August 1, 1958

To the Graduate Council:

I am submitting herewith a thesis written by Sankara Narayanna Reddy entitled "The Use of Tetrafluoroethylene (Teflon) in Farm Equipment for Reducing Friction." I recommend that it be accepted for twelve quarter hours of credit in partial fulfillment of the requirements for the degree of master of science, with a major in Agricultural Engineering.

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THE USE OF TETRAFLUOROETHYLENE (TEFLON) IN FARM EQUIPMENT FOR REDUCING FRICTION

A THESIS

Submitted to
The Graduate Council
of
The University of Tennessee
in
Partial Fulfillment of the Requirements
for the degree of
Master of Science

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by

Sankara Narayana Reddy

August 1958

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CHAPTER I

INTRODUCTION

The Honorable Ezra Taft Benson, U. S. Secretary for Agriculture stated (25, page 3) that "the basic long-range needs of American agriculture are to reduce costs." This is true and essential, not only for American agriculture; but also for world agriculture. The need for reducing costs in agriculture will always remain a standing challenge to the Agricultural Engineer and in fact it is his very duty and for which alone he can justify to exist.

With the advancement of mechanization of agriculture it has been possible to increase agricultural production and bring down the cost of production. Yet farming gives comparatively low returns when compared to other industries. There is and there will always be the need to bring down the cost of agricultural production.

One of the possible ways to bring down the cost of agricultural production is to economize in the field of mechanization and the use of farm equipment by minimizing power requirements without sacrificing efficiency and functional needs. The need for minimizing power and reducing costs is more keenly felt in underdeveloped countries, where power is more expensive and mechanization cannot immediately replace human labor for diversion to industrial needs to raise their standard of living.

One of the major sources of waste of farm power is due to friction. It has been possible to reduce power losses in overcoming friction by the use of "frictionless" bearings. But there exists a vast field in farm equipment where friction consumes a considerable portion of the power applied. Friction in tillage implements, such as plows, materials handling equipment, blowers used for elevating chopped forage, ensilage and other cattle feeds is considerable. Blevins (1, page 356) reported that nearly 20 per cent of the power in field choppers is utilized in overcoming friction. Although definite figures are not available in power losses due to friction in other farm equipment, the losses are considerable. The use of a material with a low coefficient of friction in the place of steel commonly used in farm equipment naturally suggests itself. Tetrafluoroethylene (Teflon) is a possible friction-reducing material as its manufacturers claim that it has the lowest coefficient of friction known for solids.

Statement of the Problem

The purpose of this study is to investigate the possibility of the use of Tetrafluoroethylene in farm equipment to reduce friction. The study is confined to the determination of the coefficient of friction of the following agricultural materials with Teflon and to observe their friction characteristics to decide whether there will be reduction in friction in using Teflon in farm equipment:

1. Hay.
2. Grass ensilage.
3. Long alfalfa.
4. Chopped alfalfa.

Teflon

Tetrafluoroethylene, commercially and popularly known as "Teflon" (4-9 and 23) is a heavy duty plastic of the fluorocarbon family manufactured by Du Pont. Its manufacturer claims high advantages previously unobtainable in a single material (6). Its dielectric properties (low power factor, low dielectric constant, high volume and surface resistivity, good dielectric strength), chemical inertness, heat resistance, toughness and flexibility, low coefficient of friction, nonadhesive property, zero moisture absorption and weather resistance make it an engineer's boon material for a wide use of application.

Manufacture

"Teflon" is an outgrowth of Du Pont research that led to the development of the "Freon" series of refrigerants. Research on "Freon" series of refrigerants led to the discovery of Tetrafluoroethylene resin in 1938. Semi-plant production began in 1941 at Parkersburg, West Virginia.

Teflon is manufactured by fluorspar (calcium fluoride) and sulphuric acid reacting to give hydrogen fluoride which is reacted

in turn with chloroform to give chlorodifluoro methane. This is converted by pyrolysis to gaseous tetrafluoroethylene monomer. This monomer is subsequently polymerized under high pressure and temperature to give "Teflon." The polymer consist of long straight-chain molecules packed together closely. This structure and the strong chemical bond between carbon and fluorine in the molecule impart exceptional resistance to heat and chemicals.

The manufacturing process of Teflon is depicted by the flow sheet in figure 1.

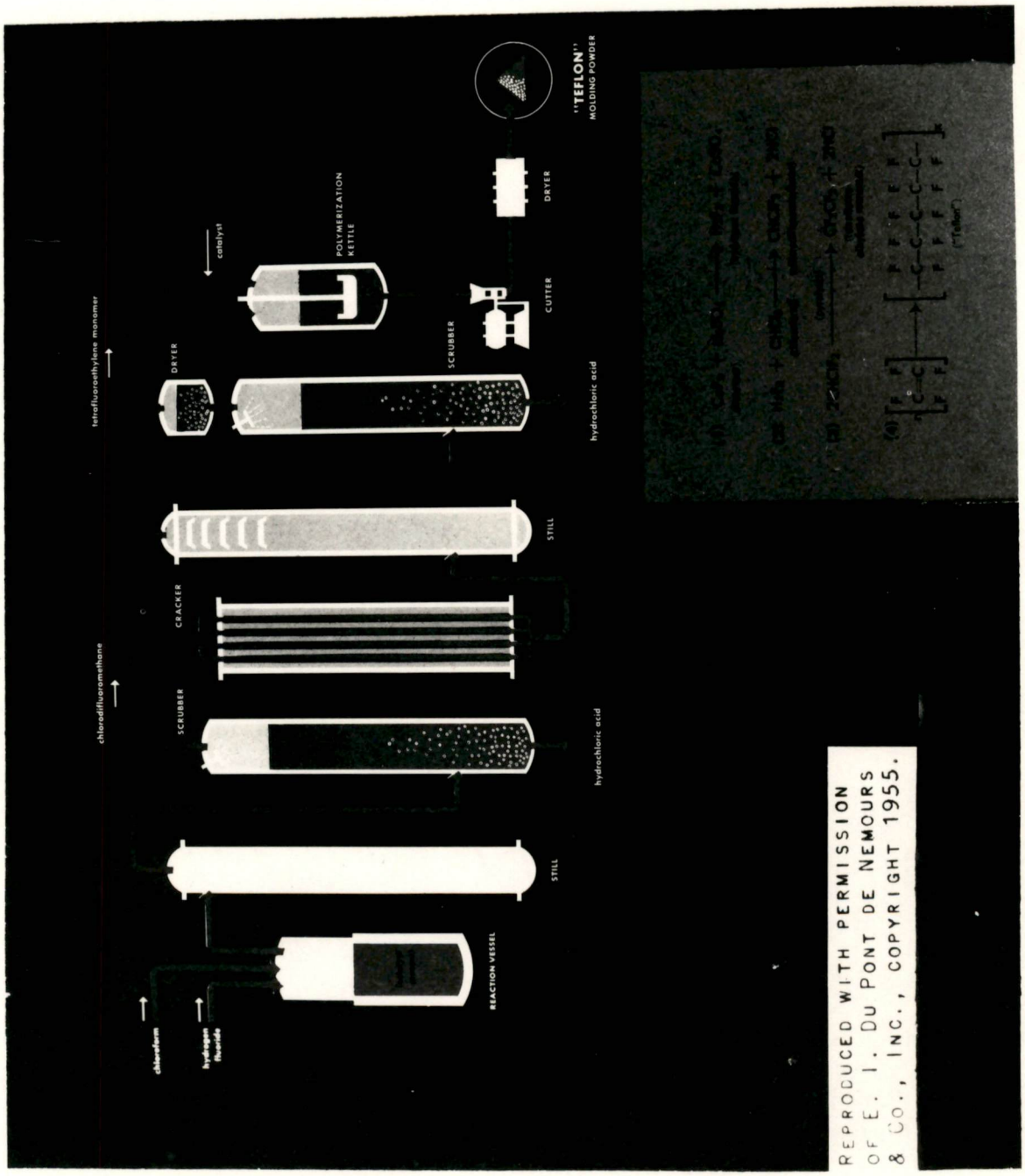
Forms Available

"Teflon" is supplied by the polychemicals department of the Du Pont Company in the forms of:

1. Granular molding powders.
2. Fine powders.
3. Aqueous dispersions.

Other processors convert Teflon into:

1. Rods.
2. Tubes.
3. Coated fabrics.
4. Coated hose.
5. Wire enamels.
6. Molded parts.
7. Tapes.
8. Sheets.



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Figure 1. Manufacturing process of Teflon

Granular Molding Powder

The granular molding powder is available in several granulations, tailored to specific uses. The general purpose powder is a white granular powder with a particle size of about thirty mesh. Its bulk density is about 575 grams per liter.

Fine Powder

The extra fine powders are prepared from a coagulated dispersion. When compounded with an extrusion aid such as naptha, they can be readily extruded as tape, tubing, wire insulation, and shapes.

Aqueous Dispersion

This is a hydropholic colloid with negatively charged particles averaging about 0.3 micron in diameter. It has a viscosity of about fifteen centi-poises at seventy degrees Fahrenheit.

Working Techniques

The conventional molding and extrusion techniques used with other plastics are not applicable to Teflon, because it does not melt and flow. "Teflon" is molded by a modification of compression molding techniques, consisting of cold preforming and sintering at high temperatures. A number of new processing techniques have been developed: extrusion of molding powder in heated dies fed by either a screw or reciprocating ram.

extrusion of their sections from a lubricated "Teflon" paste; and production of tape and coated wire by calendering. Complex articles are made by machine rods or tubes.

As a dispersion "Teflon" can be applied to surfaces by dipping or spraying the dispersion on to the surface being coated, and then drying and fusing at elevated temperatures.

For purposes of easy handling to study the characteristics (particularly friction with reference to agricultural produce) of Teflon for use in agricultural machinery, it was felt that Teflon which could be cemented to metal, wood, plastics, etc., would be ideal. It was known from the Du Pont Information Bulletin (6) that they have cementable teflon that can be cemented to almost any surface with suitable adhesives.

Cementable Teflon

The cementable "Teflon" provides a cementable surface which can be glued to any other surface like metal, wood, or plastic.

The treatment of Teflon to provide a cementable surface is invariably a one-step process and there are several methods of doing it. The most commonly used are the sodium-naphthalene-tetrahydrofuran bath process, and the sodium-ammonia process; and Nelson (17) reported that they are equally effective. The treated surfaces can be cemented to a variety of materials with conventional bonding agents like the epoxy resin adhesive. The cementable side is brown in color while the smooth side is white and may be seen from figure 2.

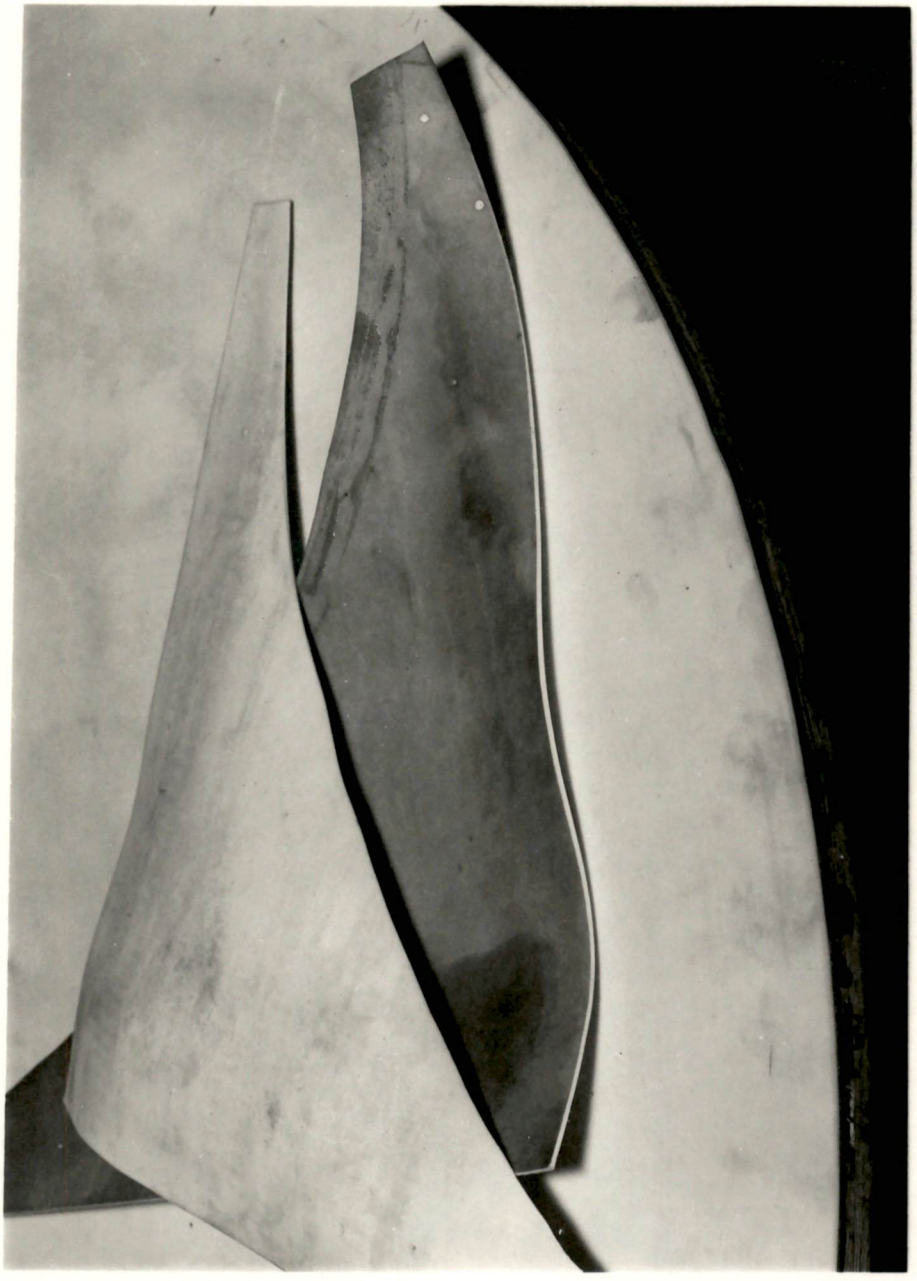


Figure 2. Teflon sheet showing cementable side and smooth side

Properties of Teflon

The manufacturers (6) claim properties and advantages in Teflon unobtainable in any other single material such as:

Dielectric properties

Mechanical strength and heat resistance

Chemical inertness

Low coefficient of friction

Resistance to adhesion

Nontoxic qualities

Zero moisture absorption

Weather resistance

The electrical properties of Teflon are outstanding, particularly since they remain so at high frequencies and high temperatures. Its power factor is less that 0.0005 even at frequencies as high as 30,000 megacycles. Its power factor, low dielectric constant (2.0), and high dielectric strength are unaffected by temperatures up to 400°F.

Its mechanical strength is high over a wide range of temperatures. Its impact strength is high at temperatures even below -90°F., and it is capable of continuous service at 500°F.

The manufacturers also claim that Teflon has the highest degree of chemical inertness of any commercial plastic being attacked only by molten alkali metals and by fluorine gas at elevated temperatures and pressures. It can be boiled in aqua

regia, hydrofluoric acid, sulfuric acid, or nitric acid with no change in weight or properties. It has zero water absorption and is unaffected by outdoor weathering.

Teflon has an extremely low coefficient of friction and the manufacturers claim that under certain test conditions, the coefficient of friction has been as low as 0.04. The static coefficient of friction for Teflon is equal to the dynamic value and does not exhibit a stick-slip type of motion.

A unique property of Teflon, related to its low friction characteristics, is the fact that few materials tend to stick to its surface. This property is utilized in a variety of operations in which sticky materials are handled. Because of its excellent heat stability, the electrical and mechanical properties of Teflon are not affected by the high temperatures to which it may be subjected during normal processing operations and in use.

The manufacturers also claim that animal feeding tests clearly show that Teflon is non-toxic when taken internally. Other animal tests have shown that Teflon does not produce skin irritation. These laboratory tests are substantiated by the fact that no such cases have arisen from the handling of "Teflon" during its fifteen year history of development, manufacture, and use (6). This property is of special significance for using Teflon in handling animal feeds, such as grains, hay, silage.

Teflon does not absorb any moisture and has little or no change when exposed to adverse weather.

Present Uses

Electrical applications. Because of its unique combination of electrical, thermal and mechanical properties, Teflon is used extensively by the electrical industry such as spacers for coaxial cables, inserts for coaxial connectors, insulation for high frequency, high temperature, and high voltage wires and cables and as a high quality wrapping tape for insulation in motors, generators, transformers and conductors. Teflon is particularly good for use in motors and generators. Uses include conductor insulation, and coil separators within the slots. Especially in the cases of motors submerged in water in submersible pumping units, teflon insulation has definite advantages over the conventional insulation material as teflon is chemically inert and has zero moisture absorption. Its use has been extended to the field of electronics in the manufacture of capacitors and other electronic equipment.

Chemical equipment application. Due to its chemical inertness, Teflon is used in the chemical industry as gaskets, pumps, and valve packings. These packings out last other materials by many, many times, greatly reducing replacement and maintenance costs. Pumps with teflon bearings, packings, and impellers are said to give much better and longer performance. The use of teflon reduces maintenance requirements, reduces wear on pistons

and shafts, increases productive capacity through less down-time for repairs. It also frequently improves the quality of the product being processed because it eliminates contamination. Several types of pipes and tubing are made of "Teflon."

Mechanical applications. A new and potentially large field of application for "Teflon" is that of mechanical parts, primarily bearing surfaces. Of particular importance in this use of Teflon is its low coefficient of friction. The use of Teflon as a bearing in pumps is an excellent example of its unusual low frictional properties and chemical inertness. Where difficult bearing applications are encountered, particularly where corrosion or high temperatures present a problem and where normal lubricants cannot be used, "Teflon" may provide the answer.

Nonadhesive applications. The unique nonadhesive property of Teflon is utilized in a variety of operations in which sticky materials are handled. For this reason it is being used in many parts of manufacturing equipment where a nonsticky surface is needed, such as jaws of heat sealing machines and on conveyors and rolls handling sticky materials such as on rolls and other parts of bread making machinery, machinery used in the preparation of candy, in the rubber and plastic industries to prevent sticking to molds and platens, and in industries in which glue is handled extensively. Teflon is thus ideal for use in food-processing equipment as nothing sticks to it and it is chemically inert.

Military use. Teflon has been successfully used by the Marine Corps (24) as a preservative for long term storage of weapons and a lubricant for small arms in troop use.

The Marine Corps Equipment Board which conducted extensive tests (24) concluded that Teflon is a suitable preservative for a long term storage of weapons. The initial coating of Teflon provided satisfactory lubrication for weapons for an almost indefinite period following the issue. The use of Teflon coated projectiles and cartridge cases gave increased muzzle velocity, reduced barrel wear, longer barrel life, improved ease of extraction, and reduced probability of "cook-off" in heated weapons. The use of Teflon coated projectiles gave better bore protection to a weapon than the use of an uncoated bore and uncoated projectiles because a Teflon film is deposited in the barrel by each round fired as the cartridge case itself is coated with Teflon.

The Marine Board has also recommended that Teflon be considered suitable as a lubricant for small arms in troop use, and that further investigation should be done for the use of Teflon as a lubricant for the moving parts of all Marine Corps weapons. Samples of all infantry regimental weapons have also been recommended to be coated with Teflon and supplied to fleet marine force units for troop testing.

