# Effect of relative humidity and temperature on grain-metal friction

J. ZHANG and R.L. KUSHWAHA

*Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Saskatoon, SK, Canada S7N 0W0.*
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Zhang, J. and Kushwaha, R.L. 1993. **Effect of relative humidity and temperature on grain-metal friction**. Can. Agric. Eng. **35**:041-044. The coefficient of friction (COF) of grains has been evaluated as a function of ambient temperature and relative humidity (RH) on aluminum and galvanized steel surfaces. The COF increased with an increase in RH for low grain moisture at low ambient temperature. For grain with a high moisture content (18.6% wheat, 16.4% canola, 21% lentil), the COF decreased as the RH increased to 70% and 85% at high ambient temperature. Temperature emerged as an important parameter influencing the COF, especially when associated with high RH.

Key Words: coefficient of friction, grain, metal surface, relative humidity, temperature.

Le coefficient de friction (COF) de grains a été évalué en fonction de la température ambiante et de l'humidité relative, sur des surfaces d'aluminium et d'acier galvanisé. Le COF a augmenté avec une augmentation de l'humidité relative pour des grains à faible teneur en humidité, à une température ambiante basse. Pour les grains à haute teneur en humidité (18.6% pour le blé, 16.4% pour le canola, 21% pour les lentilles), le COF a diminué lorsque l'humidité relative a augmenté à 70% et 85%, à des températures élevées. La température est apparue comme étant un paramètre influençant de façon importante le COF, spécialement en présence d'humidités relatives élevées

## INTRODUCTION

Grain handling is generally carried out under conditions where there is little or no control on ambient temperature and humidity. Frictional characteristics of grains are very important in the proper design of material handling and storage equipment. Therefore, coefficient of friction (COF) design data for agricultural materials on various surfaces are required for economical operation of handling and processing machinery. Often, the variation in the physical properties of the agricultural products, such as shape, size, and moisture content, affect the COF values. COF is also dependent on the surface and surrounding conditions. Much technical literature is available that recognizes the influence of the physical properties of the agricultural products on the COF. Little information is available about the influence of the ambient temperature and RH (Bickert and Bakker-Arkema 1968). The existing data are often confusing and questionable since specific ambient conditions should be defined while determining the COF values of agricultural products.

## LITERATURE REVIEW

Friction between sliding surfaces has been of concern for centuries and much of our present knowledge of friction is a result of work by Amontons and Coulombs (Mohsenin 1986). The classical laws of friction state that the frictional force: (a) is directly proportional to total force which acts normal to the sliding surface; (b) depends upon the nature of the materials in contact; (c) is independent of the area of contact; and (d) is independent of velocity of sliding.

Because of varying characteristics of agricultural materials and other solids, several questions have been raised regarding the application of classical friction laws to agricultural materials. In general, the classical laws of friction are not always valid in the case of biological materials. These materials may be deformed even by low surface pressure and their sliding surface characteristics may vary. The variation in the COF values of biological materials is caused by three different processes; (a) fracture of particles into two or more fragments; (b) particle attrition in which the particles become more rounded; and (c) abrasion caused by friction. During sliding of moist or wet materials, the friction characteristics may be altered noticeably because of adhesion characteristics.

Considerable work has addressed the frictional characteristics of agricultural cereal materials. Bickert and Buelow (1966) reported that conditioning of the test surface was necessary to obtain repeatable results in direct shear tests conducted with corn on various test surfaces. The conditioning process involved repeated passes of the test materials over the sliding surface before tests. Frictional forces exhibited a 50% increase during conditioning but reached a steady state near the end of conditioning. This variation in the frictional force occurred due to deposits of oils, waxes, and fats onto the sliding surface. Brubaker and Pos (1965) reported that the static COF increased with an increase in the moisture content of grain, except on teflon where surface moisture acted as lubricant thereby reducing frictional resistance.

