasted to viscoinelastic materials. The ligaments were seen to undergo a very large stretching motion before they breakup, resulting in long threads of liquid attached to droplets (see Fig. 1). The diameter of the ligaments at breakup, as measured by the Greenfield digital spray analyzer, was of the order of 30 μm. The drip mode of breakup was used to extract useful information on the extensional properties of CWS.

Kinematics of Extension

We suppose the ligament to be in cylindrical form undergoing uniaxial extension, with one end fixed and the other end moving with a velocity V, the axis of the ligament coinciding with the X-axis. The initial length and radius are Lo and Ro, and after a time t they are L and R (see Fig. 2). The length of the specimen at time t is given by

$$L(t) = L_o + \int_0^t V(t')\ dt' \tag{1}$$

The strain for uniaxial extension is

$$\varepsilon = ln(L/L_o) \tag{2}$$

so the strain rate is

$$\dot{\varepsilon} = \frac{d}{dt}[ln(L/L_o)] = \frac{1}{L}\ \frac{dL}{dt} = \frac{V}{L} \tag{3}$$

and

$$V = \dot{\varepsilon}\, L \tag{4}$$

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The elongational stress, T, in the sample is related to the normal force, N, and the cross-sectional area, A, by

$$T = N/A$$

The normal force can be determined from Newton's second law, whereby we have

$$-N - 2\pi R\sigma + mg - D_r = ma \tag{5}$$

where σ is the surface tension, m is the mass of the suspended droplet, g is the gravitational acceleration, a is the droplet acceleration and Dr is a correction for the aerodynamic drag on the droplet. The mass of the suspended droplet is simply the flow rate (M) divided by the frequency of formation of droplets (f). The normal force N is thus given by

$$N = \frac{\dot{M}}{f}(g - a) - 2\pi R\sigma - \frac{24}{Re}\left(1 + \frac{1}{6}Re^{2/3}\right)\frac{\pi d^2}{4}\frac{1}{2}\rho_a V^2 \tag{6}$$

where the empirical drag law for a sphere of diameter d as a function of the Reynolds number (Re) has been used. Re is defined as

$$Re = \frac{\rho_a d\, V}{\mu_a} \tag{7}$$

The elongational stress (T) as a function of time (t) is given by

$$T = \frac{N}{A} = \frac{\frac{\dot{M}}{f}(g - a) - 2\pi R\sigma - \frac{24}{Re}\left(1 + \frac{1}{6}Re^{2/3}\right)\frac{\pi d^2}{4}\frac{1}{2}\rho_a V^2}{\pi R^2} \tag{8}$$

and the strain rate was given previously by Eq. (3).

In order to evaluate the transient elongational stresses (T) that are developed in the long threads of liquid before breakup, the mass flow rate (M), the frequency of formation of droplets (f), the acceleration of the droplet (a), the diameter of the ligament (2R), the diameter (d) and the velocity of the suspended droplet (V) are required. In order to determine the strain rate (ε) both the instantaneous velocity of the droplet and the length of the ligament (L) are required. An instantaneous elongational viscosity can be defined as

$$\eta_E = T/\dot{\varepsilon}$$

The mass flow rate (M) is measured by a simple catch and measure technique. The frequency of formation of droplets (f) along with the instantaneous diameter of the ligament (2R) is measured by a laser attenuation technique. The laser attenuation technique along with high magnification, high speed photography are used in order to record the time variations of the ligament diameter. Very accurate recordings are made of the time variations of ligament diameter. The laser attenuation technique is calibrated using glass rods of various diameters. The position, velocity, and acceleration of droplets are measured using automatic image analysis.

