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An investigation into the kinetic (sliding) friction of some tablets and capsules

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ABSTRACT

The kinetic (or sliding) friction of pharmaceutical tablets and capsules influences how they will behave during the conveying, coating, and packaging operations that are used for drug product manufacturing. In order to logically design equipment for manufacturing and packaging operations, and to simulate manufacturing and packaging performance (for example, using discrete or finite element modeling approaches), it is necessary to quantify the magnitude of the kinetic friction. In this work, the coefficient of kinetic friction of a range of pharmaceutical tablets and capsules has been measured for the first time using a pin-on-disk tribometer. Binary tablet–tablet contacts and the contacts between tablets or capsules and common equipment surfaces were studied. The range of the friction coefficients was large (between 0.00 and 0.74), and the values depended strongly on the identity of both contacting materials. Tablet–tablet contacts generally exhibited lower friction coefficients than tablet–polymer or tablet–metal contacts. Polymeric surfaces were generally less frictional than metal surfaces, even those that were highly polished. Tablet coatings appeared to have a marked effect on the kinetic friction coefficient between tablets and equipment surfaces, with the hardest coatings tending to be the least frictional. The surface roughness of the tablets and contacting surfaces did not contribute to the coefficient of kinetic friction in a consistent manner. The implications of the results for the design of conveying, processing and packaging operations are discussed.

1. Introduction

During the manufacture and packaging of pharmaceutical dosage forms there are many situations where the dosage form (usually a tablet or capsule) can come into sliding contact with one or more of its neighbors. In addition, each dosage form can rub against the surfaces of the conveying, coating, or packaging equipment. In these circumstances, the kinetic friction (also known as the sliding friction) of the relevant interface will strongly influence how the dosage form responds to any applied stresses (such as gravity).

The term 'kinetic' friction is used to distinguish this interaction term from the similar terms 'static' and 'rolling' friction (Ludema, 1996; Peterson and Winer, 1980). Static friction is used when the initial movement of contacting materials is being considered, whereas rolling friction refers to the interaction between two surfaces where at least one of them is rolling without slipping, such as for the motion of a wheel. The term kinetic friction is used to describe the contact of two sliding surfaces and is quantified using the coefficient of kinetic friction (μ_K). Assuming Coulomb-type behavior, this is given simply by the ratio of the steady-state tangential force to the load applied in normal direction for two surfaces in sliding contact (Ludema, 1996; Peterson and Winer, 1980) (Fig. 1).

The coefficient of kinetic friction cannot be predicted from first principles and it must be measured experimentally for each system of interest. It usually has a value of between 0.0 and 1.0, but more extreme values are possible (for example, for sticky silicone surfaces). In theory, the value of μ_K is independent of the contact area and the sliding velocity. Factors that are reported to influence the value of μ_K are the hardness, roughness and cleanliness of the contacting surfaces, as well as the environmental conditions and the presence of lubricants (Ludema, 1996; Peterson and Winer, 1980).

In order to correctly design equipment for conveying, coating, and packaging operations, or to simulate such operations, for example, using discrete or finite element modeling approaches (Kalbag et al., 2008; Ketterhagen et al., 2009; Kremer and Hancock, 2006), it is necessary to quantify the magnitude of the coefficient of kinetic friction for common pharmaceutical systems. For example, in a blister packaging line high kinetic friction values may mean that active mechanisms (such as screw feeders) will be needed to convey the dosage forms through the equipment. In contrast, low kinetic friction values could lead to uncontrolled product flow and overloading of filling systems. This is illustrated in Fig. 2 where a single tablet in a bulk tablet bed is shown in contact with an equipment surface. This situation may occur, for example, on the feeding chute of packaging line, on the exit chute of a rotary tablet press, or within a tablet

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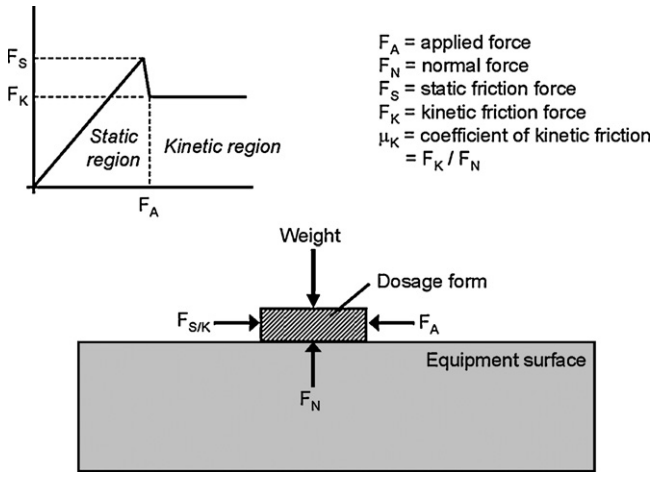

Fig. 1. Schematic defining the coefficient of kinetic friction.

coating pan. In computer simulations of tablet collision dynamics and film-coating operations reported in the literature to-date, the values of μ_K used have been arbitrarily chosen, rather than being parameterized from experimental data generated with actual pharmaceutical materials. For example, Song et al. (2006) used a value of 0.4 in their computer simulations of tablet collisions without any justification. Kalbag et al. (2008) used a kinetic friction coefficient of 0.3 for both tablet–tablet and tablet–equipment contacts in their discrete element simulations of film coating, again without any experimental data to support their choice. These authors did conduct a brief parametric study of the effect of changing the value of μ_K in their simulations and they reported a marked effect on the motion of the tablet bed in the coating pan from a 'slumping' to a 'rolling' behavior.

