JOURNAL AND PROCEEDINGS OF THE

INSTITUTION OF AGRICULTURAL ENGINEERS

VOL. 16 NO. 1 - JANUARY 1960

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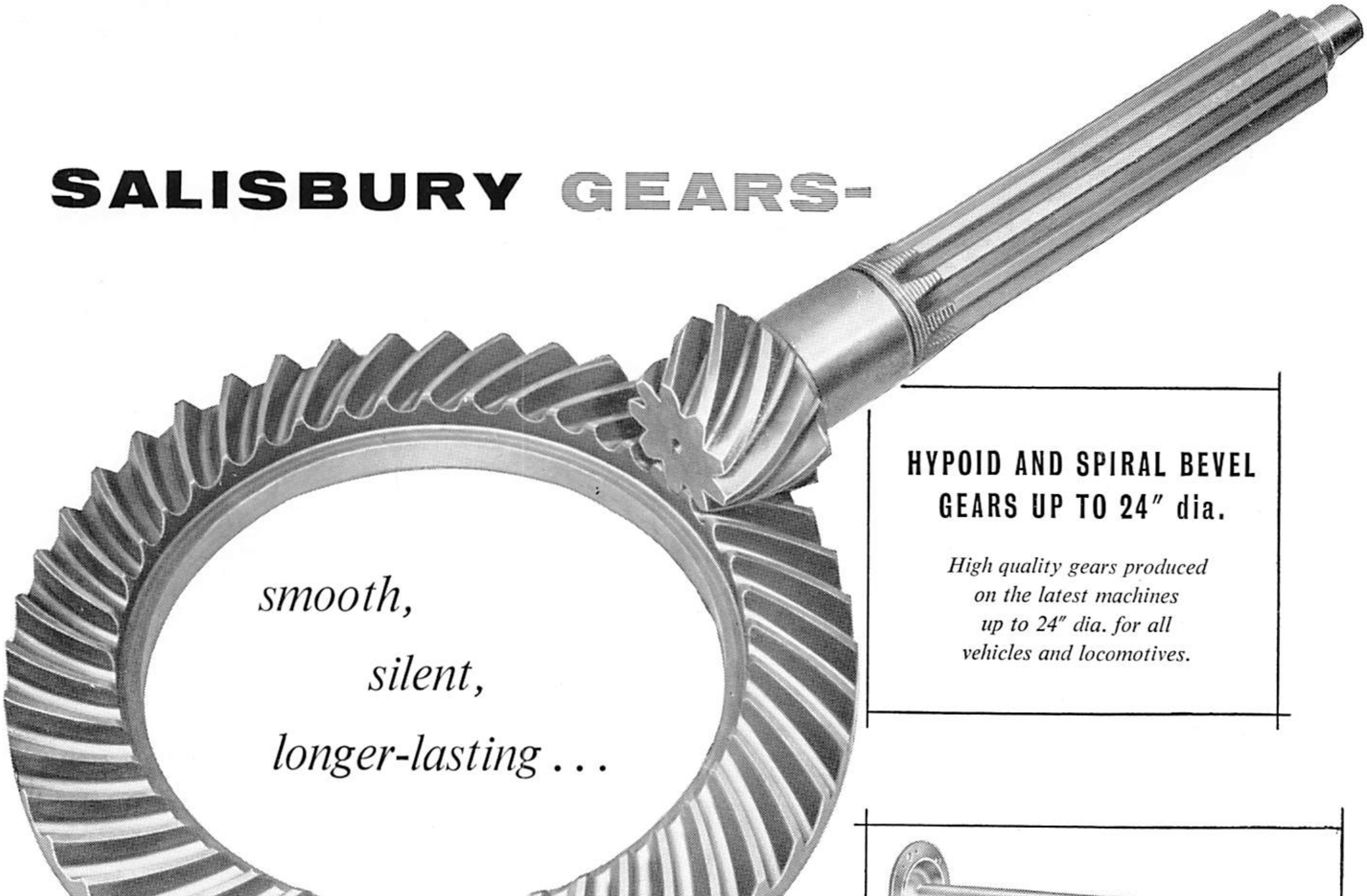