These versatile properties--chemical inertness, low coefficient of friction, nonadhesive absorption--and its present wide

use under adverse and difficult situations suggest that Teflon can be advantageously used by the agricultural engineer in the field of plows, farm machinery, food processing and materials handling equipment.

As a first step it was proposed to study the friction characteristics of agricultural materials on Teflon and to obtain basic data to decide whether or not Teflon could be used in farm equipment to reduce friction.

Friction

Friction (10, 13, 15, 16, 21, and 22) is defined as the resisting force or resistance which one body offers to another body in contact when the second body moves or tends to move past the first body. From this definition, it should be observed that friction is a retarding force always acting opposite to the motion or tendency to move. Friction exists primarily because of the roughness of the contact surfaces.

Friction is either useful or harmful depending on its relation to the mechanism or process in which it occurs. Without friction the whole world could be jeopardized. There would be absolutely no movement without friction. Friction is a dire necessity but it can be harmful, too. Examples of useful friction are brakes, self-locking mechanisms, bolted or riveted joints. Friction is harmful in bearings, plows, and agricultural machinery

like ensilage cutters, blowers, elevators, where two materials rub or move against each other and thus waste power; and in pipes where it retards flow. We are mainly concerned with harmful effects of friction which result in waste of power particularly in agricultural machinery.

Static, Sliding, and Rolling Friction

When two bodies are in contact there is frictional force when one of them moves or tends to move against the other. The force required to just start the body sliding or moving that is about to cause motion is equal and opposite to the static friction. The force required to continue the sliding motion after having started it is equal and opposite to the sliding or kinetic friction. When one (or both) of these bodies are in the shape of a cylinder or spherical body the friction that exists is referred to as rolling friction.

Coefficient of Friction

The maximum force of friction which one body is capable of exerting upon another is directly proportional to the normal or perpendicular force with which their surfaces are pressed together. Thus if F is the maximum force of friction between two bodies which are pressed together with a force N perpendicular to their contacting surfaces then F is proportional to N or

$$F = \mu N$$

where the proportionality factor μ is a dimensionless quantity which is called coefficient of friction between the surfaces. Transposing, this expression becomes

$$\mu = \frac{F}{N}$$

from which the coefficient of friction is defined as "the ratio of maximum force of friction between two bodies to the normal force pressing the surface together." It is evident from the equation, $\mu = \frac{F}{N}$, that since F and N are both forces, they may be expressed in any desired force unit so long as the same unit is used for both and that μ is a pure numeric having no unit. Since the frictional force F is always in the plane of sliding, and the normal force N pressing the two surfaces into contact is perpendicular to the plane, it follows that F and N are always at right angles to each other.

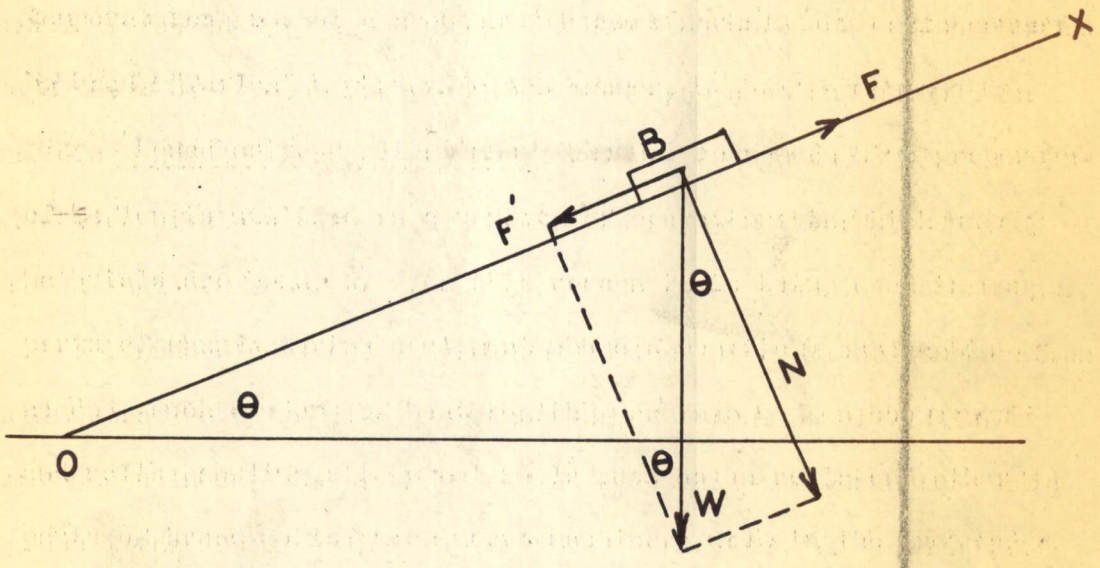
Angle of Repose or Angle of Friction and Coefficient of Friction

The angle of repose θ or friction is the maximum angle of inclination that a plane may have before a body on the plane begins to slide under the action of its weight alone.

Let the plane OX (figure 3) be gradually tilted until the body B just begins to slide down the incline. If the weight W of the body is resolved into its components F' parallel and N normal to the incline, it is evident that F' alone overcomes the friction F while N merely presses the bodies together.

FIGURE 3

FREEBODY DIAGRAM OF ANGLE OF REPOSE AND FRICTIONAL FORCE



Just before sliding begins, there is no acceleration. Hence B is in equilibrium and F' = F.

By definition $\mu = \frac{F}{N}$

But from figure 3, $\frac{F'}{N} = \tan \theta$ or $\frac{F}{N} = \tan \theta$

Therefore μ is equal to tan θ where μ is the coefficient of static friction.

After sliding begins, the angle may be decreased slightly to a value θ' so that the body will slide without acceleration. The angle is the limiting angle of kinetic or sliding friction and the coefficient of sliding or Kinetic friction is

$$\mu' = \tan \theta'$$

Laws of Friction

The laws of friction first formulated by Morris about 1830, have been modified from time to time by later research workers and experimenters. The following paragraphs form a brief statement of the generally accepted laws, based on present day practices.

1. Friction always acts to oppose the motion of the free body (or its tendency to move). It is parallel to the surfaces in contact.

2. If static friction is acting, the value of the friction force may vary from zero to the maximum available value, depending upon the resultant force tending to cause motion.

Unlubricated surfaces.

3. Friction varies approximately as the normal pressure with which the rubbing surfaces are pressed together.

4. Friction is approximately independent of the area of the surfaces (but is slightly greater for smaller surfaces than for large surfaces).

5. The coefficient of friction for dry surfaces depends on the materials sliding over each other and on the finished conditions of the surfaces. With greasy (boundary) lubrication, the coefficients depend both on the materials and conditions of the surfaces and on the lubricants employed.

6. Friction decreases slightly with increase of velocity except at very low velocity.

Thus the coefficient of friction depends on the kinds of materials in contact, the finish of their surfaces, and the nature of any lubricant used. For dry surfaces, this coefficient is usually assumed to be independent of the unit pressure between the contacting bodies, and of their relative sliding velocity (although there is slight decrease with increase of velocity, except at low velocities).

Review of Previous Work Done

Soil Friction

Soil friction materially affects the power requirements, the life and draft of plows and other tillage implements. In his monumental work on "The Dynamic Properties of Soil II Soil and Metal Friction," Nichols (18) reported that friction between a soil and metal may be classified into four distinct and separate phases. These phases depend upon the bearing capacity of the soil, its moisture content, the pressure of the metal surface and the colloidal content of the soil, which is the controlling factor. The four phases of friction and its characteristics, according to Nichols, are summarized below.

Compression phase. This condition exists when the weight of the slider compresses the soil; that is, the pressure is greater than the bearing capacity of the soil. In a soil when water does not adhere to the metal, the coefficient of sliding friction μ under the compression phase:

1. Varies with the speed
2. Is proportional to the pressure per unit area
3. Varies with the smoothness of the surface and the materials of the surface.

Friction phase. This is similar to compression phase so far as moisture is concerned. The soil water does not adhere to the metal, but the pressure per unit area is less than the bearing capacity of the soil. Then:

1. The magnitude of the friction is proportional to the total pressure between the two surfaces.

2. The coefficient of friction μ depends on the roughness of the surfaces and the materials of the surfaces.

3. It is independent of the area of contact.

4. It is independent of the sliding speed.

Adhesion phase. When there is enough moisture present to cause the soil to adhere to the sliding surface, but not enough to have moisture brought to the surface, then the coefficient of friction:

1. Varies with the speed

2. Varies with the area of contact

3. Varies with the pressure per unit area

4. Varies with the surface tension of the film moisture, that is:

   a. It varies with the amount of colloidal material present

   b. It varies with the amount of water present

   c. It varies with the temperature and viscosity of soil solution

5. Varies with the surface and kind of metal

Lubrication phase. When there is sufficient moisture present to give a lubricating effect, then the coefficient of friction μ varies:

1. With the pressure per unit area

2. With the speed

3. With the amount of moisture and viscosity of the solution

4. With the nature of the surface and kind of material of which it is composed.

Nichols found that the frictional characteristics of a metal was largely determined by its hardness and polish.

Polish was shown to affect the frictional values materially in the heavier soils, but as no measure of polish was available, no mathematical formula for its effect was attempted. A polish higher than that commonly found on commercial plows was found to be of no practical value on sandy soil. But it was found that the adhesion of soil to plow surfaces varied with the polish and composition of the metal. Steels containing chromium or nickel were the most satisfactory of those tried.

The observation that a high degree of polish, beyond those found on commercial plows had no effect on sandy soils, but reduced adhesion, has a direct bearing on the general problem of using Teflon in farm equipment, particularly in plows. This observation correlates the experience of other present day workers on Teflon; and it is this property of Teflon, namely high polish and therefore its non-adhesive nature, that is sought to be exploited for a better performance of scouring and less draft in

plows and tillage implements. Nichols used the simple method of pulling a loaded metal slider over the soil to determine friction between the metal and soil while recent workers like Payne (19) have developed the technique of measuring soil/metal friction by a shear plate, the frictional stresses being measured by the aid of electrical resistance strain gages.

Friction Coefficients of Agricultural Materials

Hintz and Schinke (11) reported that the coefficient of friction for green chopped corn and alfalfa on steel was approximately 0.5 throughout a 1000 to 6000 f.p.m. sliding velocity range. A greater variability in the coefficient was observed at velocities below 1000 f.p.m. But as the velocity range of intended application was above 1000 r.p.m. no further observations were conducted by them to evaluate the limits of these variations.

Richter (20) found coefficients of friction for various materials, but at lower speeds. He reported that the static-friction coefficient of chopped dry hay and straw may be considered as 0.4 on new galvanized steel and 0.2 on the same material after extended polishing. Considering the time necessary for polishing, a power unit based on a static coefficient of friction of 0.35 and a sliding coefficient of 0.30 was suggested by Richter for velocities below 640 f.p.m. for equipment handling chopped dry hay and straw.

Richter also reported that for chopped grass and silages, a static-friction coefficient of 0.80 and a sliding friction-coefficient of 0.70 on galvanized steel for velocity ranges 0 to 320 f.p.m. would be adequate for design purposes.

Barger (2) reported friction coefficients of corn silage from 0.79 to 0.96 for false end-gate wagon unloaders, depending on construction and surface conditions. The coefficient for sheet metal was 0.88 with slant end-gates. The data obtained by these workers including Richter were obtained at slow speeds.

Hodges (12) reported the power required to operate a canvas apron wagon loader, and stated that the power requirement for a chain-and-slat conveyor was not significantly different. Converting the power data to give friction coefficients, it was found that 0.75 was an average coefficient for corn silage on wood.

Basing on the coefficient of friction reported by Hintz and Schinke (11) namely 0.5 for green chopped corn and alfalfa on steel, Bockhop (3) calculated the horsepower required by friction in the fan housing of blowers as:

$P_f = 0.5 \alpha N^2 R^2 F (3.71) (10^{-5})$ where

P_f is the power required in horsepower

α is the angle of the material in contact with the housing

N is the rotational velocity in revolutions per second

R is the radius in feet

F is the rate of feed in pounds per minute.

The above equation will be true for any crop with a coefficient of friction of 0.5 and for other crops the appropriate value of friction coefficients have to be adapted and substituted for 0.5.

Work on Teflon

No research work pertaining to the use of Teflon in farm equipment appears to have been published. But investigations are being pursued by several research workers in different stations.

The Honolulu Star Bulletin of January 1, 1958, reported that the Hawaiian Agricultural Experiment Station was carrying on investigations on Teflon-covered moldboard plows. A reference to Dr. M. Rosenburg, Director of the Hawaiian Agricultural Experiment Station elicited a reply from Mr. D. M. Kinch, (14) Chairman, Agricultural Engineering Department of the University of Hawaii, that the research on Teflon-covered moldboard plows was being done by the agricultural engineers of the Pineapple Research Institute which is a private research organization supported by the pineapple plantations on the islands. As a policy, they do not publish their results. Mr. Kinch, however, observed from work already accomplished that the reduction brought about by using Teflon-covered plows was extremely small. He believed that the results were encouraging with reference to the scouring ability of teflon. The work was confined to moldboard plows in Hawaiian soils. The non-adhesive property of Teflon was sought to be exploited to secure better scouring performance in plowing the non-scouring soils of the Hawaiian Islands. The biggest unsolved

problem was the finding of a means to secure or fasten Teflon sheeting to the surface of the moldboard. It was also found that in rocky soils the Teflon sheets became deeply scoured and ragged.

The Du Pont Company in its communication (5) intimated that work on plow facings of Teflon was being done at the National Tillage Machinery Laboratory of the United States Department of Agriculture in Auburn, Alabama. Their work was done using pure "Teflon" sheets which do not give the degree of abrasion resistance that is possible by using a reinforced Teflon. In running some tests for property data on reinforced compositions, the Du Pont Company found that "Teflon" with a 15 per cent copper loading (very small particle size) exhibited superior abrasion resistance.

CHAPTER II

MATERIALS AND METHODS

As the problem was to determine the friction characteristics of Teflon on agricultural produce, the first requisite material was Teflon itself. Although Teflon was available in different forms, powder (granular, fine, and aqueous dispersion), tape, and sheeting; it was decided to experiment with Teflon sheeting. This was considered as most convenient and would give a wide surface for trials.

A cementable Teflon sheet 1/16 inch thick and four feet square was obtained together with Garlick No. 201 adhesive recommended by the manufacturers for fixing Teflon to any ordinary surface.

Fixing Teflon to Wood

As Teflon by itself is not rigid, it had to be mounted to a rigid material like steel, aluminum, fibre, or wood; and from considerations of economy 3/4 inch thick plywood (exterior grade) was chosen. It had the requisite strength and rigidity.

The adhesive, Garlock No. 201, recommended by the Teflon manufacturers was a general purpose adhesive of the epoxy resin type, suitable for cementing cementable Teflon to common substrate materials like wood, metals, glass, and plastics. The adhesive was furnished in two parts A and B to be mixed before each

application. The manufacturer's directions for applying the adhesive and cementing the sheet was strictly followed.

The substrate material namely the plywood surface was thoroughly degreased, cleaned, and dried prior to bonding. The Teflon sheeting was also cleaned and wiped dry. Part B of the adhesive was preheated to 125° to 135°F. and was mixed with an equal volume of part A and stirred thoroughly until creamy in appearance. The adhesive was applied immediately, as the pot life of the adhesive is about one hour. It was applied, a thin even coat, (2 to 3 mils) to the cementable surface (dark brown side) of the Teflon and also to the surface of the plywood. The sheet was then laid over the wood and an even pressure over the entire area was applied by stacking bricks over a second plywood plank laid for purposes of uniform distribution of weight. A curing period of fourteen to sixteen hours at room temperature (at least 70°F.) was allowed for final setting. After the curing period the excess Teflon sheeting protruding beyond the four feet diameter circular plywood surface was cut by scissors and brought to shape. The edges were further smoothened with sand paper.

Coverage of adhesive. The adhesive was able to cover 25 square feet for one pint of the mixture, that is a half pint of A and a half pint of B. As the glue has to be applied to both the Teflon and the substrata (wood) surfaces, double the area had to be reckoned; that is, for cementing 25 square feet of Teflon,

glue was obtained to cover fifty square feet so as to include the substrate surface.

Agricultural Produce and Other Materials

The objective of the problem was to study the friction characteristics of the following agricultural products on Teflon; and they were procured in the Knoxville area: namely hay, grass ensilage, long alfalfa, and chopped alfalfa. The hay used was a mixture of alfalfa and other grasses.

The structural material, such as mild steel angles, wood, bearings, and pulleys were either locally purchased or obtained from the existing stock of the Agricultural Engineering Department of the University of Tennessee, Knoxville. The entire instrumentation was built up and fabricated at the workshop attached to the Agricultural Engineering Department of the University of Tennessee.

CHAPTER III

INSTRUMENTATION

The method adopted for testing the friction characteristics of Teflon was similar in principle to the one used by Hintz and Schinke (11) and Richter (20). But the drive, range of speeds, speed counter, friction force indicator were entirely of a different arrangement.

A 48 inch diameter sheet of cementable Teflon was glued to a 3/4 inch thick plywood of the same diameter as the sheet and was mounted to a 7/16 inch thick and 12 inch diameter steel plate. The steel plate was keyed to a one inch diameter arbor. A driving gear belted to the arbor gave a range in peripheral speeds at three feet diameter of five feet per minute to over 6000 feet per minute.

The material to be tested was placed in wooden frames 9 inch by 9 inch and 6 inch by 6 inch. A cord tied to the frame was led over a pulley to a sensitive scale, called a Detectogram, manufactured by Detecto Scales Incorporated. When the disk was rotated, the friction force was read from the scale. Figure 4 shows a general view of the instrumentation.