The coefficient of kinetic friction of agricultural materials on metal surfaces has been shown to increase with an increase in grain moisture content and ambient RH (Snyder et al. 1967). The COF increased with the number of test runs in repeated direct shear tests with wheat on metal. Following tests, the surfaces were washed with carbon tetrachloride which reduced the COF to its original value. These results indicated that some deposition occurred on the test surface rather than alteration of the sliding surface by abrasion. Thompson and Ross (1983) studied the COF of soft red winter wheat on galvanized steel. Their results indicated that the COF increased with an increase in the moisture content of wheat from 8 to 20% and decreased as the moisture content approached 24%. At a high moisture content, the moisture acted as a surface contaminant and influenced the amount of surface contact which occurred between the two solids. The surface contaminants made the junction between the solids weaker in shear, thus causing the COF to decrease for 24% moisture content. Thompson et al. (1988) analyzed the deposits by using x-ray photoelectron spectroscopy and reported that a 40% increase occurred in the carbon content after only first test run. This indicated that an oil or wax was being deposited on the galvanized surface by wheat kernels. Further analyses showed that the deposited residue was composed of 2 to 4% fatty acids, 23 to 27% triphenol acetate and alcohol, and 70% lipid. Lang (1989) measured the COF of wheat mixed with the canola oil to reduce the dust and found that the COF increased as temperature increased from -25°C to 22°C.

The increase in the COF values with an increase in grain moisture content has been demonstrated. This increase is attributed to increasing adhesion. The temperature is also a very important parameter to the adhesive phenomenon. Some work has been done relating the influence of RH to the COF (Snyder et al. 1967). Since RH is the ratio of two vapour pressures and does not define a state point, the RH should be stated along with atmospheric temperature to be more meaningful (White and Ross 1983). Therefore, the combined effects of both the temperature and the RH on the COF should be considered. Thus, the objective of this research was to study the effects of temperature and RH on the COF between metal surfaces and different agricultural cereal grain.

## EXPERIMENTAL APPARATUS AND PROCEDURE

A Wykeham Farrace shear box apparatus with a shear box 100 mm square was used to determine the COF (Fig. 1). A normal load was applied to the sample by a weight acting through a load hanger that rested on the top plate. The bottom half of the box was pulled at a constant speed of 0.6 mm/min in the horizontal direction.The resulting frictional force was measured with an Interface Model SSM-AS-250 (Interface Inc., Scottsdale, AR) load cell. The load cell was compensated for a temperature range of -18°C to 66°C. A Fluke 2240 datalogger was used to monitor the output from the force transducer. The top and bottom plates of the shear box were made of porous sandstone to prevent the sample slipping at the boundaries. Two metals, galvanized steel and aluminum were used in the tests. Plates were cut to the size of the box and were placed level with the surface of the bottom half of the shear box (Fig. 1). The datalogger was programmed to take a set of readings every 15 seconds. Tests were conducted with Spring wheat (cv: Columbus), lentil (cv: Laird) and canola (cv: Turbine). Three replicates were conducted for each temperature and humidity level with the same moisture content of the grain. The levels of the parameters are given in Table I. A factorial analysis of variance was conducted to determine the significance of parameters.

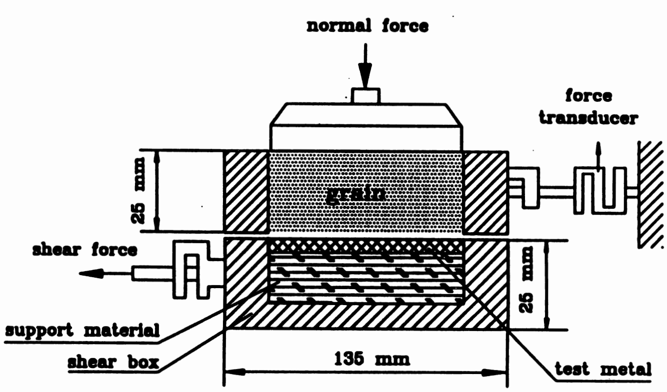


**Fig. 1. Schematic of shear box apparatus.**

**Table I. Grain metal friction variables information**

| Variable | Levels | Values |
|---|---|---|
| Grain | 3 | wheat, canola and lentils |
| RH | 4 | 25, 50, 70 and 85% |
| Metal | 2 | galvanized steel and aluminum |
| Temp | 2 | 20°C and 36°C |
| Moisture | 2 | high and low |