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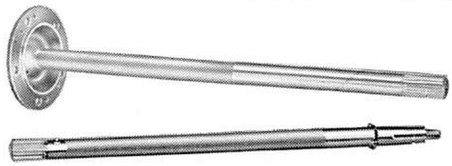

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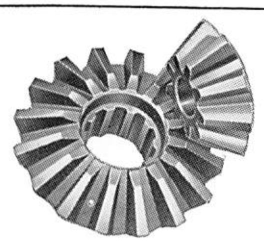

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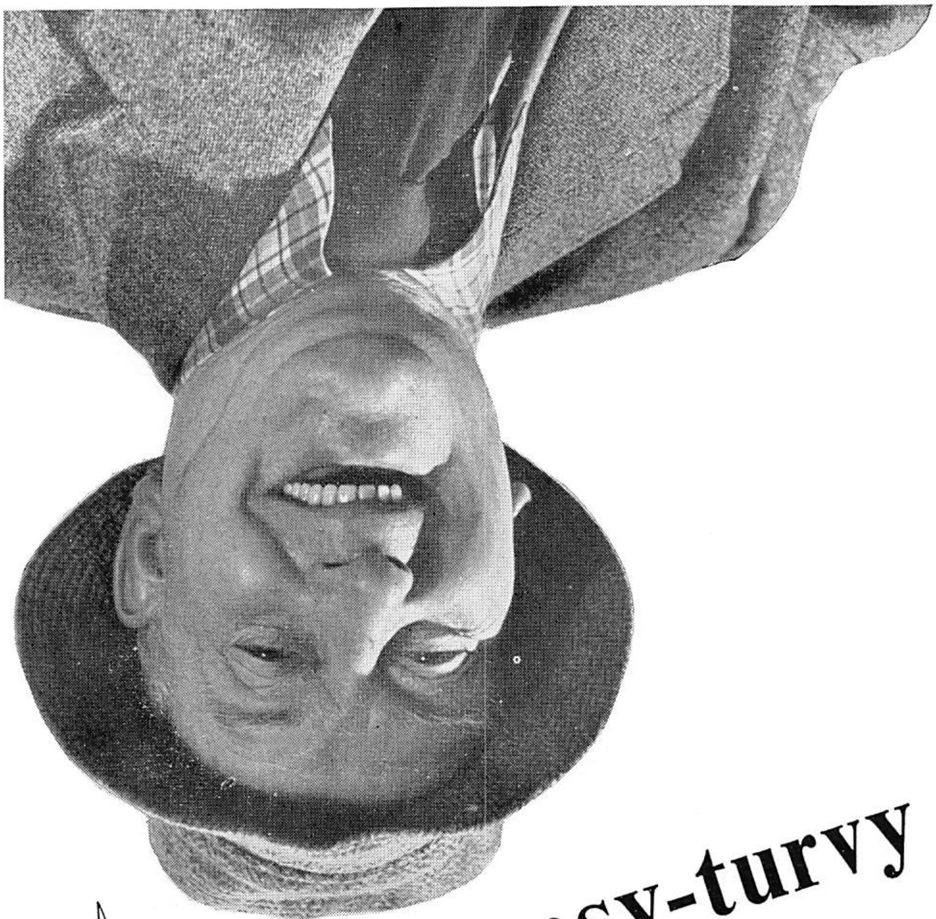