Details

The entire instrumentation thus consisted of the following:

1. A table frame carrying a vertical arbor with mounted disk carrying the Teflon surface

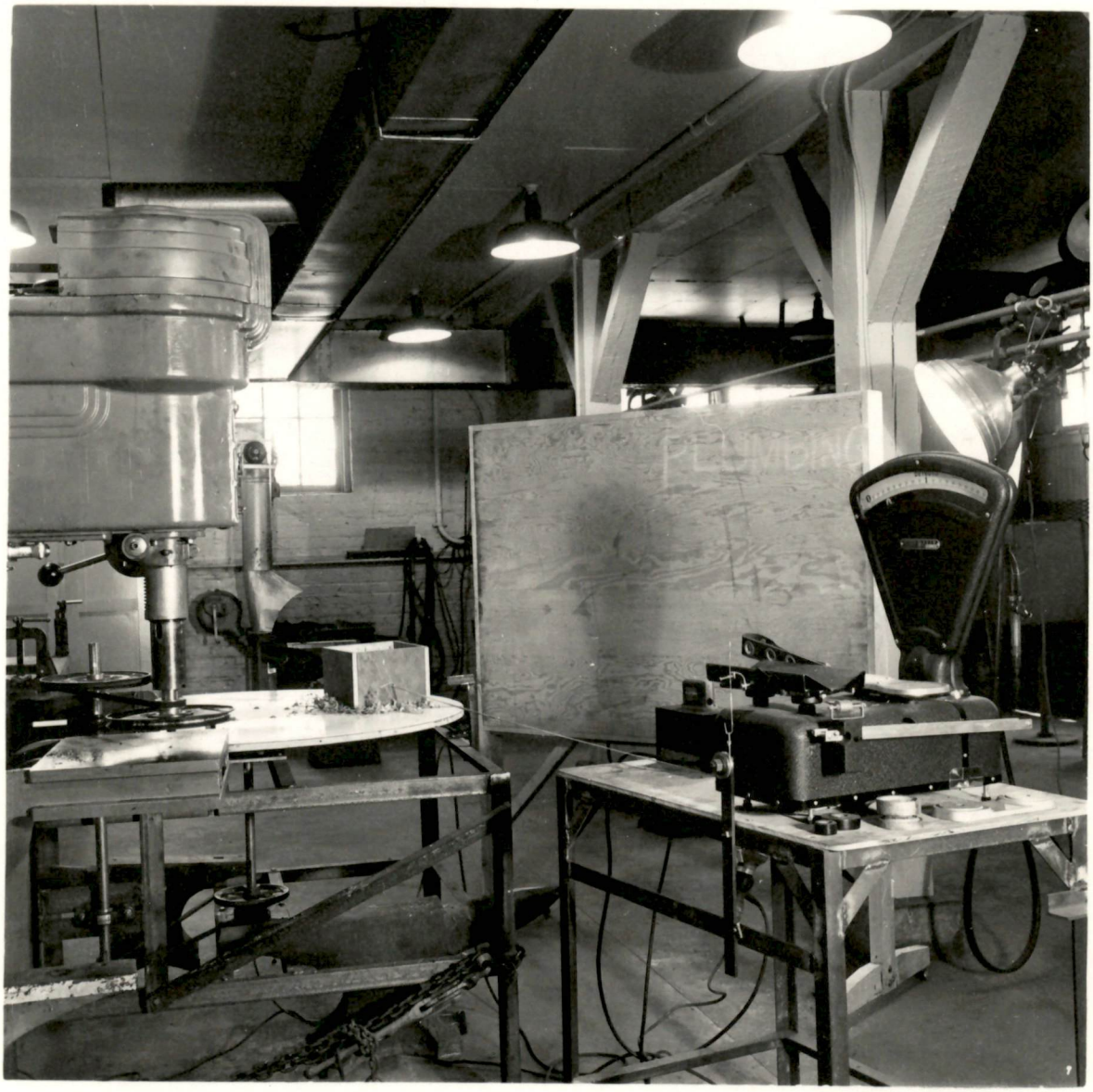


Figure 4. General view of the equipment

2. The drive and the driving gear to rotate the Teflon surface

3. Device for noting rotational speed of the arbor

4. Instrumentation for observing the frictional force

5. Moisture determination apparatus

The table frame. A skeleton table frame four feet square and two feet by eight inches high was fabricated by welding, using two inches by two inches by 1/8 inch and two inches by 1 1/2 inches by 1/8 inch iron angles. The frame was made rigid by horizontal stiffeners joining the legs at nine inches from the ground. The vertical arbor was kept in position at the center of the table by means of cross members which supported the necessary bearings for the easy rotation of the arbor. A 7/16 inch thick, 12 inches diameter steel plate was permanently attached to the upper end of the shaft. This plate and the arbor was machined so as to be at right angles. The four feet diameter plywood disk glued with the 1/16 inch Teflon sheeting was bolted to the steel plate. Thus the Teflon surface was made capable of revolving in a horizontal plane about an arbor fixed to a rigid frame.

The drive and the driving gear. Hintz and Schinke (11) and Richter (20) used a variable drive motor for determining the coefficient of agricultural materials. Hintz and Schinke had a peripheral speed range of 1000 feet per minute to 6000 feet per minute, while Richter had a range of 5 to 320 feet per minute at 32 inch diameter. But in this study a speed range of 5 to 6000

feet per minute was considered necessary to study the friction characteristics of agricultural materials on "Teflon" at slow and high speeds. The equipment could also be used for a study of soil-Teflon friction to investigate the possibility of using Teflon as plow facings.

This wide range of speed was not possible in a simple variable drive motor without reduction gears or step-down pulleys. Fortunately, a Bakewell Tapping Machine was available in the workshop. This machine had a wide range of built-in speed controls. It had a four step come pulley drive, a back and direct gear, and a low and high electrical control. Thus, it had sixteen speed control positions.

The spindle of the tapping machine was geared to the arbor through a system of V-grooved pulleys and belts to give a low speed of 4.68 feet per minute at 18 inch radius of the disk carrying the Teflon sheeting. The spindle carried a two inch diameter pulley, the Jack shaft was fitted with a 9 1/4 inch pulley at the top and a two inch pulley at the bottom, while the arbor carrying the Teflon disk had a 7 3/4 inch diameter pulley. This gave a speed range of 4.68 to 722 feet per minute in sixteen stages. This high reduction was reversed to give fast speeds and this was accomplished by interchanging the pulleys on the spindle of the tapping machine and the one on the jack shaft. This change gave a high speed range of 108.5 to 8562 feet per minute

in fifteen stages. But the frequent change of pulleys was found inconvenient, laborious, and time consuming; so, at a later stage a different arrangement was improvised to avoid interchanging of pulleys. This system consisted of a simple two stage cone pulley with a two inch and 9 1/4 inch pulley at either end. It now required only to change the belt to reverse the speed. This changed arrangement was found very expedient and gave a speed range of 5.14 to 5237 feet per minute at 27 stages. The general arrangement of the drive and the driving gear may be seen in figure 5. The speed ranges available in the original and subsequent arrangement are recorded in Table V under Appendix A.

Device for noting the rotational speed of the arbor. The conventional instrumentation for noting the rotational speed of a shaft would be an ordinary revolution counter for low speeds and a tachometer for higher speeds. In either case, the instrument has to be manually held in position at the tip of the rotating shaft and the revolutions noted against a definite interval of time to arrive at the revolutions per minute. This was considered inconvenient, time consuming, and would increase the possibility of personal errors. A revolution counter (Veeder Root) was therefore fixed to one of the frames of the table and the rotary movement of the shaft transmitted to the counter through a flexible shafting (speedometer cable used in automobiles); the ends of which were connected to the vertical shaft and the counter. The revolutions were conveniently noted against time.

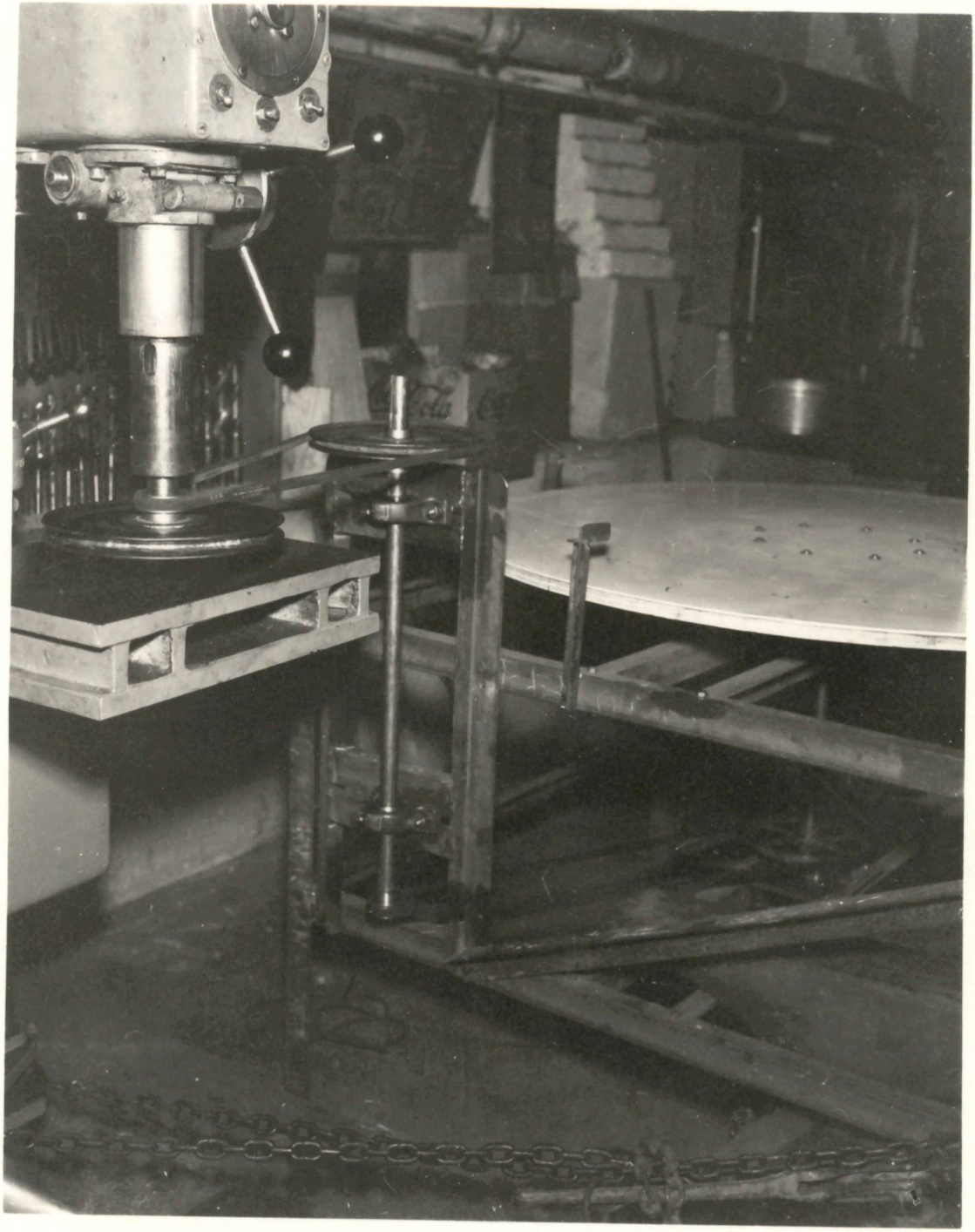


Figure 5. The drive pulleys and the jack shaft

But in the course of the experiment, the Veeder Root counter broke accidentally. Possibly the high speeds were too much for the gear wheels in the counter. The counter was therefore replaced with an electromagnetic counter which was readily available, but elaborate arrangements had to be made to fit it into the overall arrangement. The electromagnetic counter had a definite advantage over the mechanical counter as there are less gears; and, therefore, it is suited for higher speeds. It worked very satisfactorily throughout the trials.

The electromagnetic counter was meant for 110 volts d.c., while the voltage source in the laboratory was 110 volts a.c. A rectifier was placed in the circuit to supply the direct current to the counter. The counter itself worked on the principle that whenever a contact is made the electromagnet inside the counter is energized to set the counter mechanism in motion. A make and break contact arrangement was therefore necessary. This was accomplished through a microswitch actuated by a cam at the end of the flexible shafting which transmitted the revolutions of the arbor. The arrangement may be seen in figures 6 and 7. The revolutions were noted with the electromagnetic counter against time recorded with the aid of a stop watch.

Instrumentation for noting the frictional force. The material to be tested was placed in an open box and kept on the top of the Teflon disk which was rotated. A cord tied to the open box was led over a pulley to a spring scale. When the disk rotated the sliding

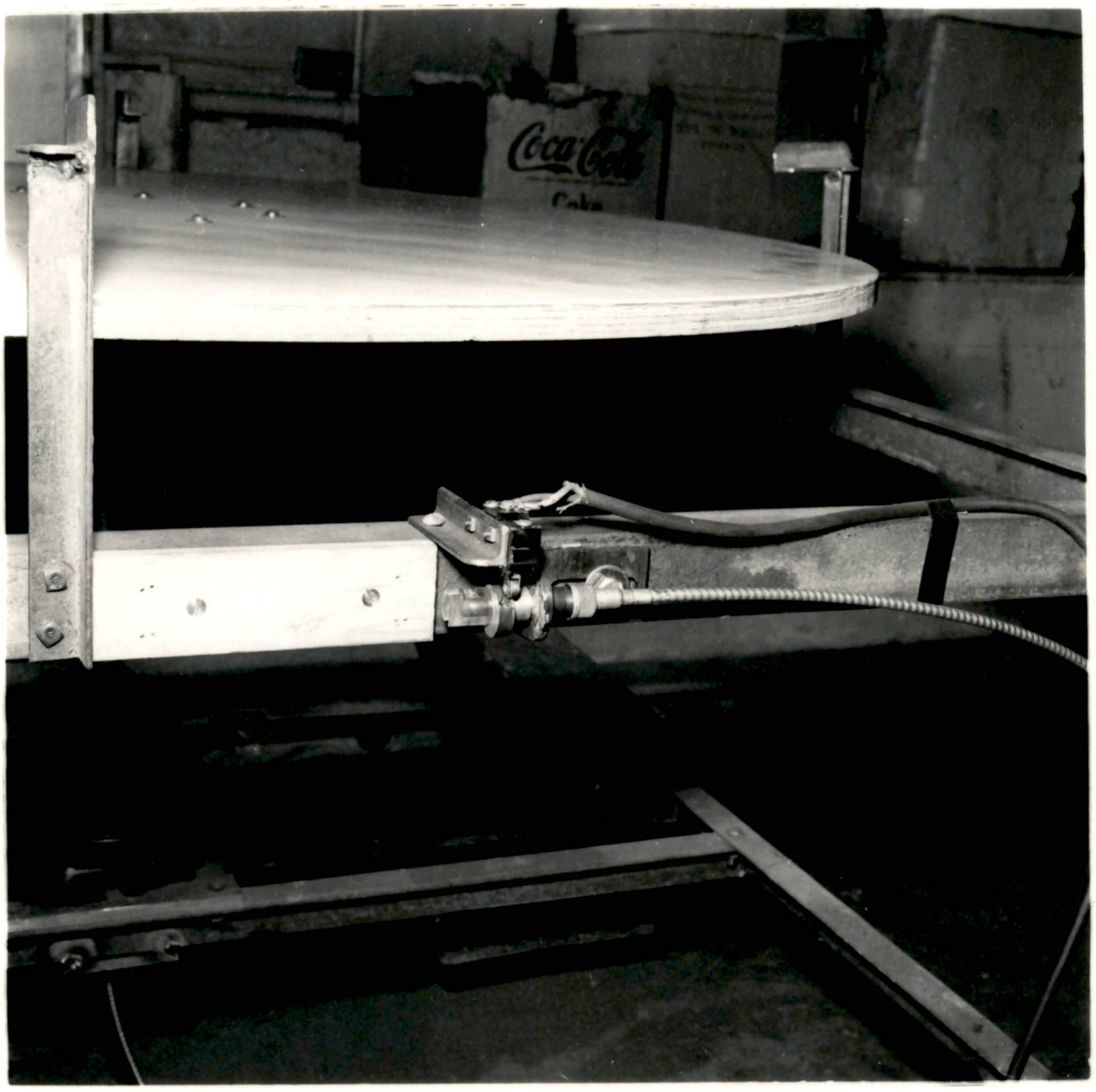


Figure 6. Flexible shaft, cam, and micro switch



Figure 7. Electro-magnetic counter

friction force was read from the scale. Figure 4 shows the general view of the arrangement.

Richter (20) and Hintz and Schinke (11) used an ordinary spring balance to note the frictional force. The conventional spring balances are normally calibrated up to a quarter pound which is not sensitive enough. However, it was tried and there was considerable vibration vitiating the results and making it difficult to take the reading. The vibrations were mainly due to the fact that the spring balance was fitted as an integral part of the table carrying the rotating Teflon disk by suitable frames. This transmitted the vibrations of the disk to the spring balances. This arrangement was therefore changed to include the "detectogram" type of balance to record frictional force. The "detectogram" was placed on an adjacent table. The cord from the box containing the material was passed through a pulley to the detectogram. The balance was sensitive to record 1/100 of a pound and gave very satisfactory service and results.

The same detectogram and set-up was used for weighing the materials and also for determining the static frictional force as may be seen in figures 8 and 9.

Moisture determination apparatus. To study the effect of moisture content of the materials on their friction characteristics, the moisture content of the materials was determined. This was done adapting the conventional oven drying method and the moisture content calculated on wet-weight basis. The materials were dried



Figure 8. Detectogram scale

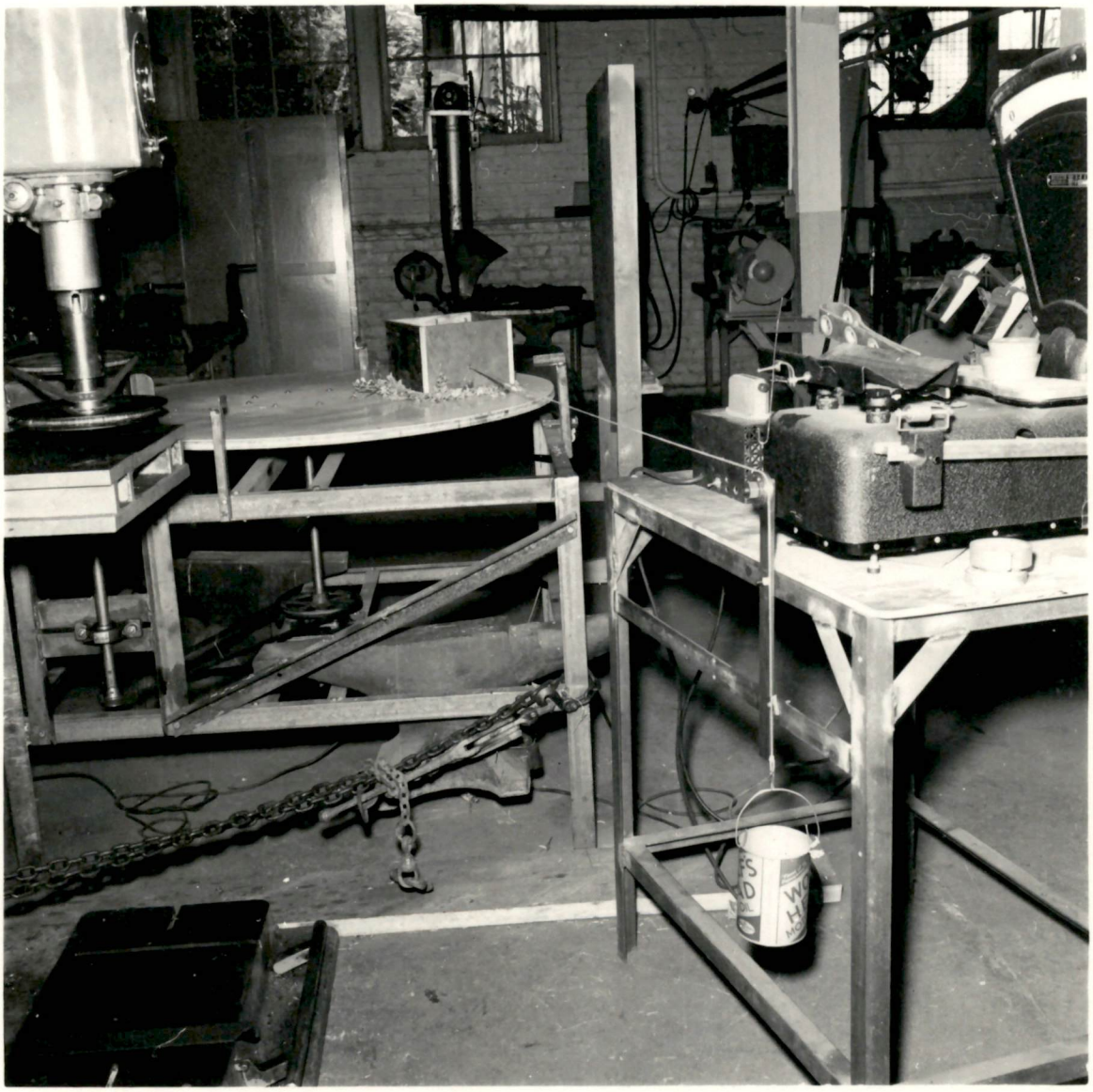


Figure 9. General view of the equipment for determination of the static coefficient of friction

at least fifteen to twenty hours at 110°F. The oven used was of the electrical type with temperature control effected through a bimetallic switch and thermometer. The oven with the bimetallic switch and thermometer may be seen in figure 10. The bimetallic switch would automatically maintain any desired pre-set temperature.

