Friction tester for the lubrication properties of ophthalmic solutions

S. Kalachandra and D. O. Shah[a)]

Departments of Chemical Engineering and Anesthesiology, University of Florida, Gainesville, Florida 32611

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A novel and useful device is described to measure the coefficient of sliding friction and the scuff load of ophthalmic solutions for polymeric surfaces. Instead of the conventional electric continuity method, a strain gauge bridge is employed to measure the stability. Vertical forces in the range of 1–10 g are applied to a spherical stylus which runs in a track of lubricating solution applied to a rotating plate of the same or different material as the stylus. The plate rotates at constant speed with respect to the stylus. The horizontal force resulting from friction has been of the order of 0.01–0.10 g. The device is capable of resolving small differences in the lubricating quality of ophthalmic solutions having a low coefficient of friction. The usefulness of the device has been demonstrated by measuring the lower coefficients of friction of an ophthalmic solution in the above-mentioned range of small vertical forces. Reproducible data have been obtained for the ophthalmic test solution.

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Ophthalmic solutions are low-viscosity aqueous solutions containing water soluble polymers as one of the major ingredients in addition to other additives. These polymers are intended to reduce the friction between eyelid and cornea or eyelid and contact lens during the blinking process which involves small loading forces. The present note describes the details of the design and fabrication of a friction testing instrument to measure the coefficient of friction of the ophthalmic solutions.

The method of measuring the electrical resistance has often been used to study the formation and breakdown of lubricant films between sliding surfaces.[1] Using this method, studies involving the lubrication of piston rings and cylinders in an engine, thrust bearings, journal bearings, gears, and disks have been carried out in recent years.[1,2] A simple device for the measurement of both metallic contact and friction, has been developed by Furey.[1] This system basically consists of a fixed metal ball loaded against a rotating steel cylinder. The extent of metallic contact has been determined by measuring both instantaneous and average electrical resistance between the two surfaces. Friction between the ball and cylinder was recorded simultaneously with contact. Askwith, Cameron, and Crouch[3] have studied the influence of the chain length of additives on the lubrication of a slow running four-ball machine. Scuff loads for the additives, long chain acids, amines, and alcohols have been measured using a four-ball apparatus. Tao and Appledoorn[4] have used a modified ball-on-cylinder device for testing the lubricity of jet fuels. An apparatus developed by Bowden and Young[5] has been used to study the frictional behavior of thoroughly degassed metal surfaces. Using this equipment, friction can be measured at any desired temperature up to 1200 °C or more either in vacuum or in a particular gas. Bowden and Tabor[6] have conducted experiments to estimate the real area of contact formed between two crossed cylinders with their axes at right angles in order to completely understand the mechanism of friction. Appledoorn and Barnett[7] have undertaken systematic investigations involving the determination of frictional characteristics of emollients which are responsible for antifriction action when applied to the skin surface. An instrument with ball and cylinder similar to the one developed by Furey[1] has been utilized to measure the coefficient of friction of these emollients. The functional aspects of skin surface lipids have been discussed in detail with a special reference to their lubrication action by Wheatley.[8]

One of the desired properties of tear substitutes or contact lens solutions is to reduce the friction between two sliding surfaces (i.e., cornea and eyelid or contact lens and eyelid). Since the lubrication occurs in this system between non-metallic surfaces in the presence of aqueous lubricants, detection of the failure of the lubricant film by electrical contact measurements was not feasible. The failure of the lubricant to maintain an effective film beyond a critical load is sensed by an abrupt transition in the output signal from a stationary value to rapid fluctuations as load is increased. The vertical loading force is provided by dead-weight loading of the stylus in increments between 1 and 10 g.

As shown in Fig. 1, a square flat test plate is clamped to a table whose rotational movement is maintained at a controlled and uniform velocity (in pilot experiments 100 mm/s at the stylus radius).

The stationary contacting surface is a spherical stylus held in a chuck attached to a restraining arm which allows highly compliant vertical movement, high resistance to torsional deformation, and full transmission of bending moment to a short flexure-gauging section near its support column. The vertical component of friction force is adjusted in increments by annular disks added to the stylus chuck. Rotation of the plate element produces a horizontal component of force at the stylus. An increment of vertical force will result in an increment of horizontal force according to the defining equation

$$C_f = F_h / F_v,$$

where C_f is the dimensionless coefficient of friction, F_h is the

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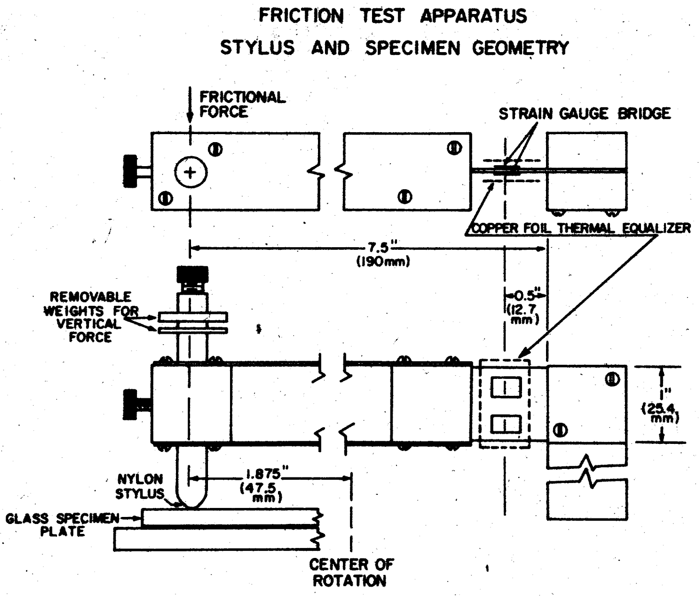

FIG. 1. Friction test apparatus stylus and specimen geometry.