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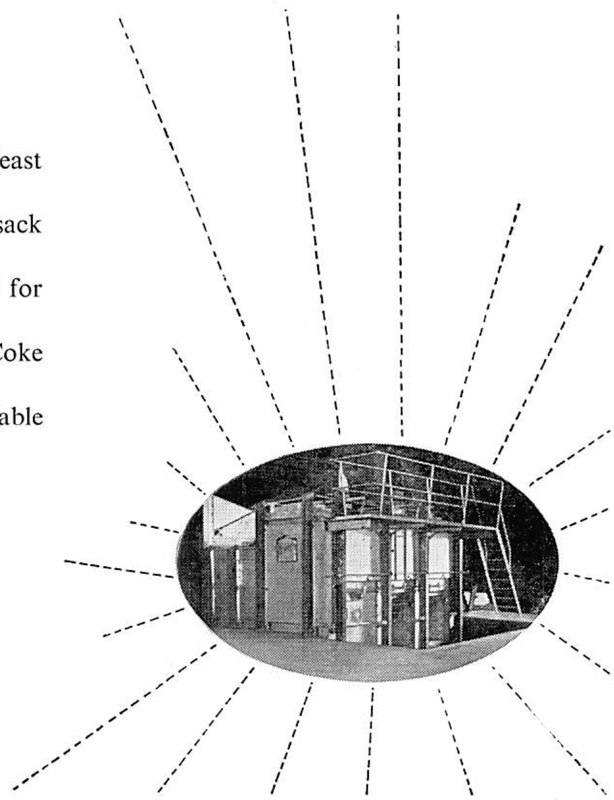

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JOURNAL AND PROCEEDINGS OF THE INSTITUTION OF AGRICULTURAL ENGINEERS

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CONTENTS

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INSTITUTION NOTES

Articles of Association and Membership Certificates

THE Certificate of Incorporation having been received, the revised Memorandum and Articles of Association are now printed, and copies, together with a Certificate of Membership, may be obtained upon application to the Secretary. Those members who have already requested membership certificates will receive these without further application.

Submission of Papers

Members are again reminded that the Council is prepared to consider Papers or Articles for publication in the Journal, or possibly, in the case of Papers, for presentation at Open Meetings of the Institution. Particulars of requirements are set out in " Notes for the Guidance of Authors," prepared by the Council, and copies may be obtained from the Secretary.

Branches of the Institution

The Council has decided, after consultation with the present " Local Centres " of the Institution, that in view of the growth of the Institution, and in particular of these Centres, it would be more appropriate to regard them as branches and for them to be known as such in future.

New Year Honours

Four members were mentioned in the New Year's Honours List. They were Dr. E. W. Russell (C.M.G.), Mr. W. T. Price (C.B.E.), Mr. J. C. Gough (O.B.E.) and Mr. H. J. Hamblin (O.B.E.). Congratulations, on behalf of the Institution, have been sent by the Council to these gentlemen. Dr. Russell and Mr. Gough are, of course, Past Vice-Presidents.

Recovery of Income Tax on Subscriptions

Those members who have not already done so are reminded that their subscriptions to the Institution are allowable as an expense for Income Tax purposes. Application should be made to local Tax Inspectors for Form No. P358, which gives full details.

Appointments Service

This service is growing steadily, and employers and those seeking positions are invited to send their requirements to the Secretary for addition to the Register.

National College of Agricultural Engineering

The first meeting of the Board of Governors has been held and certain Committees appointed to undertake preliminary work.

BOOK REVIEW

" FARM ENGINEERING "

by A. W. RIDDOLLS, B.E. (Civil), B.Sc., A.M.I.Mech.E., M.I.Agr.E.

R. E. Owen, Government Printer, Wellington, New Zealand. 1958. 42s.

This is a publication which has been needed for a long time. It deals with levelling, farm drainage, water supply, irrigation, farm concrete work, materials and methods of construction and farm structures—all of them subjects which are usually classified in this country under the heading of field engineering. The author, who is head of the Agricultural Engineering Department of Canterbury Agricultural College in New Zealand, is one of the leading experts in this field. He has endeavoured not only to give information on field engineering principles to students of agriculture and agricultural engineering, but also to provide a useful reference book for farmers. This book, which is very well illustrated, is likely to become a standard textbook on the subject.

SOIL EROSION BY WIND AND MEASURES FOR ITS CONTROL

prepared by the
AGRICULTURAL ENGINEERING BRANCH, FOOD AND AGRICULTURE ORGANISATION OF THE UNITED NATIONS,
Rome, Italy.