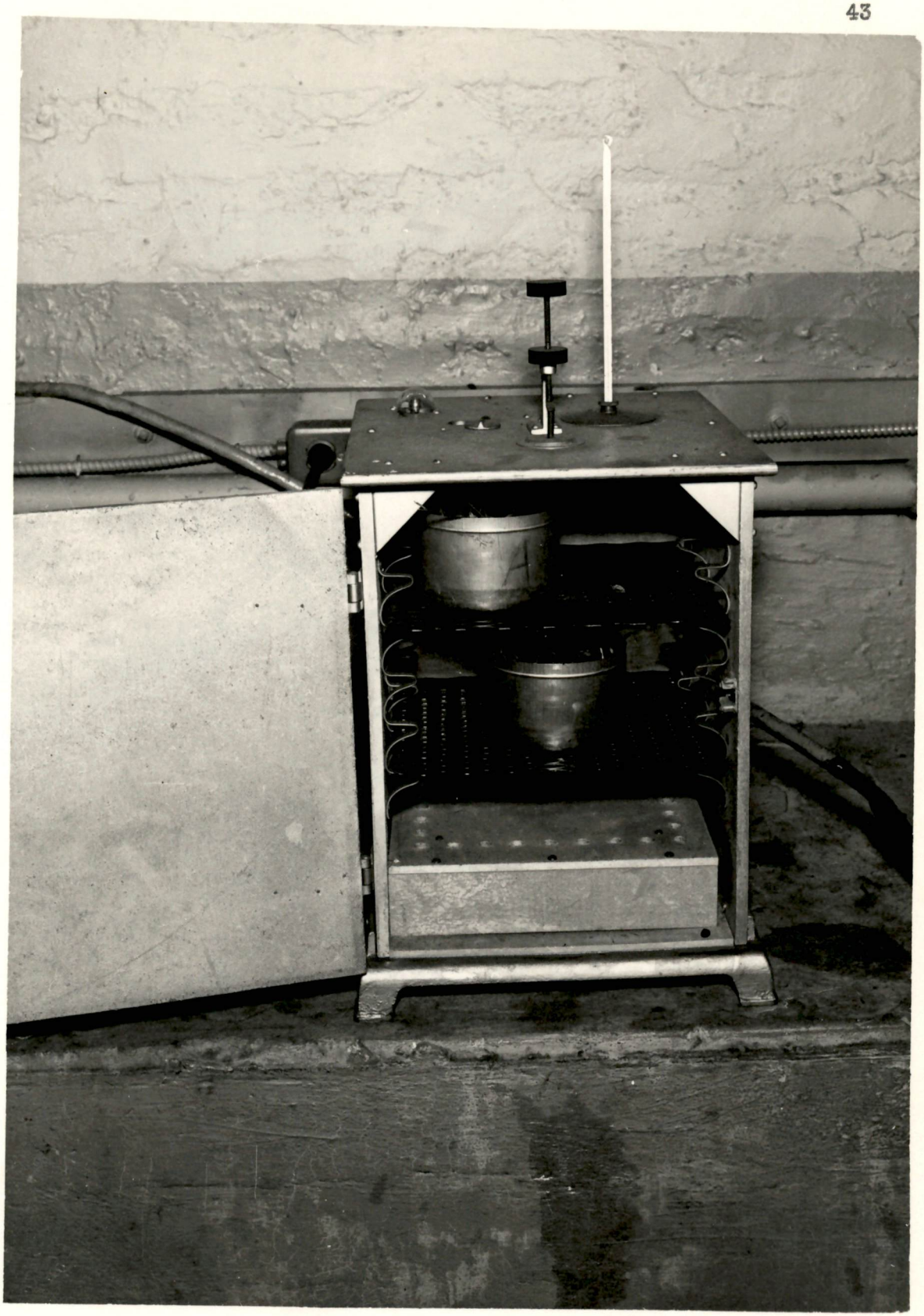


Figure 10. Electric oven for moisture determination

CHAPTER IV

PROCEDURE

The work involved in the laboratory in the study of the problem was as follows:

1. Calibration of the equipment for various speeds
2. Noting the weight of the material and frictional force for each material tested on Teflon at different speeds
3. Determination of the moisture content of the materials under test to study the effect of moisture on coefficient of friction

Calibration of the Equipment for Speeds

As already indicated under instrumentation, the drive for the test equipment was not a variable drive, but was from the tapping machine which was improvised to give thirty-two stages of definite speeds from five to six thousand feet per minute at eighteen inch radius. These different stages of speeds were established by actual observation so that the speed need not be observed at every stage of the test. In other words, if the machine was once calibrated, it was possible to record the speed from the position of the various speed controls such as the cone pulley, the gear, the switch and the slow or fast speed pulley on the final belt transmission from the tapping machine to the table. Care was taken to daily check whether there was change

in the speed due to any possible slip in the belt. This check-up was done thrice daily during the test; in the morning, in the afternoon, and finally at the end of the test. Differences in speed from these already recorded from the calibration was never noticed. As a further precaution, care was taken to loosen the V-belts after each day's test to prevent the possibility of the belts slackening and causing variations in speed.

The procedure involved in calibrating the speed was simple. The revolutions at each stage or position of controls were noted from the electromagnetic counter against time and the speed at 18 inch radius of the disk was calculated. The data collected were the position of controls, revolutions and time and these are recorded in Table V under Appendix A along with the calculations for arriving at the speed at 18 inch radius and are self-explanatory.

As this was a basically important record, the readings were taken thrice, but no variation was observed. The periodical daily check for speed always tallied with this initial observation. A conversion chart for arriving at the peripheral speed from rotational speed is also shown in figures 23 and 24 under Appendix A. At a later stage when it was found expedient to change the final drive pulleys on the tapping machine and the table from an interchange type to a fixed step-down pulley, the procedure was repeated for calibrating the machine under the new set-up. The data

of speed controls, revolutions, time and speed under the revised set-up may be seen in the same Table V under Appendix A.

Weight and Frictional Force

The material to be tested together with the wooden container were weighed on the Detectogram as may be seen from Figure 8, and the weight was recorded. The weight was observed twice and the average of the two readings was taken into account. There was invariably no difference.

The frictional force for different materials and speeds were also observed from the Detectogram and recorded. Considerable difficulty was experienced in getting at the correct reading due to vibrations at certain low speeds. At high speeds the readings were constant and steady. At low speeds the vibrations caused fluctuations and took some time for the readings to become steady. Care was taken to wait until the readings were steady. Even so, there were slight fluctuations indicating a maximum variation of ± 2 per cent in coefficient of friction which is considered insignificant and does not materially vitiate the results. The mean reading was therefore observed and recorded. The static frictional force was obtained by having the Teflon disk stationary and noting the pull required to just cause movement of the material. The set-up was discussed already and may be seen in Figure 9. The weights were added in the can in the form of sand and its weight together with the container were weighed on the Detectogram.

The weight of the material, the frictional force observed for the several materials tested are recorded in Tables VI, VII, VIII, and IX under Appendix B.

Determination of Moisture

Moisture was determined by the conventional oven drying method as described under instrumentation. The two samples were taken from the material after each day's test, weighed on the Detectogram and placed in the oven for drying at 110°F. The dry weight was recorded after at least fifteen to twenty hours to calculate the percentage of moisture content. The percentage of moisture content was given by the formula:

$$\text{Percentage of moisture content} = \frac{(\text{Weight of sample before drying} - \text{weight of sample after drying})}{\text{Weight of sample before drying}} \times 100$$

This is on wet weight basis unlike the case of soils which is on the dry weight basis. The weights observed and the percentage of moisture content arrived at are recorded in Table X under Appendix B and the calculations indicated therein are self-explanatory.

Precautions

Care was taken to see that the weight of the material was transmitted to the Teflon only through the material under test. In other words the box containing the test material was never allowed to come in contact with the Teflon. The box was always

kept at 18 inch radius from the center and kept in position by adjusting the length of cord connecting the box and the balance. A slip buckle was introduced in the cord for the adjustment of the length. The position of the Detectogram was also shifted and adjusted to keep the box in position and to have the frictional force tangential to the circumference.

CHAPTER V

RESULTS AND DISCUSSIONS

Friction tests on Teflon were conducted with the following materials at different speeds, unit pressures, and moisture contents:

1. Hay (mixture of alfalfa and other grasses)
2. Grass ensilage
3. Long alfalfa
4. Chopped alfalfa

Hay

The first of the series of tests was started with hay. The Teflon was in its original condition namely not highly polished. The first few days' tests revealed that the coefficient of friction was slowly dropping as the Teflon became polished by hay rubbing against it. After nearly two weeks, when the sheeting became smooth, the test gave steady results. The first two weeks' readings, which were fluctuating, were therefore disregarded.

Friction tests on hay were conducted for different speeds and unit pressures. Determination of moisture content revealed that the hay was completely dry. A summary of the tests of friction of hay on Teflon at different unit pressures is given in Table I. The graphs in figures 11 to 15 reveal the effect of speed and unit pressure on coefficient of friction of hay on Teflon. The results show that the coefficient of friction was more or less constant at all speeds and at varying unit pressures.

TABLE I

COEFFICIENT OF FRICTION OF HAY ON TEFLON

Sliding Speed	Normal Pressure in lbs./sq. ft. 5.40	7.08	9.50	15.15	Average
	Coefficient of Friction				
Static	0.19	0.19	0.21	0.20	0.20
904	0.23	0.23	0.23	0.22	0.23
1343	0.22	0.21	0.24	0.22	0.22
2110	0.22	0.22	0.23	0.21	0.22
2686	0.22	0.22	0.24	0.22	0.22
4220	0.22	0.23	0.22	0.22	0.22
5650	0.22	0.23	0.22	0.24	0.23
Average Sliding	0.22	0.22	0.23	0.22	0.22

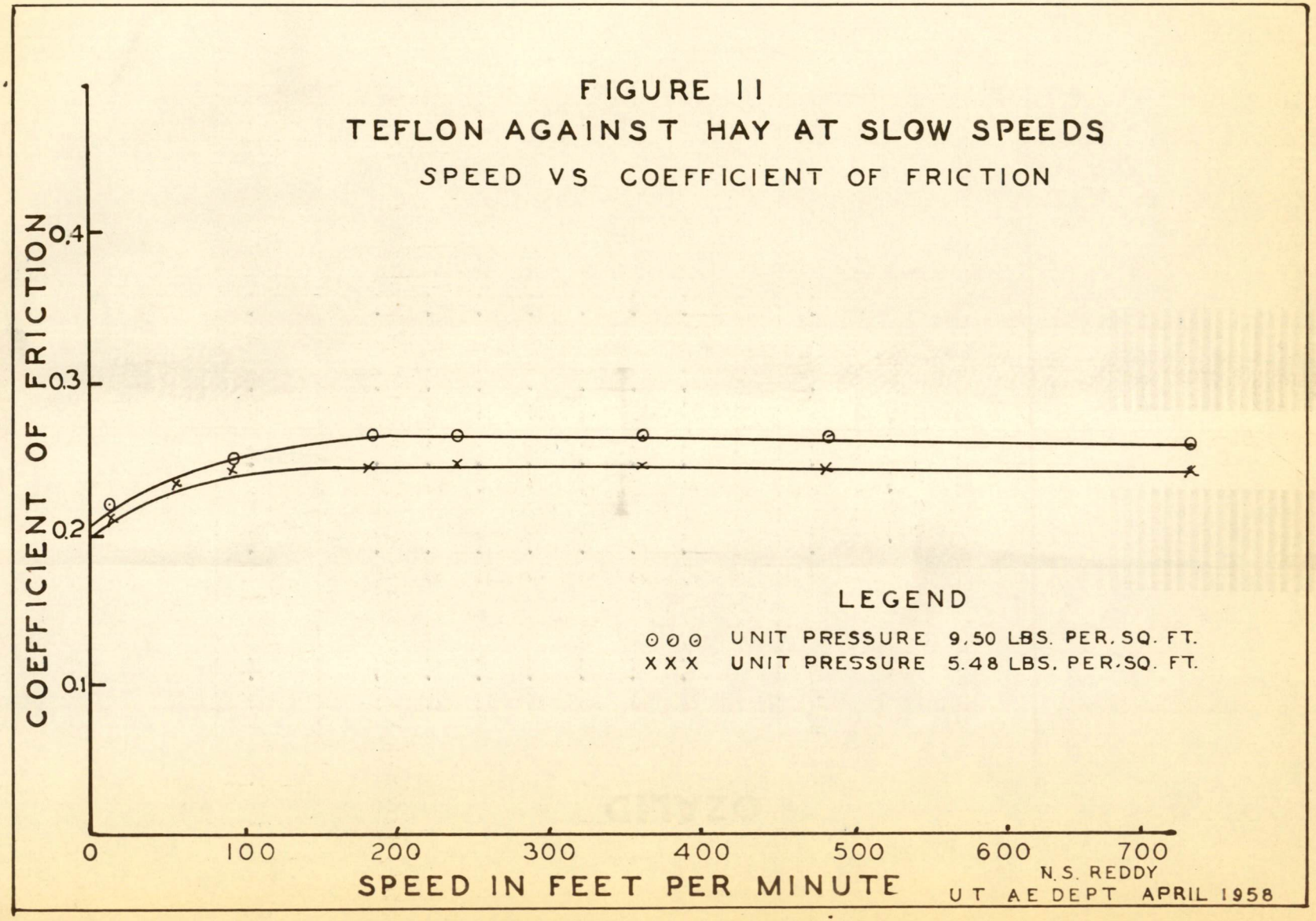

FIGURE 11
TEFLON AGAINST HAY AT SLOW SPEEDS
SPEED VS COEFFICIENT OF FRICTION
COEFFICIENT OF FRICTION
0.4
0.3
0.2
0.1
0
100
200
300
400
500
600
700
SPEED IN FEET PER MINUTE
LEGEND
000 UNIT PRESSURE 9.50 LBS. PER. SQ. FT.
XXX UNIT PRESSURE 5.48 LBS. PER. SQ. FT.
N.S. REDDY
UT AE DEPT APRIL 1958

FIGURE 12

TEFLON AGAINST HAY AT HIGH SPEEDS

SPEED VS COEFFICIENT OF FRICTION

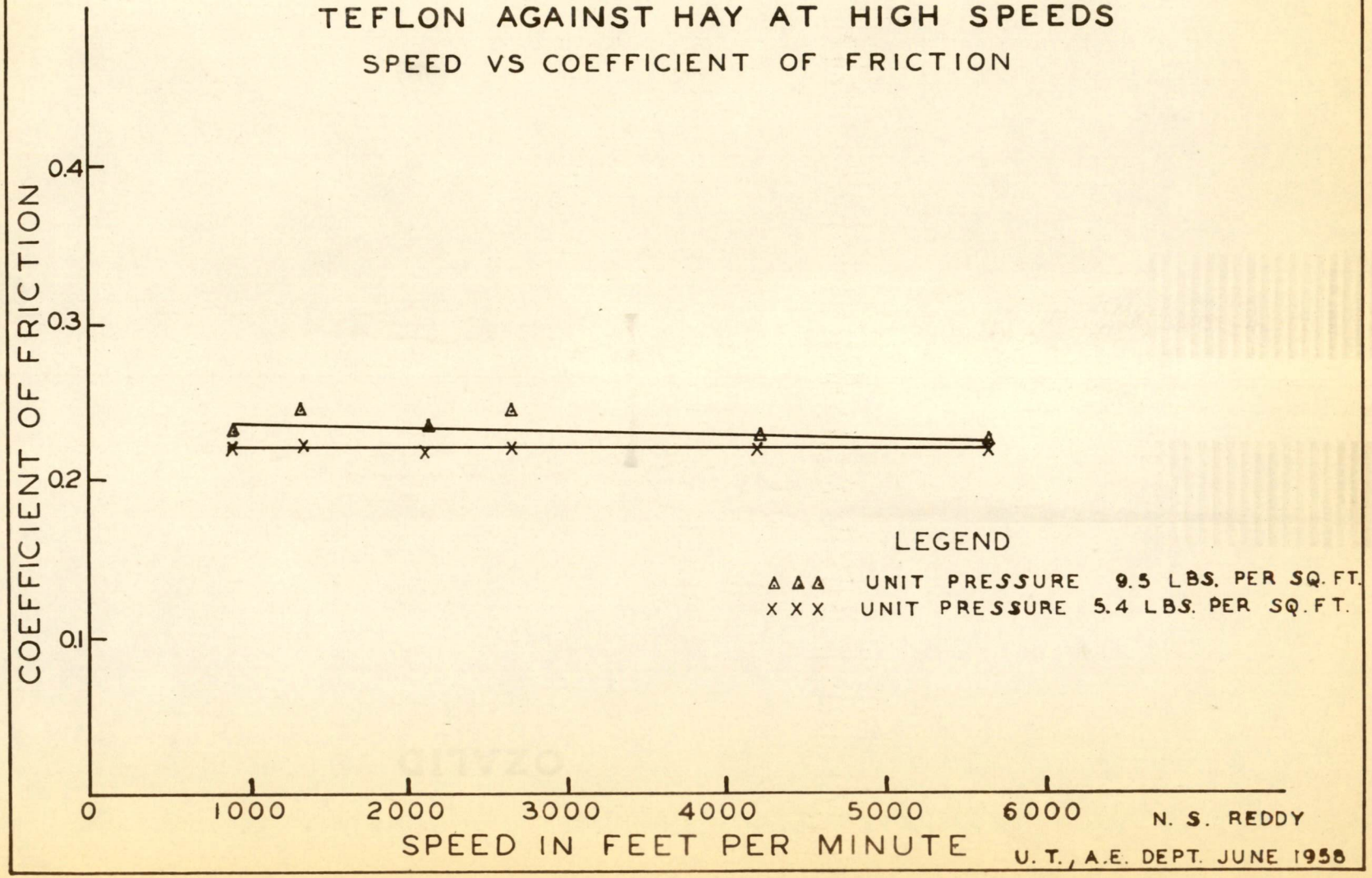
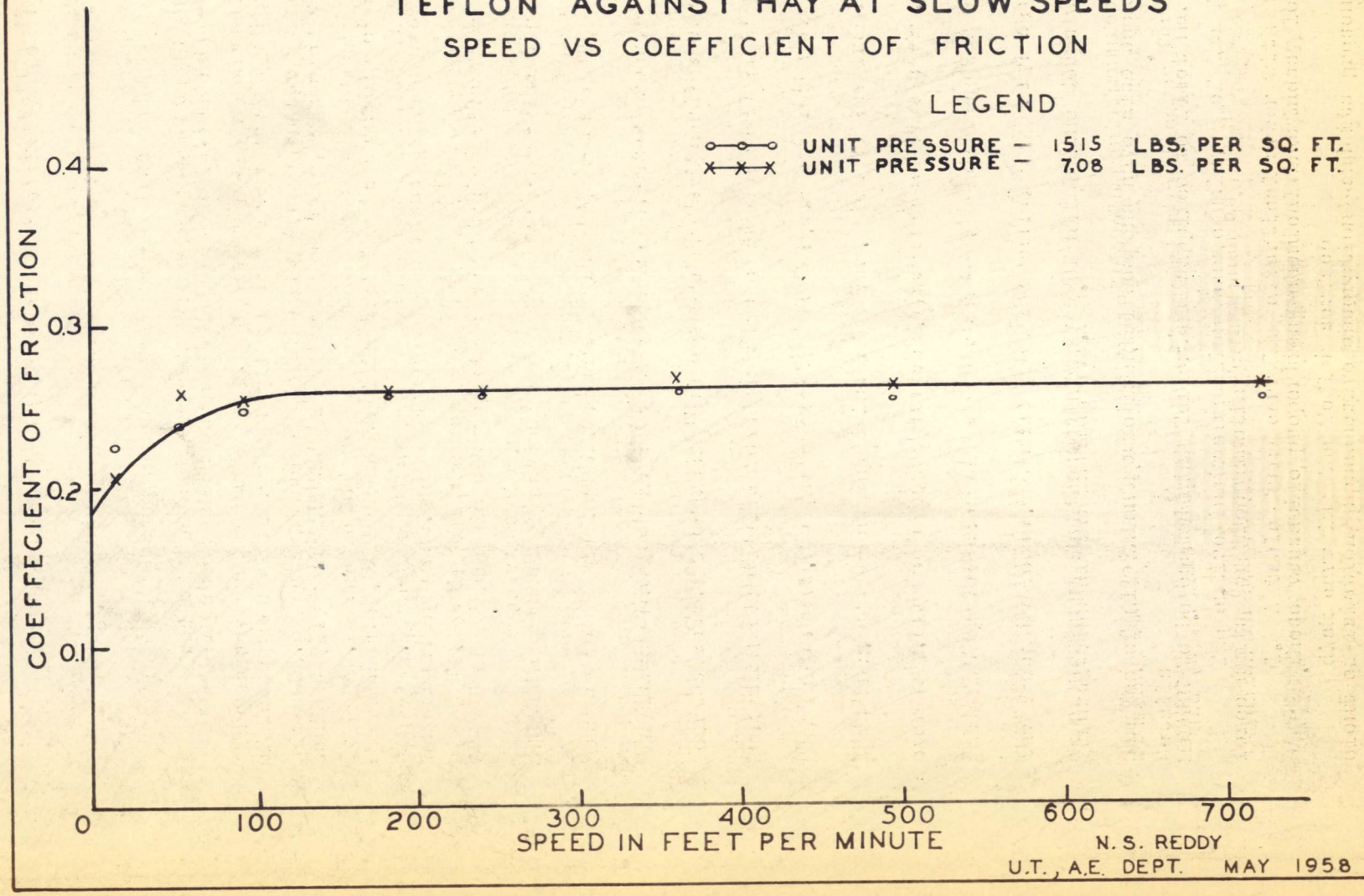