Up to this point, kinetic friction coefficient measurements on pharmaceutical materials have been mainly restricted to bulk powder systems. Powder 'internal friction' measurements with shear cells are commonly performed and used to predict the real-life flow behavior of pharmaceutical powders (Hiestand and Wilcox, 1968; Podczeck and Mia, 1996). So-called 'wall friction' measurements on pharmaceutical powders (also performed using shear cells) are regularly used to model the flow performance of these materials in industrial and laboratory scale hoppers and chutes (Behres et al., 1998; Haaker, 1999; Prescott et al., 1999). Such measurements of bulk friction coefficients for pharmaceutical powders have also been used to optimize the selection of lubricants to reduce powder-equipment friction (Baichwal and Augsburger, 1985, 1988). Powder friction measurements during punch-and-die compaction (conducted using instrumented tablet presses) have been widely reported (Baichwal and Augsburger, 1985, 1988; Ernst et al., 1991; Guyoncourt et al., 2000, 2001; Holzer and Sjogren, 1981a,b; Korachkin et al., 2008; Lewis and Train, 1965a,b; Strijbos, 1977), and the data generated used to identify potential issues during tablet manufacturing operations (e.g., premature tooling wear). Similar data have also been used as inputs for finite element computer simulations of tablet compaction (Cameron and Gethin, 2001; Cunningham et al., 2004; Sinka et al., 2003). On a much smaller scale, several reports have documented the measurement of kinetic friction between individual particles of pharmaceutical powders and solid surfaces (Bunker et al., 2006; Jones et al., 2004; Lee, 2007; Mullier et al., 1991). Measurements of the friction between drug and excipient particles have also been made using a specialized centrifuge technique (Podczeck et al., 1995). Unfortunately, all these different types of friction measurements on powders and single particles cannot be simply related to the friction at sliding contacts involving solid dosage forms which is the central topic of this work.

To the authors knowledge there are no previous reports of friction measurements on commercial solid dosage forms. However, two reports of this type of work with model pharmaceutical systems exist (James and Newton, 1983, 1985). In the first of these reports (James and Newton, 1983), the authors described a novel 'disk-brake' style testing apparatus and used it to measure the friction of acetyl salicylic acid and poly(tetrafluoroethylene) (PTFE) compacts against a steel surface. The kinetic friction coefficients varied from ~0.9 for the acetylsalicylic acid compacts to <0.1 for the PTFE samples, depending on the experimental conditions selected. In the second report (James and Newton, 1985), the same authors investigated the impact of the roughness of the steel surface on the

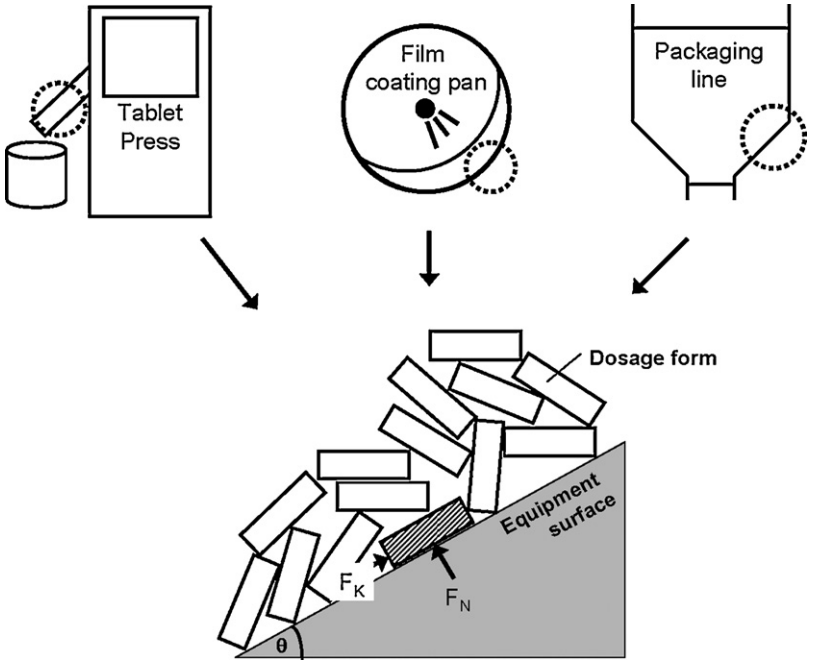

Fig. 2. Schematic of pharmaceutical processing situations where kinetic friction is important.