Presented at an Open Meeting by M. E. B. NEAL,* B.Sc.(Agric.), M.I.Agr.E., *on Tuesday, 10th November, 1959.*

FOREWORD

"*Go to the ruins of ancient and rich civilisations in Asia Minor, northern Africa, or elsewhere. Look at the unpeopled valleys, at the dead and buried cities, and you can decipher there the promise and the prophesy that the law of soil exhaustion held in store for all of us . . . Depleted of humus by constant cropping, land could no longer reward labour and support life, so the people abandoned it. Deserted, it became a desert ; the light soil was washed away by the rain and blown around by the shifting winds.*" DR. VLADIMIR G. SINKHOVITCH, " Hay and History," p. 161.

THIS Paper on " Soil Erosion by Wind and Measures for its Control " has been prepared by collaborators from North America and Australia and by staff members of the Agricultural Engineering, and Soil Survey and Fertility Branches, Land and Water Development Division of the Food and Agriculture Organisation of the United Nations.

The material from North America is a joint contribution from officers of the Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, and the Department of Agronomy, Kansas Agricultural Experimental Station, Manhattan, Kansas. The contributing officers are : W. S. Chepil, Soil Scientist ; N. P. Woodruff, Agricultural Engineer ; and F. H. Siddoway, Soil Scientist.

It will be noted that conditions that cause excessive wind erosion and resultant damages, as well as its nature, have been covered in some detail. Although not dealing specifically with methods of erosion control, they are the basis upon which control measures are built, and therefore essential for inclusion in the Paper.

The information included in the general chapter on control measures covers those that have been successfully developed, and pays particular attention to the part that improved cultural practices and machinery play in the control of soil erosion by wind and in soil and moisture conservation in dry-land farming areas.

Finally, the Paper indicates the almost total lack of control measures in many areas of the world, but especially in North Africa and the Near East.

Grateful acknowledgment is extended by the Agricultural Engineering Branch, FAO, Rome, to all those who have collaborated and contributed to the Paper, and it is felt that the information will materially assist agricultural workers in many areas of the world in approaching with increased knowledge and confidence the problems of soil erosion by wind and measures for its control.

INTRODUCTION

Wind erosion in various parts of the world became serious only after man had destroyed or depleted the natural vegetative cover on the land by improper cultivation, burning and over-grazing, and this accelerated soil erosion by both wind and water (Fig. 1).

The cure would thus seem to be merely to restore the cover that existed under natural conditions. But man must till and graze the land to produce food and fibre, and cut trees for fuel and timber. These practices tend to deplete the vegetative cover, however, so great care is required if the soil is to be conserved.

FIG. 1 : An advanced stage of wind erosion in Australia.

* Land and Water Development Division, Agricultural Engineering Branch of the F.A.O.

CONDITIONS THAT CAUSE EXCESSIVE WIND EROSION

The primary causes of wind erosion are (*a*) loose, dry, and finely-divided soil ; (*b*) smooth and bare soil surfaces ; (*c*) large fields ; (*d*) strong winds.

Thus, wherever (*a*) the soil is compacted, moist, or made up of stable clods large enough so they cannot be moved by wind, (*b*) the surface is roughened or covered with vegetation or vegetative residue, (*c*) the fields are narrowed, or (*d*) the wind near the ground is reduced, erosion can be controlled.

DAMAGE FROM WIND EROSION

Wind erosion causes far more crop destruction than water erosion. Silt, clay and organic matter are sorted from the surface soil and carried away, leaving the remaining sandy material much more erodible than was the original soil. Sands usually pile up in dunes and encroach on better surrounding lands. Throughout recorded history, huge agricultural areas have been ruined in this manner (Fig. 2). There are districts in Great Britain where dunes have invaded good farming land, parts of Morayshire being an example.