Number of observations in data set = 96
Number of replicates = 3

Tests were conducted in an environmental control chamber at temperatures of 20°C and 36°C with four different RH settings ranging from 25 - 85% (Table I). The upper limit of 36° was the practical working temperature attained in the environment chamber. The initial moisture content of wheat, lentils, and Canola was 11.9%, 11% and 6% (wet basis), respectively. All three grains were stored in plastic containers at a room temperature of 20°C until processed for the experiment. The desired moisture content was obtained by adding water and then placing the grain in sealed bags in a refrigerator for 48 hours to reach equilibrium. Twenty four hours before the test, the sealed bags of grain were placed in the environmental control chamber to obtain equilibrium test temperature. The test metal pieces were also conditioned in the environmental chamber for at least 10 hours prior to the test. This procedure provided equilibrium conditions for the grain and the sliding surface. The period of grain exposure to the environment was limited to about 20 minutes during the test. The grain was discarded after each test. Thus the grain sample reached equilibrium temperature in the sealed bags, but did not reach its equilibrium moisture content during the test. Oxidation of metal surfaces at high temperature and humidity would also effect the COF, however, no attempts were made to measure metal oxides on the sliding surfaces due to short duration of a test run. Moisture contents were determined on a wet basis by the oven dry method according to the ASAE Standards (ASAE 1989). However, there was no method available in the ASAE standard for the lintels. A recommended method presented by Tang and Sokhansanj (1991) was used where the lentils were dried at 130°C for 20 hours.

The roughness of the two metal contact surfaces was determined using a roughness test unit (Mitutoyo Surftest 211). The surface roughnesses of galvanized steel and aluminum were found to be 1.35 and 0.58 m, respectively.

Exploratory studies were conducted to determine the appropriate velocity and normal force for the COF tests. A statistical analysis of preliminary results showed that velocities near 0.6 mm/min had a constant COF. Normal pressure was varied from 7 kPa to 28 kPa. The pressure variations caused some changes in the COF. The COF for canola at 6% moisture content decreased from 0.40 to 0.24 as the pressure increased from 7 kPa to 28 kPa. All tests were performed at 28 kPa since the pressure of 28 kPa was reported to have been found in grain storage bins (Mohsenin 1986). The preliminary tests also showed that the COF decreased with the number of test runs. The COF decreased dramatically for the aluminum surface. After ten runs, it decreased from 0.21 to 0.16 for wheat at 11% moisture. The variation was attributed to the deposits which accumulated on the metal surface. Therefore, to obtain repeatability among tests, the metal surface was washed with acetone after each test run.

As mentioned earlier, the preliminary tests showed that the COF decreased from 0.40 to 0.24 for an increase in normal pressure from 7 kPa to 28 kPa. This is in agreement with the results of Thompson and Ross (1983) who explained this phenomenon with the Hertz equation. The Hertz equation indirectly predicts that a decrease in the COF occurs for an increase in normal pressure. The COF also decreased with the increase in the number of trials. This may have been caused by the deposits of the wax and fatty acid materials which helped to lubricate the sliding surface hence reduce the COF. This result was contrary to the results found by Bickert and Buelow (1966) and Snyder et al. (1967). According to their results, the COF increased with the increase in the number of trials. However, Thompson and Ross (1983) and Thompson et al. (1988) reported that the COF decreased as the number of trials increased. The difference may be attributed to the various test conditions and materials.

Preliminary tests also showed that the operating technique had a considerable effect on the results. Sample filling method and starting time for data recording were two of the most influential factors. The filling method used in this test was a loose fill. The sample was poured through a funnel which was set at 20 mm above the bottom surface of the box. The grain was levelled with an aluminum plate. The top plate was placed on the surface of the sample and pressed slightly. The top half of the box was raised 2 to 3 mm to eliminate friction between the two halves of the box before the shear force was applied. The total horizontal displacements, which were greater than the mean length of the individual kernels, were 3 to 4 mm, 5 to 6 mm, and 7 to 8 mm for canola, wheat, and lentil, respectively.