FIGURE 13
TEFLON AGAINST HAY AT SLOW SPEEDS
SPEED VS COEFFICIENT OF FRICTION



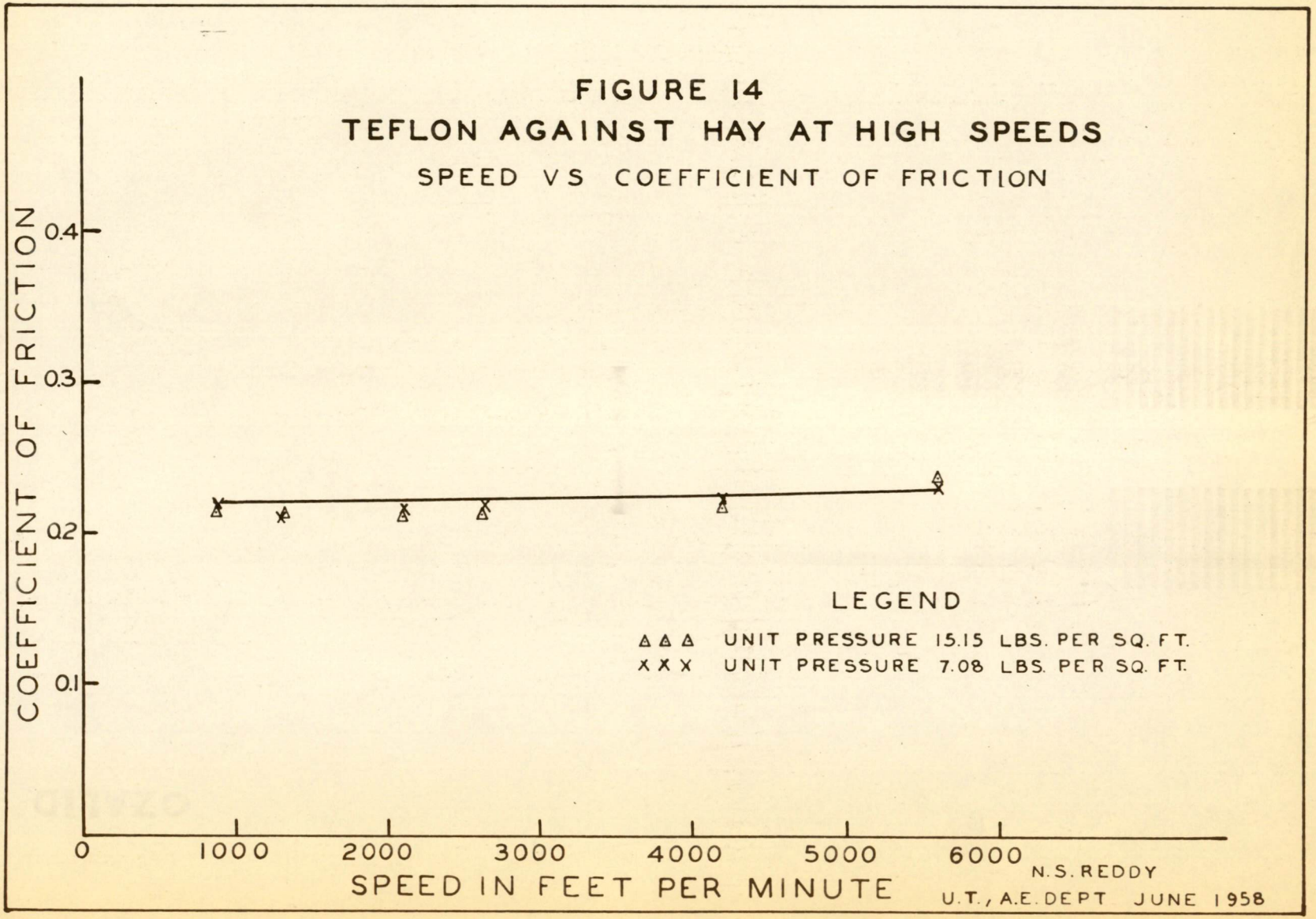
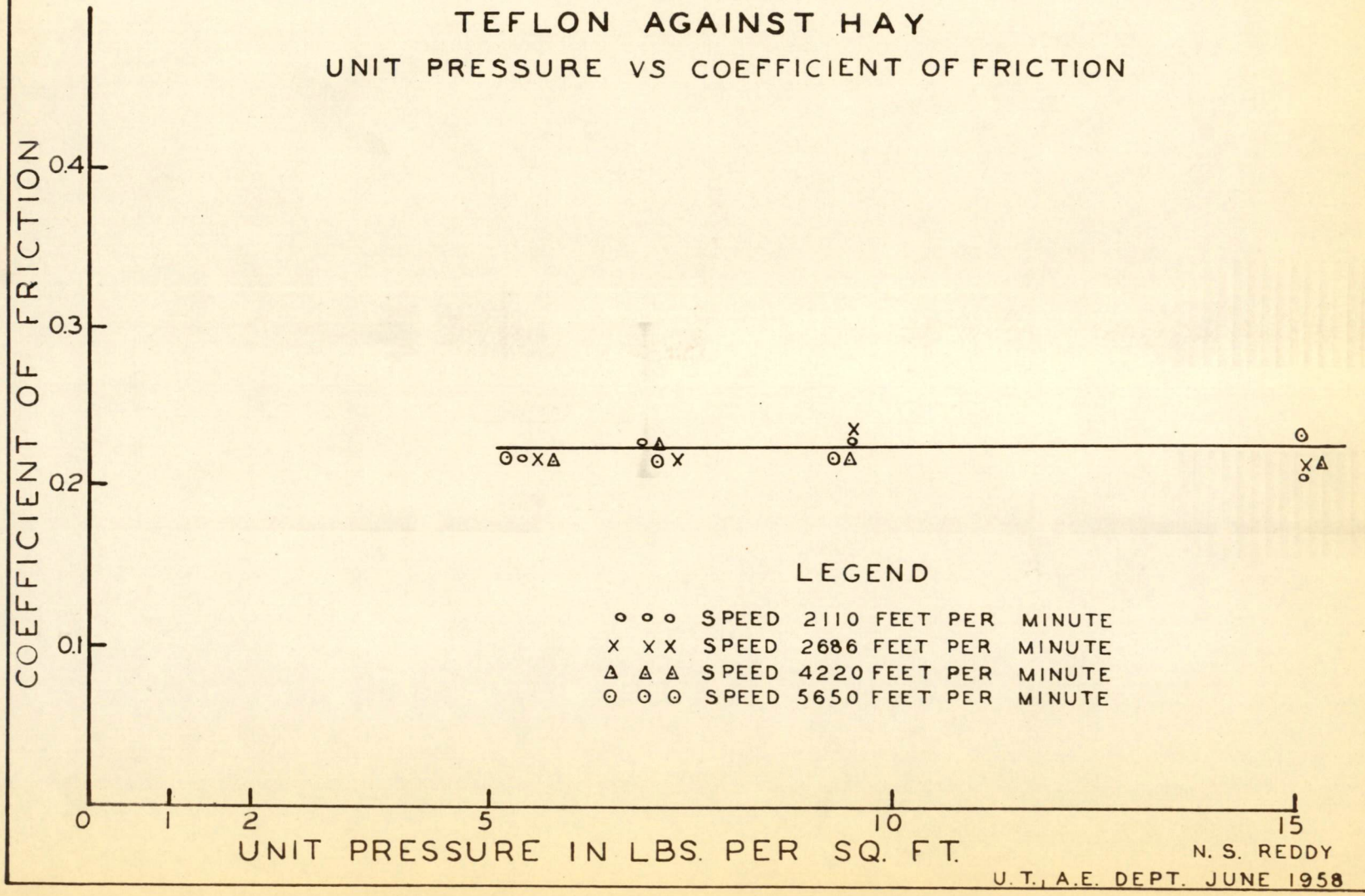

FIGURE 14
TEFLON AGAINST HAY AT HIGH SPEEDS
SPEED VS COEFFICIENT OF FRICTION
COEFFICIENT OF FRICTION
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
SPEED IN FEET PER MINUTE
LEGEND
ΔΔΔ UNIT PRESSURE 15.15 LBS. PER SQ. FT.
XXX UNIT PRESSURE 7.08 LBS. PER SQ. FT.
N.S. REDDY
U.T., A.E. DEPT JUNE 1958

FIGURE 15

TEFLON AGAINST HAY

UNIT PRESSURE VS COEFFICIENT OF FRICTION



Therefore, the coefficient of friction is independent of unit pressure and speed. This agreed with the accepted theory and was also found to be true by Richter (20) in the case of chopped hay on galvanized steel. At speeds less than 100 feet per minute there was slight fall in sliding coefficient of friction and the static coefficient of friction was the lowest. With the conventional metal like steel, the static coefficient of friction is invariably high. But, in the case of hay on Teflon, the static coefficient of friction was low. This may be due to the highly polished nature of the Teflon surface, and its nonadhesive property. Richter also found that when galvanized steel was highly polished the static coefficient of friction for chopped hay dropped from an initial value of 0.42 to a final value of 0.17.

From the results of the friction test on Table I it may be seen that the average sliding friction coefficient for hay on Teflon was 0.22 and the static coefficient of friction 0.20.

Grass Ensilage

Friction tests on grass ensilage covered different unit pressures, speeds, and moisture contents. The results were similar to the tests on hay or alfalfa. Unit pressure and speeds had no significant effect on the coefficient of friction. The test results in Table II and the graphs in Figures 16 and 17 clearly indicate the inference. The moisture content did affect the coefficient of friction as in the case of alfalfa, but was not very significant.

TABLE II

COEFFICIENT OF FRICTION
OF GRASS ENSILAGE ON TEFLON

	Percentage of Moisture Content	
Sliding Speed	65.15	Dry
	Coefficient of Friction	
Static	0.29	0.21
838	0.28	0.24
1258	0.30	0.26
1985	0.28	0.25
2516	0.28	0.26
3970	0.27	0.26
5237	0.28	0.26
Average Sliding	0.28	0.26

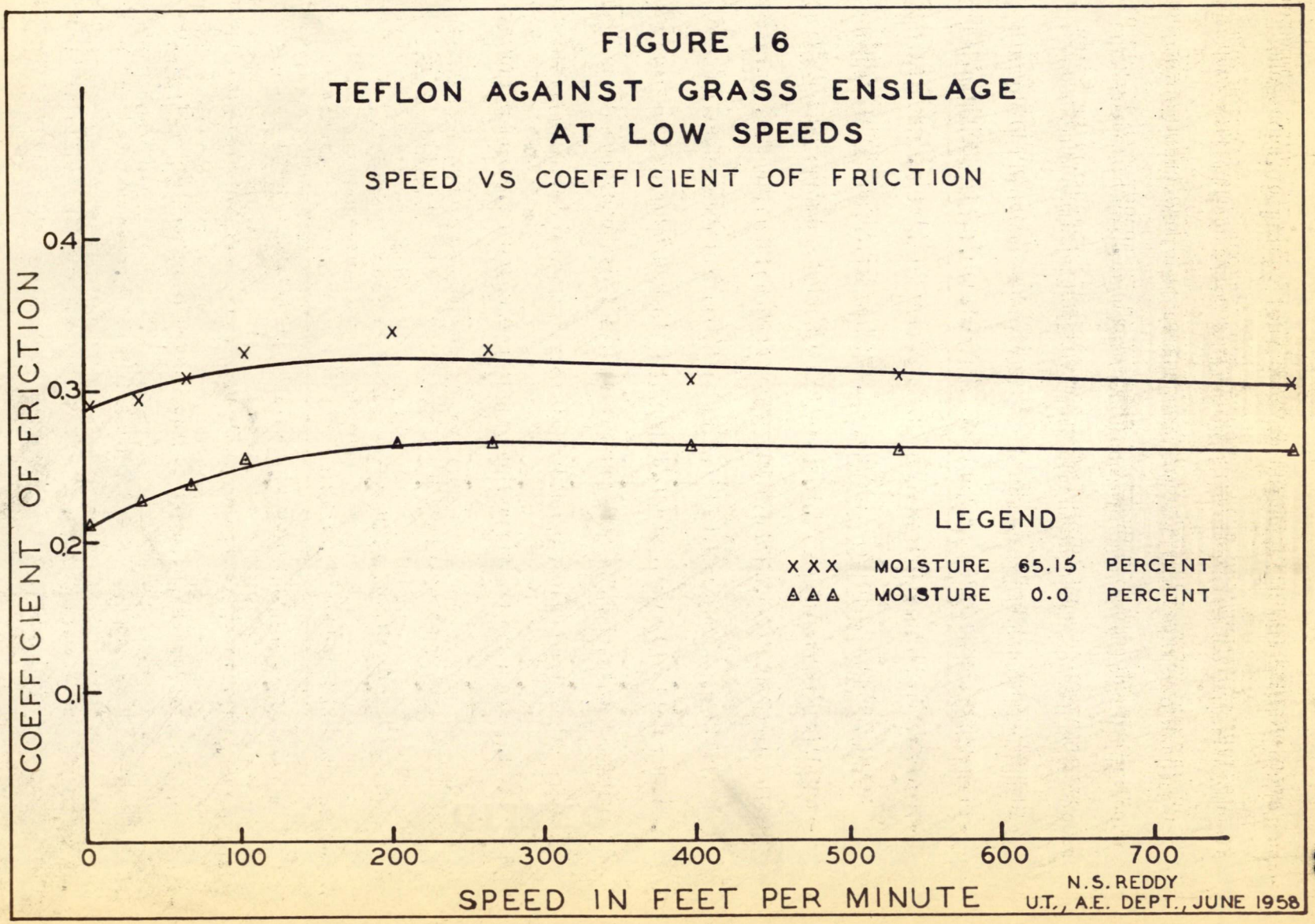
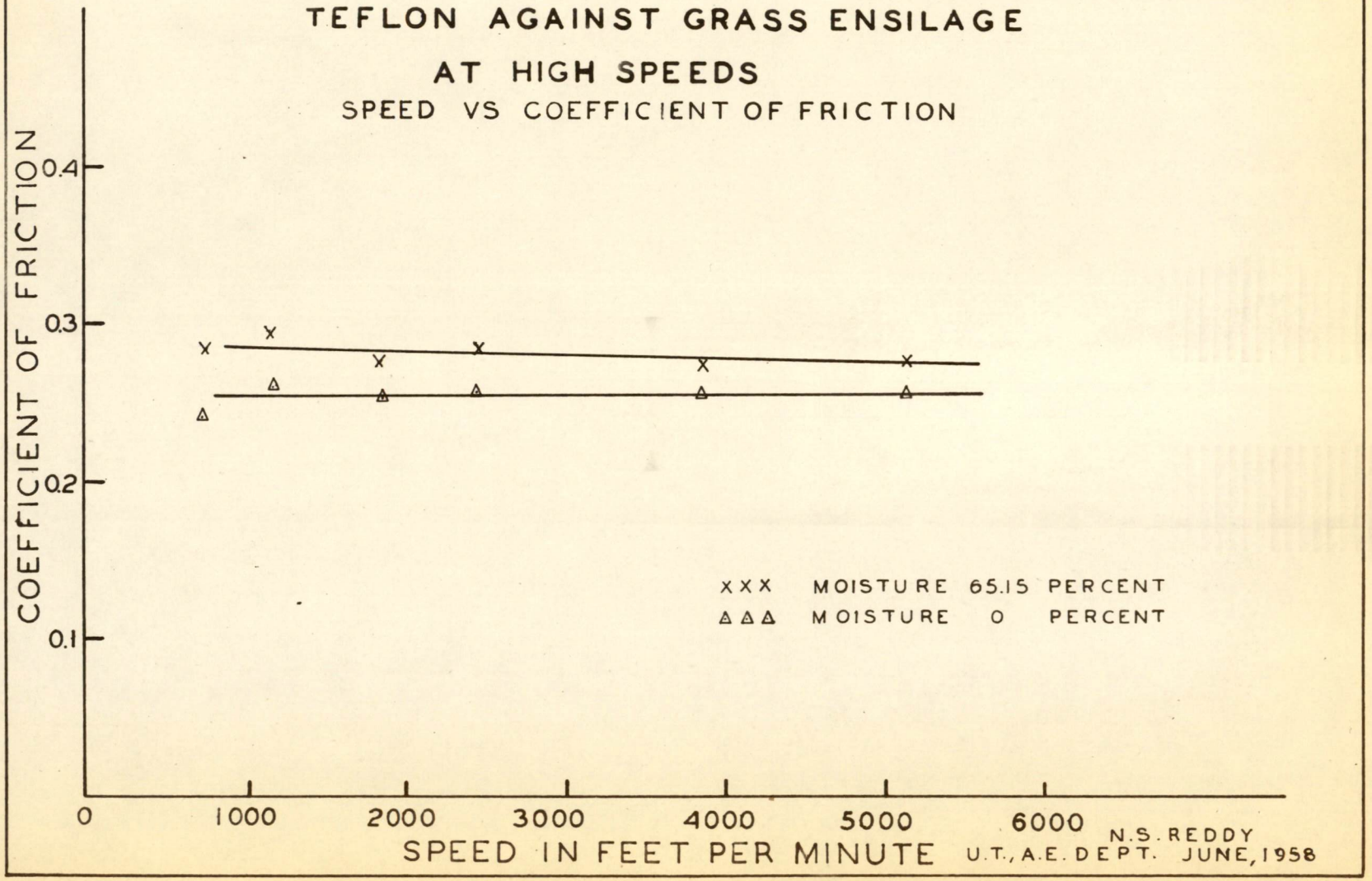

FIGURE 16
TEFLON AGAINST GRASS ENSILAGE
AT LOW SPEEDS
SPEED VS COEFFICIENT OF FRICTION
COEFFICIENT OF FRICTION
0.4
0.3
0.2
0.1
0
100
200
300
400
500
600
700
SPEED IN FEET PER MINUTE
LEGEND
XXX MOISTURE 65.15 PERCENT
ΔΔΔ MOISTURE 0.0 PERCENT
N.S. REDDY
U.T., A.E. DEPT., JUNE 1958

FIGURE 17

TEFLON AGAINST GRASS ENSILAGE

AT HIGH SPEEDS

SPEED VS COEFFICIENT OF FRICTION



From a summary of test results on Table II, the average sliding coefficient of friction may be taken as:

Moisture Content	Coefficient of Friction
65.15	0.28
dry	0.26

The results also revealed that the static coefficient of friction was almost equal to the sliding coefficient of friction for the same reasons explained in the case of other materials.