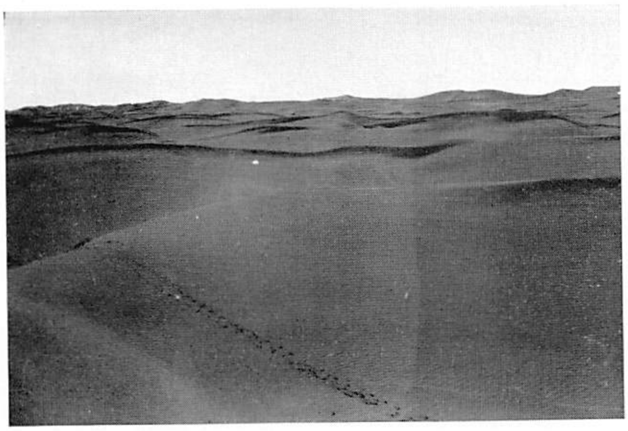

FIG. 2 : Once cultivated land in Iraq.

Railways and roads are often buried, traffic is sometimes held up and accidents are common during severe dust storms. Insects and weed seeds are carried to clean fields. Fences, hedges, ditches, channels and shelter-belts are often buried and ruined. Grass, shrubs and trees may be smothered. Farmsteads are often blocked and rendered uninhabitable (Fig. 3). Dust storms are disagreeable and sometimes unbearable. Farm animals suffer and sometimes die from suffocation. People in villages, towns and cities also suffer inconveniences.

THE NATURE OF SOIL EROSION BY WIND

Wind erosion can be divided into four major phases—soil denudation, weathering, erosion and stabilisation. Denudation is devegetation of the surface ; weathering is loosening and disintegration of the surface soil ; erosion includes soil stirring and transportation, sorting, abrasion and avalanching ; stabilisation includes soil deposition, consolidation and aggregation, and surface revegetation. Each of these is influenced by conditions of the air, the ground surface, and the soil. Of those

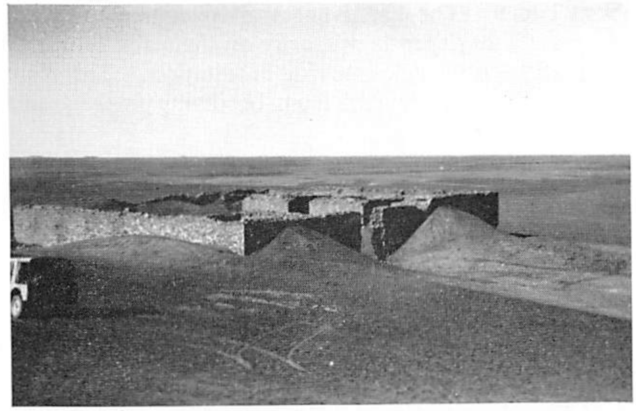

FIG. 3 : Farmstead deserted due to drifted soil.

connected with air, the velocity and turbulence are the most important. The major factors connected with ground surface are roughness, cover, barriers, temperature, topography, and size of the eroding area, and those connected with soil are its structure, texture, organic matter, density and moisture.

Denudation and Disintegration of the Surface Soil

When land is denuded of vegetation, wetting and drying and freezing and thawing loosen and disintegrate surface clods to sizes that are highly erodible.

Initiation of Soil Movement

Soil aggregates larger than a wheat kernel or a bean, depending on their density and the wind velocity, are non-erodible. The smallest non-erodible clods are more effective than larger clods in protecting the erodible fractions because they have more protective surface in proportion to their weight. An ideal soil would contain about 90 per cent. of non-erodible clods not exceeding one centimetre (0·4 in.) in diameter.

Soil Transportation

Eroded soil fractions are carried by wind in three types of movement : *Saltation*—jumping or bouncing ; *surface creep*—rolling and sliding along the surface ; and *suspension*—floating in the airstream.

Jumping particles account for most of the movement. These particles generally range from 0·05 to 0·5 millimetre in diameter (Fig. 4).

The particles in surface creep are too heavy to be lifted in the air, but are moved by the jumping particles and not appreciably by the direct impact of the wind. They are about 0·5 to 1 or 2 millimetres in diameter.

The only way fine dust can be lifted off the ground by wind is to be kicked up by jumping particles. Once kicked up, dust can be lifted to great heights by upward eddies having a velocity of at least 2 or 3 miles per hour (Fig. 5).