## RESULTS AND DISCUSSION

Figures 2 to 4 show the mean COF as a function of both RH and temperature for galvanized steel and aluminum for wheat, canola, and lentils at two levels of grain moisture. Since there were considerable differences among the three grains, the analysis of variance for individual grain type was carried out. The results of these analyses showed that the COF was highly significant as affected by the grain moisture, ambient temperature, RH, and the two metal surfaces.

The COF increased significantly for an increase in the RH

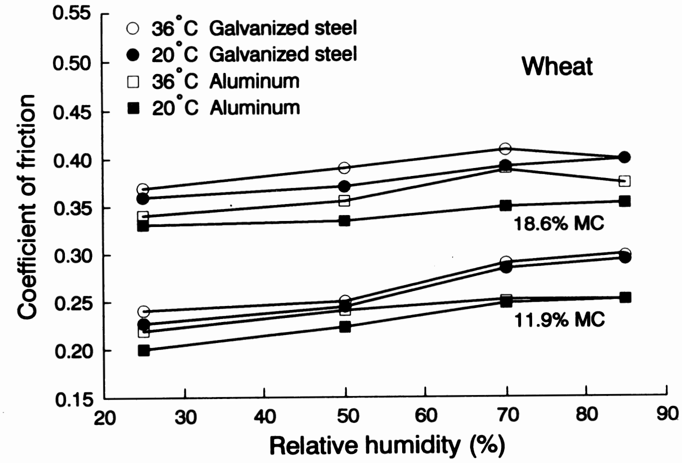


**Fig. 2. Coefficient of friction of wheat as a function of RH and temperature at two moisture levels.**

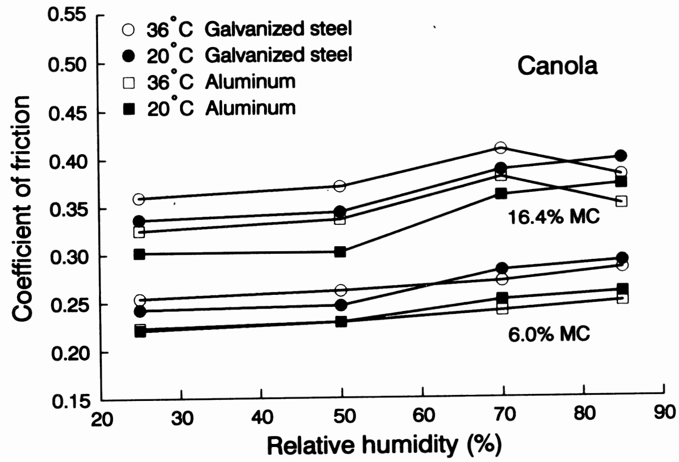


**Fig. 3. Coefficient of friction of canola as a function of RH and temperature at two moisture levels.**

from 25% to 85%. The RH which reflects the moisture content of contact surface was a very important parameter that influenced the COF. Similar results have been reported by Snyder et al. (1967). Since RH is a factor, it should always be stated along with the atmospheric temperature. The COF increased for both an increase in RH and temperature. The COF was higher at 36°C than at 20°C in most cases. This may be caused by the fact that the partial vapour pressure is higher at 36°C which would have increased the moisture level of the sliding surface. It appears that the increased moisture level of the sliding surface caused adhesion hence increased the COF.

The COF was higher at 36°C temperature than that at 20°C for the range of RH from 25% to 50%. However, for the range of 25% to 50% RH, the value of COF was nearly the same for both the temperatures. Furthermore, at the high temperature of 36°C, the COF decreased as the RH increased to 85% for the high moisture content of the grains (18.6% wheat, 16.4% canola, 21% lentil). The decrease in COF may have resulted from a lubrication phenomenon caused by the increased