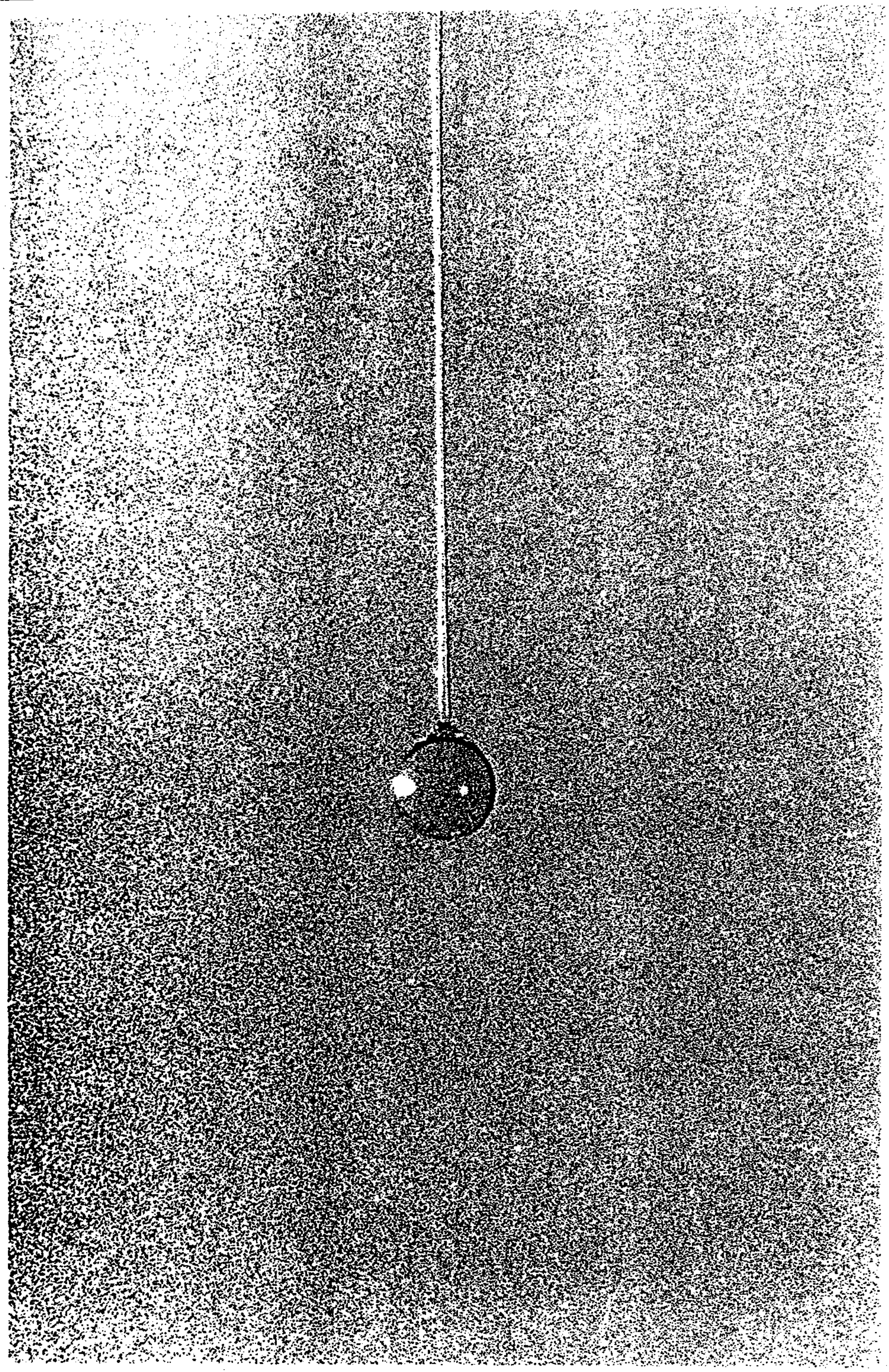

Fig. 1 Breakup of Droplets in the Drip Mode

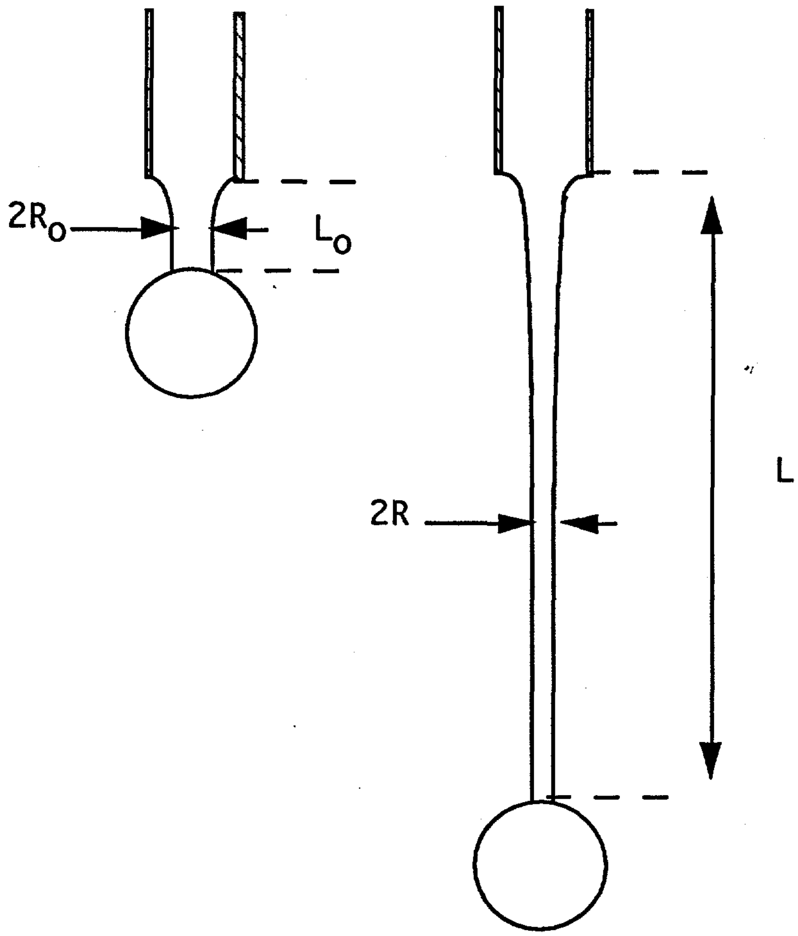

Fig. 2 Homogeneous Extension of Liquid Ligaments