Alfalfa

Friction tests on alfalfa were conducted at different speeds, different unit pressures and at different moisture contents. The alfalfa was tried in long lengths and also as chopped alfalfa. Chopping was done by scissors cutting the alfalfa into four to five inch lengths.

The test results are summarized in Tables III and IV and the graphs in Figures 18 to 22 reveal its friction characteristics. The results confirm the previous inference on hay and grass ensilage; namely that the unit pressures and speeds have no great significant effect on the coefficient of friction of alfalfa on Teflon. But moisture had an effect to increase the friction characteristics of alfalfa. The summary of results on chopped alfalfa in Table IV and the moisture content vs. coefficient of friction graph in Figure 22 reveal that the coefficient of friction increases with the moisture content.

TABLE III

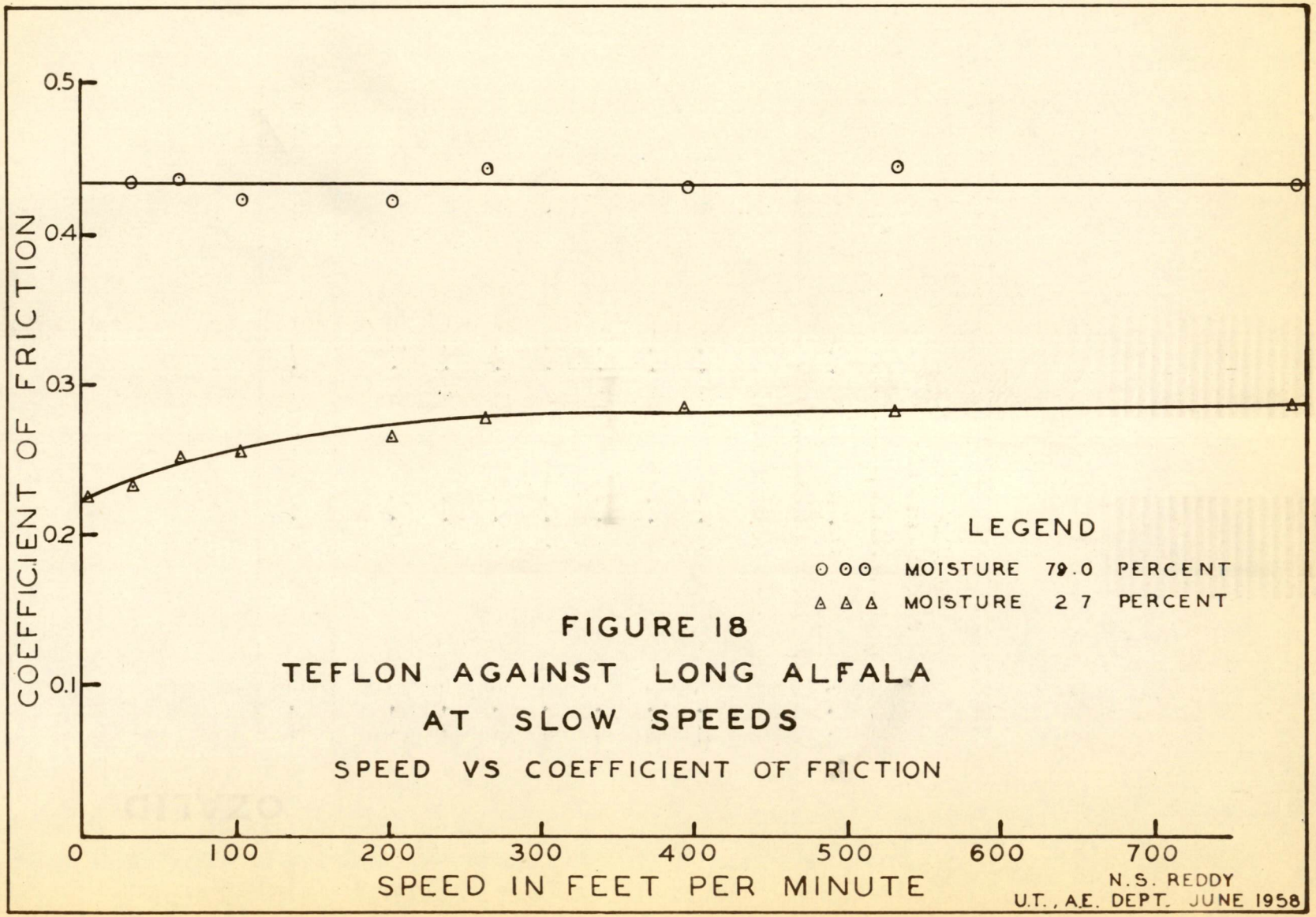
COEFFICIENT OF FRICTION OF LONG ALFALFA ON TEFLON

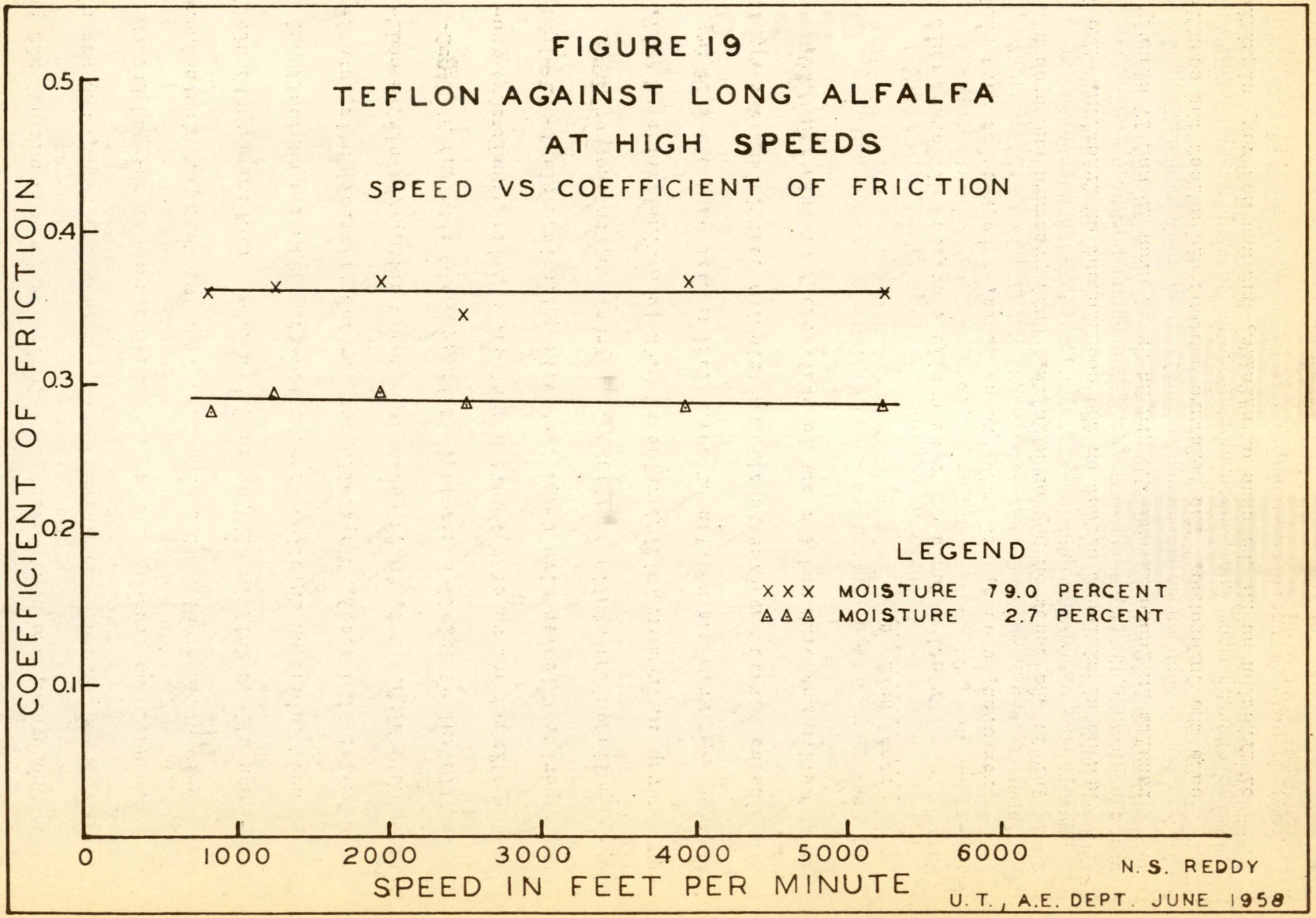
Sliding Speed	Percentage of Moisture Content	
	79.00	2.70
Static	0.43	0.22
838	0.36	0.28
1258	0.36	0.29
1985	0.37	0.29
2516	0.35	0.29
3970	0.37	0.29
5237	0.36	0.28
Average Sliding	0.36	0.29

TABLE IV

COEFFICIENT OF FRICTION OF CHOPPED ALFALFA ON TEFLON

	Percentage of Moisture Content		
Sliding Speed	68.30	54.50	15.80
	Coefficient of Friction		
Static	0.32	0.27	0.22
838	0.34	0.28	0.25
1258	0.35	0.29	0.25
1985	0.34	0.27	0.25
2516	0.34	0.27	0.25
3970	0.34	0.27	0.25
5237	0.34	0.27	0.25
Average Sliding	0.34	0.27	0.25


0.5
0.4
0.3
0.2
0.1
COEFFICIENT OF FRICTION
LEGEND
○ ○ ○ MOISTURE 79.0 PERCENT
△ △ △ MOISTURE 2 7 PERCENT
FIGURE 18
TEFLON AGAINST LONG ALFALA
AT SLOW SPEEDS
SPEED VS COEFFICIENT OF FRICTION
0
100
200
300
400
500
600
700
SPEED IN FEET PER MINUTE
N.S. REDDY
U.T., A.E. DEPT. JUNE 1958


FIGURE 19
TEFLON AGAINST LONG ALFALFA
AT HIGH SPEEDS
SPEED VS COEFFICIENT OF FRICTION
COEFFICIENT OF FRICTIOIN
0.5
0.4
0.3
0.2
0.1
0
1000
2000
3000
4000
5000
6000
SPEED IN FEET PER MINUTE
LEGEND
XXX MOISTURE 79.0 PERCENT
ΔΔΔ MOISTURE 2.7 PERCENT
N. S. REDDY
U.T., A.E. DEPT. JUNE 1958

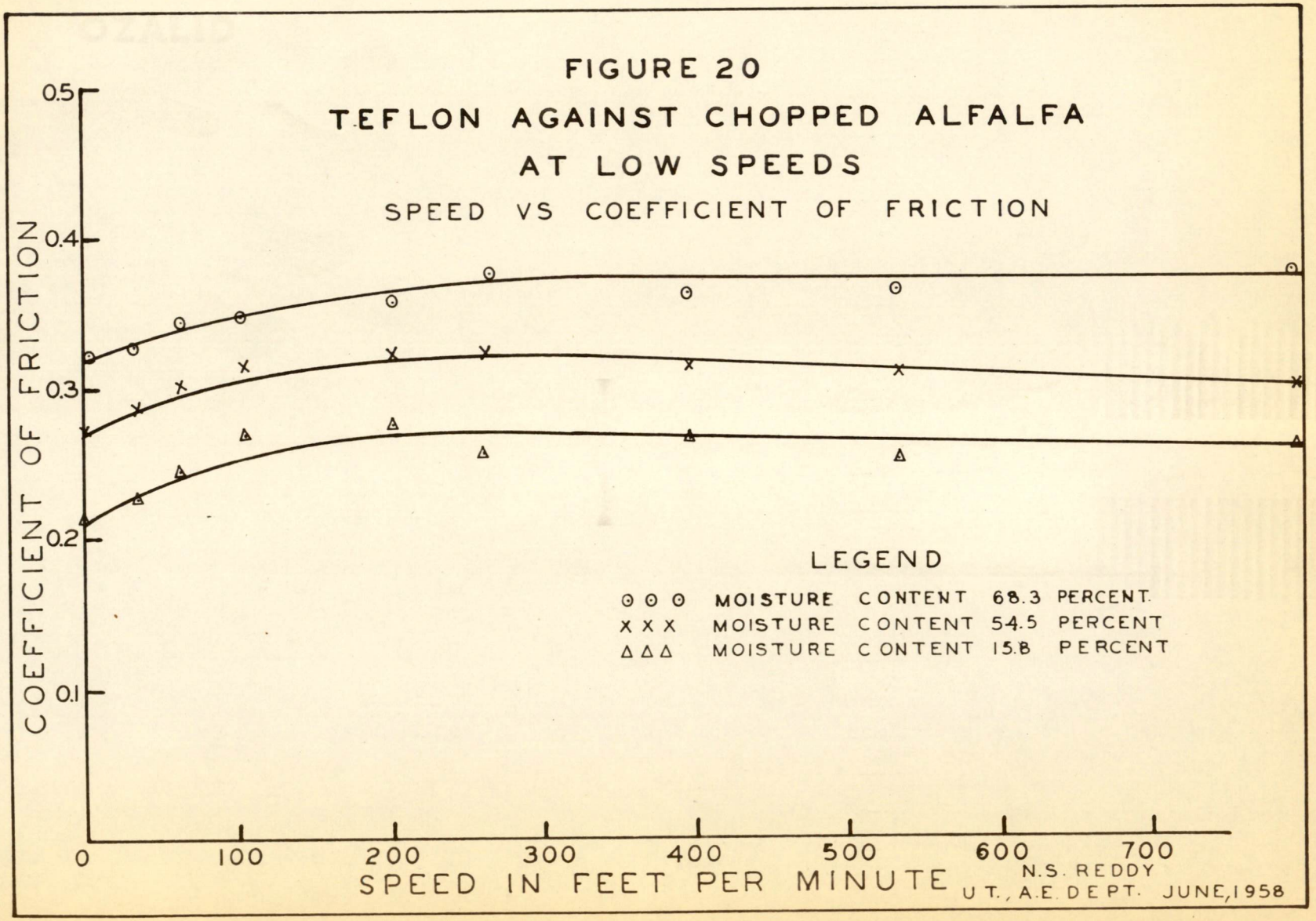
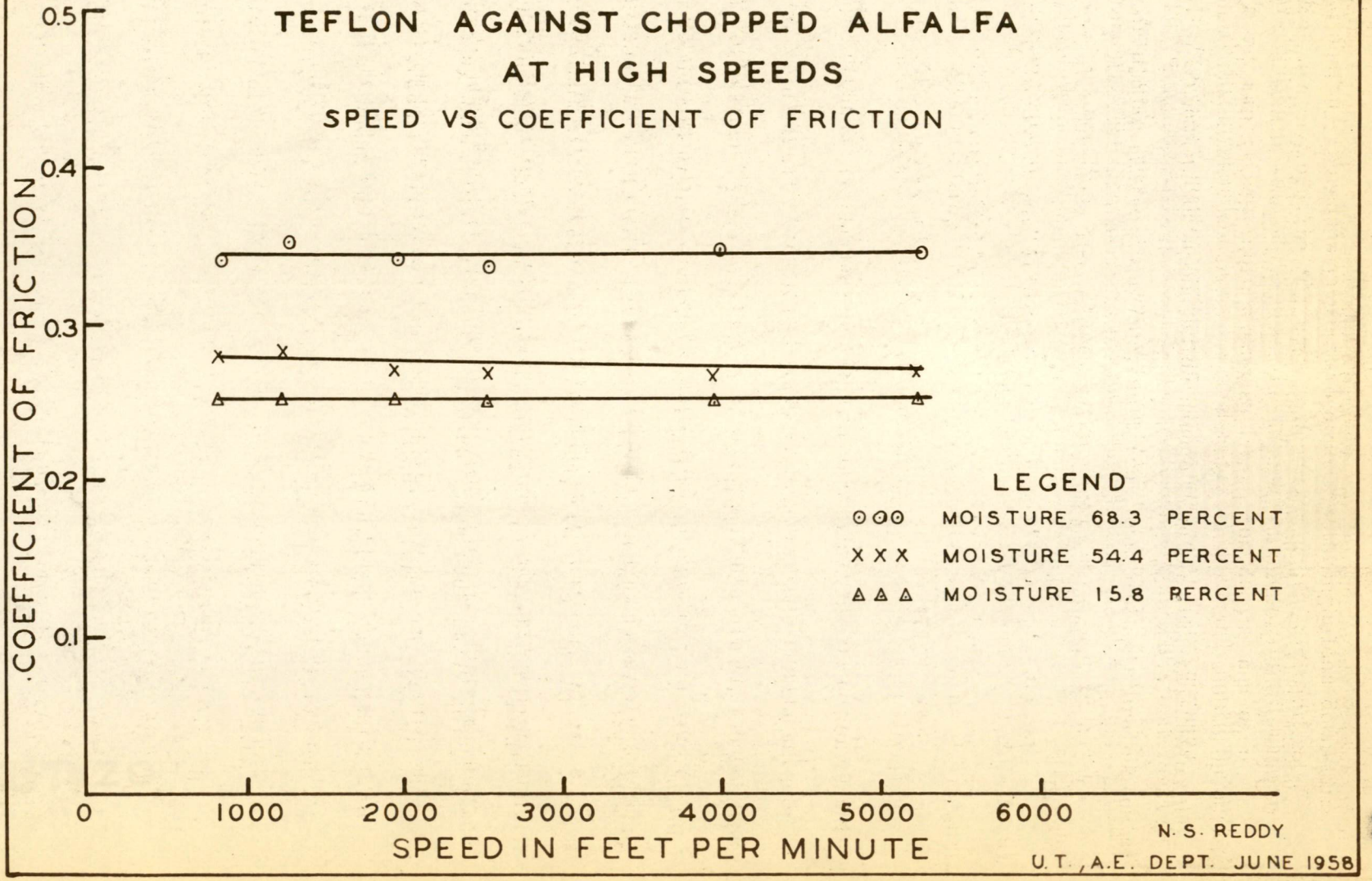