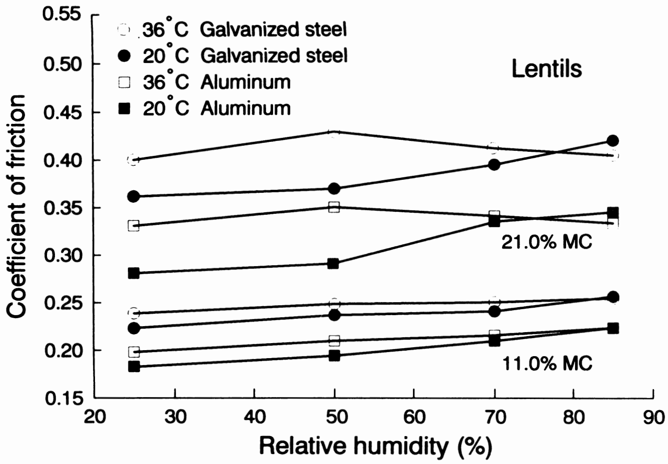


**Fig. 4. Coefficient of friction of lentils as a function of RH and temperature at two moisture levels.**

moisture level of sliding surfaces. However, for the grain with low moisture content, the COF still increased with the increase in the RH at the high temperature of 36°C. However, the ratio of increase of COF was reduced. The decrease in COF at high temperature may have also been caused by appearance of fatty acids, wax and like substances more often than those at normal temperature. The fatty acids combined with surface moisture level would help to reduce the COF.

An interesting phenomenon was observed with lentil with grain moisture content of 21%. The COF began to decrease at the RH of 50% as compared to wheat (18.6%) and canola (16.4%) at the RH of 85%. This may be attributed to the higher moisture content of lentil and smooth surfaces of grains.

## CONCLUSIONS

1. The influence of the temperature on the coefficient of friction was significant for a given relative humidity.
2. The influence of relative humidity and temperature on the coefficient of friction changed significantly for different grain types.
3. The coefficient of friction decreased from 0.40 to 0.24 for an increase in normal pressure from 7 kPa to 28 kPa at a grain moisture of 6% for canola.
4. The coefficient of friction increased with an increase in the relative humidity. However, for high relative humidity values at high temperatures, the coefficient of friction decreased for the grain with high moisture content.
5. The coefficient of friction decreased with increasing number of tests, because of material deposition on the sliding surface. The value of the coefficient of friction remained at its original level when the sliding surface was washed with acetone after each test.

## REFERENCES

ASAE. 1989. ASAE Standards, 36th ed. Standard S352.1. Moisture measurement-Grain and seeds. St. Joseph, MI: ASAE.

Bickert, W.G. and F.W. Bakker-Arkema. 1968. Inconsistencies among friction data for grain. Quarterly Bulletin of the Michigan Agricultural Experiment Station 50(4):591-598. Michigan State University, East Lansing, MI.

Bickert, W.G. and F.H. Buelow. 1966. Kinetic friction of grains on surfaces. *Transactions of the ASAE* 9(1):129-131,141.

Brubaker, J.E. and J. Pos. 1965. Determining static coefficients of friction of grains on structural surface. *Transactions of the ASAE* 8(1):53-55.

Lang, W. 1989. Canola oil as dust suppressant: A system approach. Unpublished M.Sc. thesis, University of Saskatchewan, Saskatoon, SK.

Mohsenin, N.N. 1986. *Physical Properties of Plant and Animal Materials*, 2nd ed. New York, NY: Gordon and Breach Science Publishers.

Snyder, L.H., W.L. Roller and I.E. Hall. 1967. Coefficients of kinetic friction of wheat on various metal surfaces. *Transactions of the ASAE* 10(3):411-413,419.

Tang, J. and S. Sokhansanj. 1991. Determination of moisture content in whole kernel lentils by oven method. *Transactions of the ASAE* 34(1):255-256.

Thompson, S.A., R.I. Bucklin, C.D. Batch and E.G. Ross. 1988. Variation in the apparent COF of wheat on galvanized steel. *Transactions of the ASAE* 31(5):1518-1524.

Thompson, S.A. and I.J. Ross. 1983. Compressibility and frictional coefficients of wheat on various metal surfaces. *Transactions of the ASAE* 26(4): 1171-1176,1180.

White, G.M. and I.J. Ross. 1983. Humidity. In *Instrumentation and Measurement for Environmental Sciences*, 2nd ed., ed. B.W. Mitchell, chapter 8. ASAE Special Publication 13-82. St. Joseph, MI:ASAE.