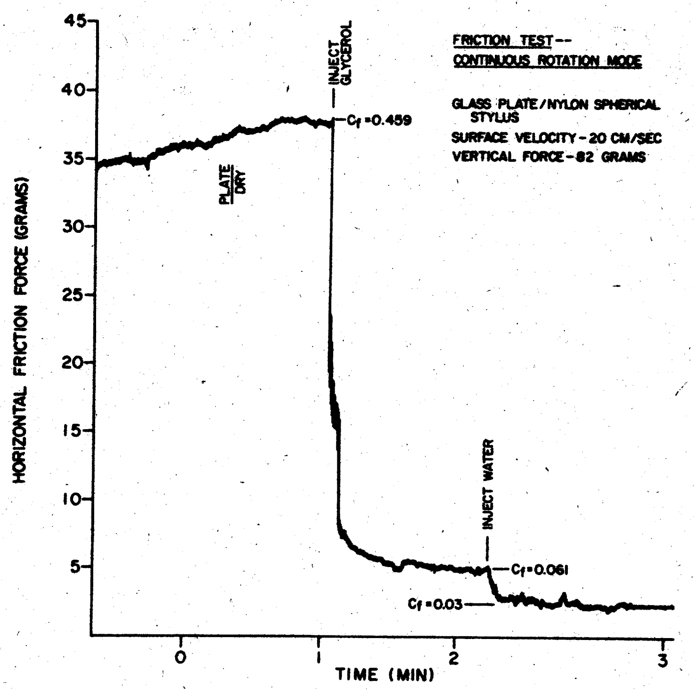

FIG. 2. Friction test-continuous rotation mode: Lubrication action of pure glycerol and glycerol/water mixture (95/5 by volume) on glass plate/nylon spherical stylus; surface velocity: 20 cm/s; vertical force: 82 g.

change in horizontal force resulting from F_v, an increment of vertical force.

In the experiments, vertical force increments were customarily of 1 g. The horizontal force is measured as the flexural moment on the thin gauge section. A full strain gauge bridge is bonded to this section of 0.02-in. stainless steel. Error potentials can result from the thermoresistive nature of the gauges and the thermoelectric properties of the wire connections and tend to obscure the very small signal which is proportional to the horizontal force. It is necessary, therefore, to maintain all four strain gauges and their lead wire junctions at equal temperatures in order to prevent the relatively small signal generated by the horizontal component. The amplifier arrangement is drift stable and provides gain at the oscillatory frequencies involved when film failure occurs.

Materials other than glass can also be used as the rotary plate and a wide variety of polymeric materials is available in the form of precisely manufactured balls which can be chucked in the stylus. Balls of 1/8- and 1/4-in. diameter can be used. Such balls are available in nylon, Delrin, Teflon, polystyrene, polyethylene, metals, and ceramics machined to a diameter tolerance of 0.002- to 0.001-in. sphericity. The plates are also available in these materials.

TABLE I. Coefficient of friction of an ophthalmic solution between a Plexiglas plate and a spherical nylon stylus: velocity 350 mm/s at the stylus radius (70.3 rev/min).

Load in grams	Coefficient of friction "μ"
1	0.038
2	0.041
3	0.046
4	0.050
5	0.052
6	0.054
7	0.057
8	0.062
9	0.065
10	0.069

In its present version the device is covered with a heavy acrylic shield box with top openings to allow manipulation of the vertical component weights and to position a pipette to dispense lubricant onto the running track of the stylus. A tube is also provided to hold a brush of polyurethane foam to spread the dispensed lubricant into a uniform film before it rotates to the stylus contact point.

Table I represents the data for an opthalmic solution obtained at small vertical forces in the range of 1–10 g between a Plexiglas plate and a spherical nylon stylus of 1/4-in. diameter at a stylus velocity of 350 mm/s (70.3 rev/min). These results demonstrate the usefulness of the device for measuring lower coefficients of friction.

A chart record showing the performance of the instrument is shown in Fig. 2. The test surfaces here are a plate glass and a stylus point of 1/4-in. nylon sphere. A fixed 82-g vertical load is applied. The initial tracing in Fig. 2 represents the friction force in the absence of a lubricant (dry surfaces). The resulting horizontal force is stabilized at 37.8 g, indicating a coefficient of friction of 0.459 for these materials under dry conditions. Injection of enough dry glycerol to form a film between the sliding surfaces resulted in a reduction of the coefficient of friction to 0.06 within 2 min. (Fig 2). A few drops of water were added to the plate to make a glycerol/water ratio of 95/5 by volume. Within 20 s the coefficient of friction decreased from 0.061 to 0.03 due to decreased viscosity of the glycerol/water mixture.

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[a] To whom all correspondence should be addressed.

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