FIGURE 20
TEFLON AGAINST CHOPPED ALFALFA
AT LOW SPEEDS
SPEED VS COEFFICIENT OF FRICTION
COEFFICIENT OF FRICTION
0.5
0.4
0.3
0.2
0.1
0
100
200
300
400
500
600
700
SPEED IN FEET PER MINUTE
LEGEND
⊙ ⊙ ⊙ MOISTURE CONTENT 68.3 PERCENT
X X X MOISTURE CONTENT 54.5 PERCENT
Δ Δ Δ MOISTURE CONTENT 15.8 PERCENT
N.S. REDDY
U.T., A.E. DEPT. JUNE, 1958

FIGURE 21

TEFLON AGAINST CHOPPED ALFALFA AT HIGH SPEEDS

SPEED VS COEFFICIENT OF FRICTION

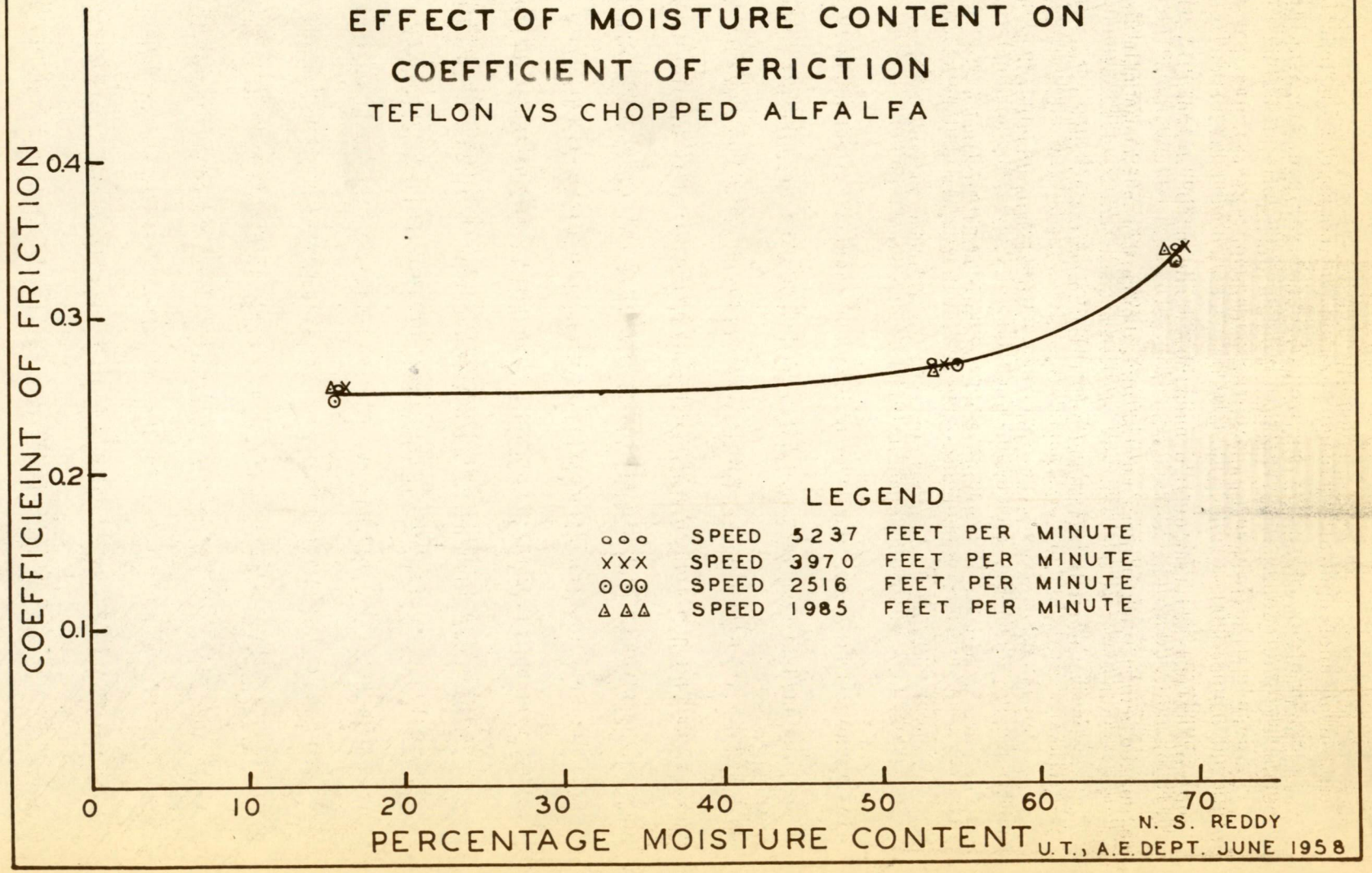


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U.T., A.E. DEPT. JUNE 1958

FIGURE 22

EFFECT OF MOISTURE CONTENT ON COEFFICIENT OF FRICTION

TEFLON VS CHOPPED ALFALFA



The moisture in soils and the moisture in green leaves such as in alfalfa are two different phenomena. The moisture in soils is free moisture available to affect the surfaces in contact either as a sticky adhesive to increase friction or as a lubricant to reduce friction. While in the case of alfalfa the moisture is incorporated in its body and not available as free moisture to affect as an adhesive or lubricant. Its presence in the material alters its roughness and friction characteristics and there is fall in coefficient of friction when moisture content comes down. On an average, the coefficient of friction of chopped alfalfa at three different stages of moisture content was found to be:

Percentage Moisture Content	Coefficient of Friction
68.3	0.34
54.5	0.27
15.8	0.25

The results in the case of alfalfa that was not chopped were rather erratic. During tests it was observed that stalks protruded and came into contact with the Teflon and whenever this happened the results varied. Actually the long alfalfa is a non-homogenous mixture of two materials; namely the stalks and leaves. Both have two different friction characteristics and it was difficult to control and say which material was in contact with the Teflon. But the results in Table III confirm the general

finding that the coefficient of friction was independent of speed and the average sliding coefficient of friction may be taken as:

Percentage Moisture Content	Coefficient of Friction
79	0.36
2.7	0.29

In the case of tests in all the materials the coefficient of friction was approximately constant at all speeds except that it had a slight fall at speeds less than 100 feet per minute and a slight increase of nearly five per cent at speeds between 100 to 700. The static coefficient of friction was almost equal to sliding coefficient of friction and is possibly due to the low friction characteristics of Teflon and its nonadhesive quality and no affinity for moisture.

CHAPTER VI

CONCLUSIONS

1. The ultimate aim was to study the friction characteristics of certain agricultural materials on Teflon to decide whether Teflon could be used in farm equipment to reduce friction. For this purpose the average static and sliding coefficient of friction as arrived at by tests were:

Materials	Moisture Content Percent	Static Coefficient of Friction	Sliding Coefficient of Friction
Hay	dry	0.20	0.22
Chopped Alfalfa	68.30	0.32	0.34
Alfalfa	79.00	0.43	0.36
Ensilage	65.15	0.29	0.28

The values for coefficient of friction for the materials tested on Teflon are low when compared to similar materials on steel or galvanized iron. Hintz and Schink (11) found that coefficient of friction for chopped alfalfa was 0.5 for the speed ranges of 1000 to 6000, while it was only 0.34 in the case of Teflon. Thus there is a 32 per cent reduction in the value of the coefficient of friction. Bockhop (3) had calculated that the power taken up by friction is proportional to the coefficient of friction (the formula has already been indicated under review of work done). Therefore, there will be a 32 per cent saving in power used for overcoming friction.

It is clear that the coefficient of sliding friction of agricultural materials on Teflon is definitely less, and Teflon could therefore be used in farm equipment where these materials are handled as the frictional losses will be less. The possible instances are choppers, blowers, elevators, and other material handling equipment.

2. Throughout the test, and in all cases, the static coefficient of friction was almost equal to the sliding coefficient of friction. This was mainly due to the nonadhesive nature of Teflon. These low values for static coefficient of friction particularly makes Teflon ideal for application in material handling equipment, such as wagon unloaders, self-unloading wagons and conveyors. The slight variation in the case of long alfalfa was due to changes in the pattern of material as it is composed of stalks and leaves.

3. The friction tests also revealed that values of coefficient of friction was low at slow speeds namely speeds less than 100 feet per minute. This is again due to Teflon's nonadhesive nature and makes it particularly suited in equipment where agricultural materials are moved slowly.

4. Throughout the tests, Teflon was found to be unaffected by moisture in the material unlike the conventional metal like steel, which gets rusted or corroded due to moisture. Richter (20) observed that the oxidation of zinc surfaces increases the

friction values; but it does not happen in the case of Teflon due to its zero moisture absorption and chemical inertness. Thus the application of Teflon will result in reducing frictional losses.

5. The friction characteristics of the agricultural materials tested namely; hay, grass ensilage, long and chopped alfalfa showed that the coefficient of friction was independent of sliding velocities and unit pressure had practically no effect. Moisture content had an effect on the coefficient of friction. Increased presence of moisture in the material increased the values of the coefficient of friction.

CHAPTER VII

RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE STUDY

1. This study was performed on the friction characteristics of only four materials namely; hay, grass ensilage, long alfalfa, and chopped alfalfa on Teflon. The results were an indication that both the static and sliding coefficient of friction was less than on metals conventionally used in farm equipment. The study should now be extended to cover all other agricultural materials such as: chopped corn, corn silage, grains, and grass.

2. It is desirable to run comparative tests immediately with the same materials on conventional metals used in farm equipment such as: steel, and galvanized iron, under similar conditions of moisture.

3. Friction studies should be extended to Teflon-Soil friction to judge the suitability of using Teflon in plows. These studies should necessarily include observations of the zero moisture absorption and non-adhesive nature of Teflon and whether these properties increase the scouring performances of Teflon-coated plows.

4. Friction studies with agricultural materials should be extended to greater ranges of unit pressures taking into account the working pressures these materials and Teflon would be subjected to in farm equipment.

5. Future tests should include a study of the abrasive resistance of Teflon and its wearability to decide whether Teflon is able to withstand the wear and tear.

6. The study could advantageously be extended to include the different forms of Teflon particularly the reinforced Teflon and aqueous dispersion. These appear particularly suited for farm equipment for easy application and to bring down costs.

The greatest aspect to be considered is the economics. At the moment Teflon is prohibitively expensive. It is possible that wide application may reduce the cost and prompt the manufacturers to evolve a cheaper and easier method of application to farm equipment.

CHAPTER VIII

SUMMARY

The basic long range need in agriculture is to reduce cost of production. One of the possible ways is to economize in the field of mechanization by minimizing power losses in farm equipment. At present 20 to 35 per cent of power is lost in overcoming friction in farm equipment. This could be avoided by the use of "frictionless" materials in farm equipment. Tetrafluoroethylene, commercially known as Teflon, was investigated to determine whether it could be used in farm equipment to reduce friction.

Teflon is a heavy duty plastic and is an outgrowth of Du Pont research. Its manufacturer's claim that it has the lowest coefficient of friction known for solids. It has versatile properties like chemical inertness, nonadhesive nature, mechanical strength, dielectric properties and zero moisture absorption. These unique combination of properties unobtainable in any other single material has found wide use for Teflon as a friction reducing material in bearings and in chemical and electrical equipment. Its use in farm equipment has not so far been tried, and several workers appear to be investigating the possibilities. The Pineapple Research Institute at Hawaii and the National Tillage Machinery Laboratory of the United States Department of Agriculture at Auburn have taken up work on Teflon covered plows. No results have been published so far.

In this investigation it was proposed to study the friction characteristics of agricultural produce on Teflon to decide whether or not it will be advantageous to use Teflon in farm equipment such as choppers, blowers, and elevators with a view to reduced power losses due to friction. It was known that roughly 20 to 25 per cent of power is lost due to friction in these farm machines. Previous workers in the field and notably Nichols, Hintz, Schink, and Richter have reported that the coefficient of friction is independent of unit pressure and sliding speed. They, however, did not study the friction characteristics of agricultural produce on Teflon and particularly at slow speeds and the effect of moisture in the material on the coefficient of friction. The present study covered these aspects on agricultural materials like hay, grass ensilage, long and chopped alfalfa.

The equipment for the tests consisted of a table with revolving circular top, being fixed to a rotating arbor. Teflon was mounted to this disk and the material to be tested was placed on Teflon and kept in position by an open box. The box was in turn tied to a scale to measure the force of friction. The Teflon disk was rotated at different speeds varying from five feet per minute to over 6000 feet per minute by a tapping machine which had different stages of speeds and this was further retarded or accelerated through a two stage cone pulley and jack shaft. The speed and frictional force was recorded. Percentage of moisture content of the material was determined by the conventional

electrical oven method. Tests were carried out on hay, grass ensilage, long and chopped alfalfa against Teflon at different speeds, unit pressures, and percentage of moisture contents.

The results showed that the coefficient of friction of agricultural materials against Teflon was independent of speed, and unit pressure. Moisture content in the material had an effect to increase the coefficient of friction. There were slight variations of the coefficient of friction at slow speeds, but these were not significant. The static coefficient of friction was invariably equal to the sliding coefficient of friction. The values of the coefficient of friction revealed that they were 32 per cent less than on conventional metal, like steel. This means that there will be 32 per cent saving in power used in overcoming friction. Indications are therefore clear that Teflon could be used in farm equipment particularly blowers, choppers, and elevators to reduce friction. The low values for static coefficient of friction, being equal to sliding coefficient of friction, makes Teflon particularly suited in material handling equipment. But its use has to be preceded by further study including Teflon's wearability.

Future study should include Teflon-soil friction, and friction characteristics of all agricultural materials against Teflon. At present the cost of Teflon is prohibitively expensive, but it is hoped that its wide and possibly extensive use in farm equipment will prompt the manufacturer to bring down the cost and evolve easier ways of applying it to farm equipment.

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APPENDIX A

TABLE V

TEST RESULTS OF SPEED CALIBRATION OF TEFLON DISK AT 18" RADIUS

Position of Speed Controls	Revolutions of Arbor	Time Min.	Time Sec.	Revolutions Per Minute	Speed in Ft./Minute at 18" Radius
Original Set Up -- Slow Speeds					
1 BLS	5	10	4	0.50	4.68
1 BHS	10	10	4	0.99	9.36
1 DLS	50	8	2	6.23	58.70
1 DHS	50	4	1	12.46	117.40
2 BLS	8	10	12	0.78	7.40
2 BHS	8	5	6	1.57	14.80
2 DLS	60	6	6	9.85	92.90
2 DHS	60	3	3	19.70	185.80
3 BLS	20	9	40	2.07	19.50
3 BHS	20	4	50	4.14	39.00
3 DLS	100	3	54	25.65	242.00
3 DHS	200	3	54	51.30	484.00
4 BLS	20	6	26	3.11	29.30
4 BHS	20	3	13	6.22	58.60
4 DLS	120	3	8	38.30	361.00
4 DHS	120	1	34	76.60	722.00

TABLE V (continued)

TEST RESULTS OF SPEED CALIBRATION OF TEFLON DISK AT 18" RADIUS

Position of Speed Controls	Revolutions of Arbor	Time Min.	Time Sec.	Revolutions Per Minute	Speed in Ft./Minute at 18" Radius
Original Set Up -- High Speeds					
1 BLF	60	5	13	11.50	108.5
1 BHF	120	5	13	23.10	217.0
1 DLF	150	1	3	142.85	1343.0
1 DHF	200	0	42	285.71	2686.0
2 BLF	120	6	35	18.25	172.0
2 BHF	120	3	18	36.40	344.0
2 DLF	400	1	47	224.40	2110.0
2 DHF					4220.0*
3 BLF	100	2	5	48.00	452.0
3 BHF	110	1	9	95.80	904.0
3 DLF					5650.0*
3 DHF					11300.0*
4 BLF	120	1	39	72.75	685.0
4 BHF	220	1	31	145.40	1370.0
4 DLF					8562.0*
4 DHF					17124.0*

*Calculated speeds.

TABLE V (continued)

TEST RESULTS OF SPEED CALIBRATION OF TEFLON DISK AT 18" RADIUS

Position of Speed Controls	Revolutions of Arbor	Time Min.	Time Sec.	Revolutions Per Minute	Speed in Ft./Minute at 18" Radius
Revised Set Up -- Slow Speeds					
1 BLS	2	3	40	0.54	5.14
1 BHS	4	3	40	1.09	10.28
1 DLS	25	3	40	6.83	64.30
1 DHS	50	3	40	13.66	128.60
2 BLS	5	5	50	0.86	8.08
2 BHS	5	2	55	1.72	16.16
2 DLS	25	2	20	10.71	101.00
2 DHS	50	2	20	21.43	202.00
3 BLS	10	4	24	2.27	21.40
3 BHS	10	2	12	4.54	42.80
3 DLS	100	3	33	28.20	266.00
3 DHS	200	3	33	56.40	532.00
4 BLS	5	1	29	3.37	31.70
4 BHS	10	1	29	6.74	63.40
4 DLS	100	2	23	42.00	396.00
4 DHS	200	2	23	84.00	792.00

TABLE V (continued)

TEST RESULTS OF SPEED CALIBRATION OF
TEFLON DISK AT 18" RADIUS

Position of Speed Controls	Revolutions of Arbor	Time Min.	Time Sec.	Revolutions Per Minute	Speed in Ft./Minute at 18" Radius
Revised Set Up -- High Speeds					
1 BLF	20	1	52	10.72	101.0
1 BHF	40	1	52	21.44	202.0
1 DLF	200	1	30	133.30	1258.0
1 DHF	400	1	30	266.60	2516.0
2 BLF	50	2	57	16.95	159.5
2 BHF	100	2	57	33.90	319.0
2 DLF	400	1	54	210.50	1985.0
2 DHF					3970.0*
3 BLF	100	2	15	44.50	419.0
3 BHF	200	2	15	89.00	838.0
3 DLF					5237.0*
3 DHF					10474.0*

*Calculated speeds.

FIGURE 23

CONVERSION CHART FOR SLOW SPEEDS OF THE TEFLON DISK

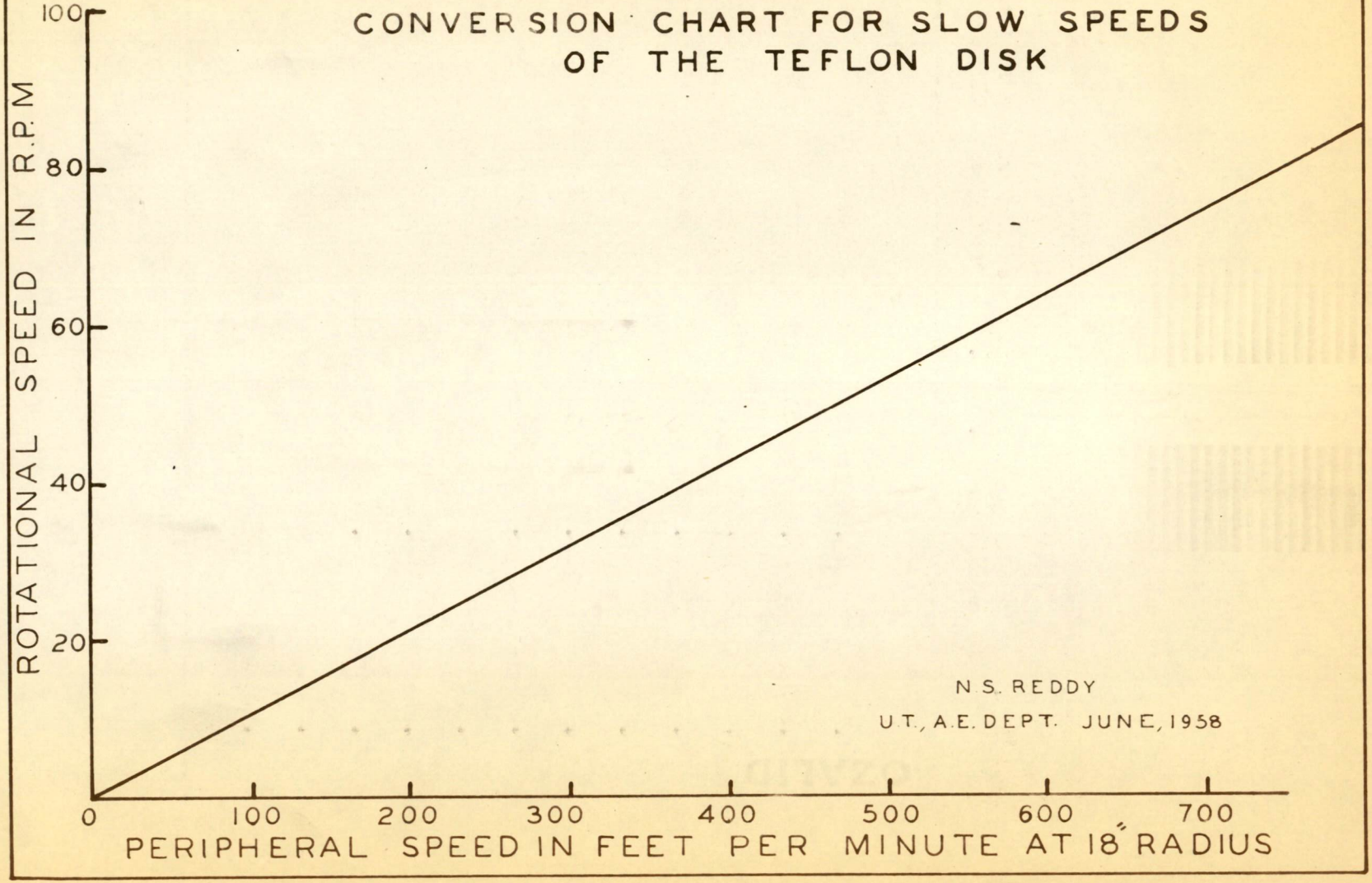
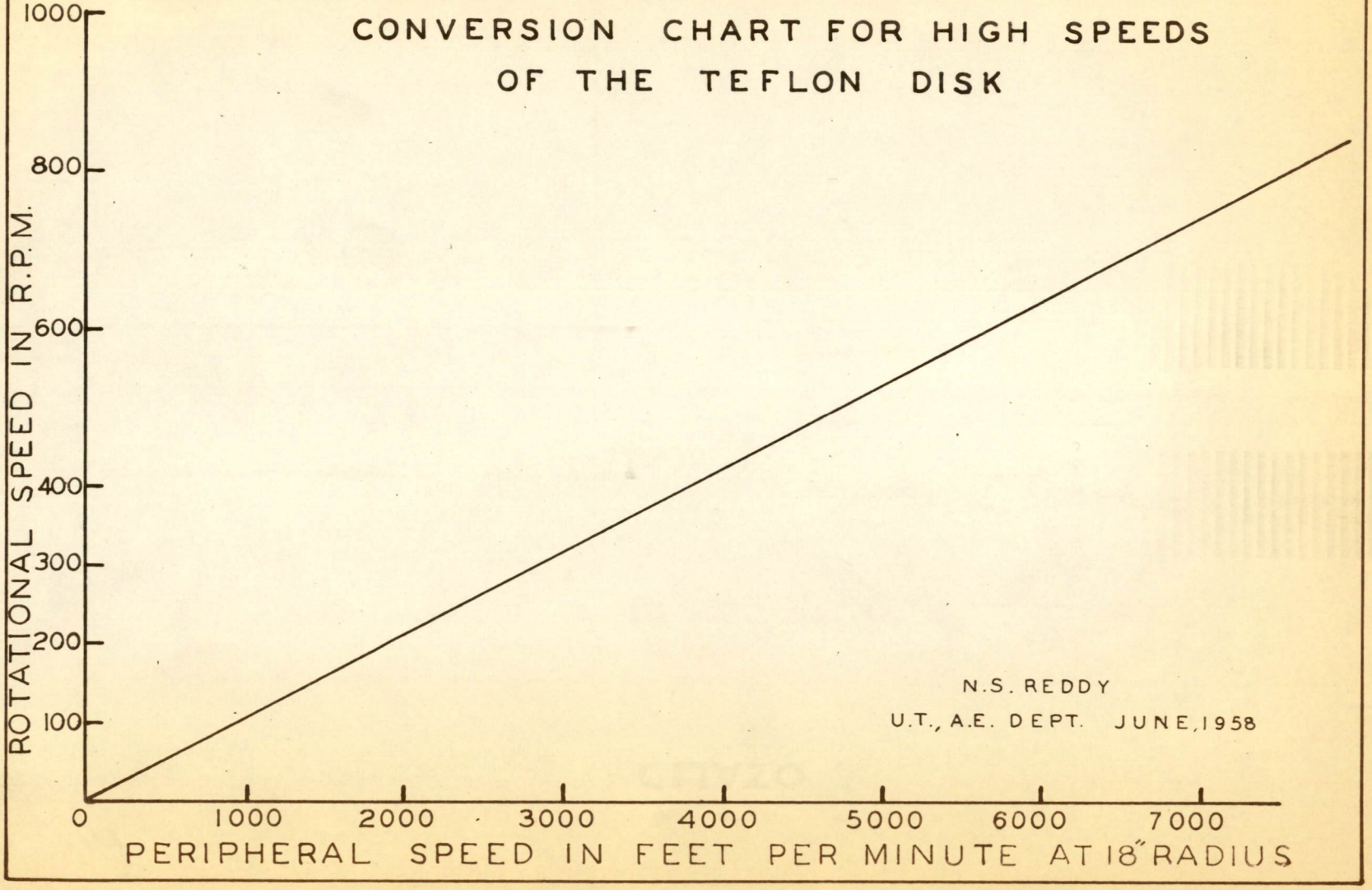


FIGURE 24

CONVERSION CHART FOR HIGH SPEEDS OF THE TEFLON DISK



APPENDIX B

TABLE VI

FRICTION TESTS ON TEFLON VS. HAY

DATE OF TESTS: April 29, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 5.4 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 0

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2BHS	3.04	0.64	0.210	14.8
2	2DLS	3.04	0.73	0.240	92.9
3	2DHS	3.04	0.74	0.242	185.8
4	3DLS	3.04	0.75	0.247	242.0
5	3DHS	3.04	0.74	0.243	484.0
6	4BHS	3.04	0.71	0.234	58.6
7	4DLS	3.04	0.74	0.243	361.0
8	4DHS	3.04	0.73	0.240	722.0
9	1DLF	3.04	0.68	0.224	1343.0
10	1DHF	3.04	0.66	0.217	2686.0
11	2DLF	3.04	0.66	0.217	2110.0
12	2DHF	3.04	0.66	0.217	4220.0
13	3BHF	3.04	0.69	0.227	906.0
14	3DLF	3.04	0.68	0.224	5650.0
15	Static	3.04	0.58	0.190	-

TABLE VI (continued)

FRICTION TESTS ON TEFLON VS. HAY

DATE OF TEST: April 30, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 9.5 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 0

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2BHS	5.35	1.16	0.217	14.8
2	2DLS	5.35	1.33	0.248	92.9
3	2DHS	5.35	1.40	0.262	185.8
4	3DLS	5.35	1.40	0.262	242.0
5	3DHS	5.35	1.40	0.262	484.0
6	4BHS	5.35	1.35	0.252	58.6
7	4DLS	5.35	1.40	0.262	361.0
8	4DHS	5.35	1.38	0.258	722.0
9	1DLF	5.35	1.31	0.245	1343.0
10	1DHF	5.35	1.30	0.243	2686.0
11	2DLF	5.35	1.24	0.232	2110.0
12	2DHF	5.35	1.20	0.224	4220.0
13	3BHF	5.35	1.23	0.230	904.0
14	3DLF	5.35	1.20	0.224	5650.0
15	Static	5.35	1.10	2.060	-

TABLE VI (continued)

FRICTION TESTS ON TEFLON VS. HAY

DATE OF TEST: May 2, 1958
SIZE OF BOX: 6 inch x 6 inch
NORMAL PRESSURE: 15.15 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 0

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2BHS	3.79	0.85	0.224	14.8
2	2DLS	3.79	0.92	0.245	92.9
3	2DHS	3.79	0.96	0.253	185.8
4	3DLS	3.79	0.98	0.258	242.0
5	3DHS	3.79	0.97	0.256	484.0
6	4BHS	3.79	0.90	0.237	58.6
7	4DLS	3.79	0.97	0.256	361.0
8	4DHS	3.79	0.94	0.248	722.0
9	1DLF	3.79	0.82	0.216	1343.0
10	1DHF	3.79	0.83	0.219	2686.0
11	2DLF	3.79	0.82	0.214	2110.0
12	2DHF	3.79	0.84	0.222	4220.0
13	3BHF	3.79	0.83	0.219	904.0
14	3DLF	3.79	0.86	0.237	5650.0
15	Static	3.79	0.76	0.201	-

TABLE VI (continued)

FRICTION TESTS ON TEFLON VS. HAY

DATE OF TEST: May 3, 1958
SIZE OF BOX: 6 inch x 6 inch
NORMAL PRESSURE: 7.08 lbs./sq.ft.
PERCENTAGE OF MOISTURE CONTENT: 0

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2BHS	1.77	0.36	0.204	14.8
2	2DLS	1.77	0.45	0.254	92.9
3	2DHS	1.77	0.46	0.260	185.8
4	3DLS	1.77	0.46	0.260	242.0
5	3DHS	1.77	0.46	0.260	484.0
6	4BHS	1.77	0.46	0.260	58.6
7	4DLS	1.77	0.47	0.265	361.0
8	4DHS	1.77	0.46	0.260	722.0
9	1DLF	1.77	0.38	0.214	1343.0
10	1DHF	1.77	0.39	0.220	2686.0
11	2DLF	1.77	0.39	0.220	2110.0
12	2DHF	1.77	0.40	0.226	4220.0
13	3BHF	1.77	0.40	0.226	904.0
14	3DLF	1.77	0.42	0.237	5650.0
15	Static	1.77	0.33	0.187	-

TABLE VII

FRICTION TESTS ON TEFLON VS. LONG ALFALFA

DATE OF TEST: June 3, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 9.6 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 79

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2DLS	5.40	2.28	0.422	101.0
2	2DHS	5.40	2.28	0.422	202.0
3	3DLS	5.40	2.40	0.444	266.0
4	3DHS	5.40	2.38	0.440	532.0
5	4BLS	5.40	2.35	0.435	31.7
6	4BHS	5.40	2.40	0.444	63.4
7	4DLS	5.40	2.32	0.430	396.0
8	4DHS	5.40	2.32	0.430	792.0
9	1DLF	5.40	1.96	0.363	1258.0
10	1DHF	5.40	1.86	0.350	2516.0
11	2DLF	5.40	1.98	0.367	1985.0
12	2DHF	5.40	2.00	0.370	3970.0
13	3BHF	5.40	1.94	0.360	838.0
14	3DLF	5.40	1.95	0.360	5237.0
15	Static	5.40	2.35	0.430	-

TABLE VII (continued)

FRICTION TESTS ON TEFLON VS. LONG ALFALFA

DATE OF TEST: June 10, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 6.38 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 2.7

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2DLS	3.59	0.92	0.256	101.0
2	2DHS	3.59	0.95	0.265	202.0
3	3DLS	3.59	1.00	0.278	266.0
4	3DHS	3.59	1.01	0.280	532.0
5	4BLS	3.59	0.84	0.234	31.7
6	4BHS	3.59	0.90	0.250	63.4
7	4DLS	3.59	1.02	0.284	396.0
8	4DHS	3.59	1.03	0.287	792.0
9	1DLF	3.59	1.06	0.295	1258.0
10	1DHF	3.59	1.03	0.286	2516.0
11	2DLF	3.59	1.05	0.292	1985.0
12	2DHF	3.59	1.03	0.287	3970.0
13	3BHF	3.59	1.01	0.280	838.0
14	3DLF	3.59	1.02	0.284	5237.0
15	Static	3.59	0.80	0.223	-

TABLE VIII

FRICTION TESTS ON TEFLON VS. GRASS ENSILAGE

DATE OF TEST: June 11, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 9.82 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 65.15

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed at 18" Radius in ft./min.
1	2DLS	5.54	1.80	0.325	101.0
2	2DHS	5.54	1.85	0.334	202.0
3	3DLS	5.54	1.81	0.326	266.0
4	3DHS	5.54	1.70	0.306	532.0
5	4BLS	5.54	1.61	0.290	31.7
6	4BHS	5.54	1.67	0.302	63.4
7	4DLS	5.54	1.70	0.306	396.0
8	4DHS	5.54	1.63	0.294	792.0
9	1DLF	5.54	1.65	0.298	1258.0
10	1DHF	5.54	1.57	0.285	2516.0
11	2DLF	5.54	1.53	0.276	1985.0
12	2DLF	5.54	1.52	0.274	3970.0
13	3BHF	5.54	1.58	0.285	838.0
14	3DLF	5.54	1.54	0.278	5237.0
15	Static	5.54	1.60	0.290	-

TABLE VIII (continued)

FRICTION TESTS ON TEFLON VS. GRASS ENSILAGE

DATE OF TEST: June 13, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 6.35 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 0

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed at 18" Radius in ft./min.
1	2DLS	3.57	0.91	0.255	101.0
2	2DHS	3.57	0.94	0.263	202.0
3	3DLS	3.57	0.94	0.263	266.0
4	3DHS	3.57	0.92	0.258	532.0
5	4BLS	3.57	0.81	0.227	31.7
6	4BHS	3.57	0.85	0.238	63.4
7	4DLS	3.57	0.93	0.260	396.0
8	4DHS	3.57	0.92	0.258	792.0
9	1DLF	3.57	0.93	0.260	1258.0
10	1DHF	3.57	0.92	0.258	2516.0
11	2DLF	3.57	0.90	0.252	1985.0
12	2DHF	3.57	0.92	0.258	3970.0
13	3BHF	3.57	0.86	0.241	838.0
14	3DLF	3.57	0.92	0.258	5237.0
15	Static	3.57	0.75	0.210	-

TABLE IX

FRICTION TESTS ON TEFLON VS. CHOPPED ALFALFA

DATE OF TEST: June 13, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 7.56 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 54.5

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2DLS	4.26	1.34	0.314	101.0
2	2DHS	4.26	1.39	0.326	202.0
3	3DLS	4.26	1.39	0.326	266.0
4	3DLS	4.26	1.31	0.307	532.0
5	4BLS	4.26	1.23	0.289	31.7
6	4BHS	4.26	1.29	0.303	63.4
7	4DLS	4.26	1.34	0.314	396.0
8	4DHS	4.26	1.27	0.298	792.0
9	1DLF	4.26	1.22	0.286	1258.0
10	1DHF	4.26	1.15	0.270	2516.0
11	2DLF	4.26	1.15	0.270	1985.0
12	2DLF	4.26	1.15	0.270	3970.0
13	3BHF	4.26	1.19	0.280	838.0
14	3DLF	4.26	1.15	0.270	5237.0
15	Static	4.26	1.15	0.270	-

TABLE IX (continued)

FRICTION TESTS ON TEFLON VS. CHOPPED ALFALFA

DATE OF TEST: June 16, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 6.45 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 15.8

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2DLS	3.63	0.98	0.270	101.0
2	2DHS	3.63	1.00	0.275	202.0
3	3DLS	3.63	0.93	0.256	266.0
4	3DHS	3.63	0.91	0.250	532.0
5	4BLS	3.63	0.83	0.228	31.7
6	4BHS	3.63	0.89	0.245	63.4
7	4DLS	3.63	0.95	0.262	396.0
8	4DHS	3.63	0.94	0.259	792.0
9	1DLF	3.63	0.92	0.253	1258.0
10	1DHF	3.63	0.91	0.250	2516.0
11	2DLF	3.63	0.92	0.253	1985.0
12	2DHF	3.63	0.92	0.253	2970.0
13	3BHF	3.63	0.92	0.253	838.0
14	3DLF	3.63	0.92	0.253	5237.0
15	Static	3.63	0.78	0.215	-

TABLE IX (continued)

FRICTION TESTS ON TEFLON VS. CHOPPED ALFALFA

DATE OF TEST: June 16, 1958
SIZE OF BOX: 9 inch x 9 inch
NORMAL PRESSURE: 9.4 lbs./sq. ft.
PERCENTAGE OF MOISTURE CONTENT: 68.3

Serial No.	Position of Speed Controls	Weight of Material Including Container N in lbs.	Frictional Force F in lbs.	Coefficient of Friction $\frac{F}{N}$	Speed in ft./min.
1	2DLS	5.28	1.85	0.349	101.0
2	2DHS	5.28	1.88	0.355	202.0
3	3DLS	5.28	1.99	0.376	266.0
4	3DHS	5.28	1.94	0.366	532.0
5	4BLS	5.28	1.72	0.326	31.7
6	4BHS	5.28	1.81	0.344	63.4
7	4DLS	5.28	1.99	0.360	396.0
8	4DHS	5.28	1.98	0.375	792.0
9	1DLF	5.28	1.86	0.351	1258.0
10	1DHF	5.28	1.79	0.338	2516.0
11	2DLF	5.28	1.80	0.340	1985.0
12	2DHF	5.28	1.83	0.345	3970.0
13	3BHF	5.28	1.80	0.340	838.0
14	3DLF	5.28	1.83	0.345	5237.0
15	Static	5.28	1.70	0.323	-

TABLE X

MOISTURE CONTENT DETERMINATION TESTS

Date of Test	Sample	Weight of Sample with Container: Before Drying	Weight of Sample with Container: After Drying in Oven	Weight of Container	Weight of Sample Before Drying (3-5)	Weight of Moisture Alone (3-4)	Percentage of Moisture 7/6 x 100
April	HAY						
29	A	0.205	0.205	0.160	0.045	0	0
29	B	0.205	0.205	0.160	0.045	0	0
29	C	0.220	0.220	0.160	0.060	0	0
		Average percentage of moisture content					0
June	LONG ALFALFA						
3	A	0.190	0.170	0.165	0.025	0.020	80.00
4	B	0.210	0.175	0.165	0.065	0.035	78.00
		Average percentage of moisture content					79.00
June							
10	A	0.220	0.205	0.165	0.055	0.015	2.73
10	B	0.240	0.220	0.165	0.075	0.020	2.67
		Average percentage of moisture content					2.70
June	GRASS ENSILAGE						
11	A	0.255	0.195	0.165	0.090	0.060	66.70
11	B	0.275	0.205	0.165	0.110	0.070	63.60
		Average percentage of moisture content					65.15
June 13							
13	A	0.195	0.195	0.165	-	0	0
13	B	0.200	0.200	0.165	-	0	0
		Average percentage of moisture content					0
June	CHOPPED ALFALFA						
13	A	0.115	0.082	0.055	0.060	0.033	55.00
13	B	0.105	0.078	0.055	0.050	0.027	56.00
		Average percentage of moisture content					55.50
June							
16	A	0.195	0.190	0.165	0.030	0.005	16.70
16	B	0.212	0.205	0.165	0.047	0.007	14.90
		Average percentage of moisture content					15.80
16	C	0.290	0.200	0.155	0.135	0.090	66.60
16	D	0.26	0.190	0.160	0.100	0.070	70.00
		Average percentage of moisture content					68.30