The height to which particles rise in saltation has an important bearing on methods of wind erosion control. The height of jump varies with type of soil, surface roughness and velocity of wind. Usually from 95 to 99 per cent. of jumping particles are carried below a height of 1 ft., the average height being about 2 ins. The ratio of height of jump to horizontal distance moved is about 1 to 8. The effectiveness of vegetative cover and rough surfaces depends primarily on their ability to trap and shield soil particles moving in saltation. Therefore, soils should be prevented from becoming finely granulated.

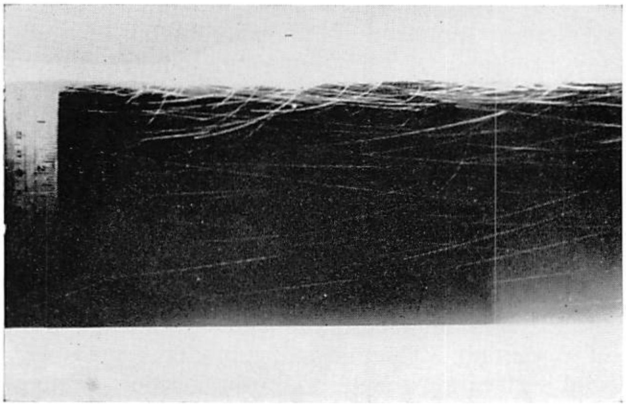

FIG. 4 : Paths of soil grains moved primarily by saltation. Dots and dashes indicate that particles are spinning. Camera exposure is 1/25th second. Wind direction is from left to right. Scales on the right are in inches and centimetres.

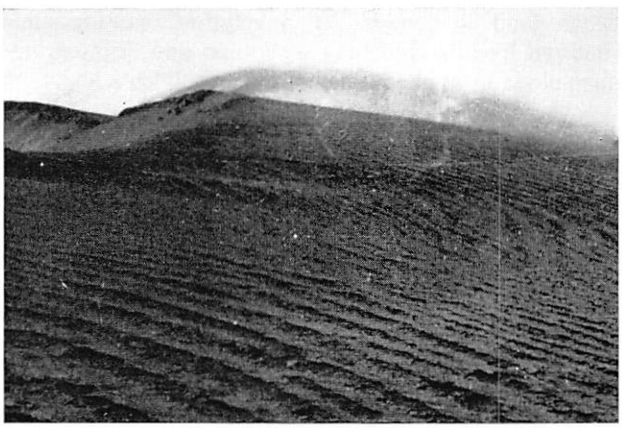

FIG. 5 : The start of a dust storm on cultivated land in the Middle East.

Sorting (Elutriation)

Some soils are more subject to the sorting action of wind than others. It is normally greatest on sandy soils, which lose silt, clay and organic matter rapidly and become still more sandy as erosion progresses.

Abrasion

Once soil grains are loosened, their jumping action wears into the surface crust. The larger the field the more often the grains strike the surface and the sooner the surface and clods are worn down to erodible grains, most of which in turn bounce and abrade the surface. The coarser the soil texture the more susceptible it is to abrasion and the narrower the field has to be to control erosion.

Avalanching

This is the movement of soil in mass. The rate of flow is zero at the windward edge of an eroding field, and increases with distance to leeward until it reaches a maximum that a given wind can carry. The rate of avalanching varies directly with soil erodibility.

Deposition

The first step in soil stabilisation is to trap jumping soil grains. Trapping can be done by placing barriers in the path of the wind, by roughening the surface, or by burying the eroding particles.

Consolidation and Aggregation

Eroded soil particles tend to cement together into larger, non-erodible aggregates by rain, compaction and micro-organisms. But repeated wetting and drying and freezing and thawing tends to soften and disintegrate the surface soil and enhance wind erosion. Because of these two counteracting processes, the maximum soil consolidation and aggregation usually occurs below the depth of 3 to 4 ins. Implements that bring consolidated soil to the surface will reduce wind erosion, if the vegetation they bury is negligible.

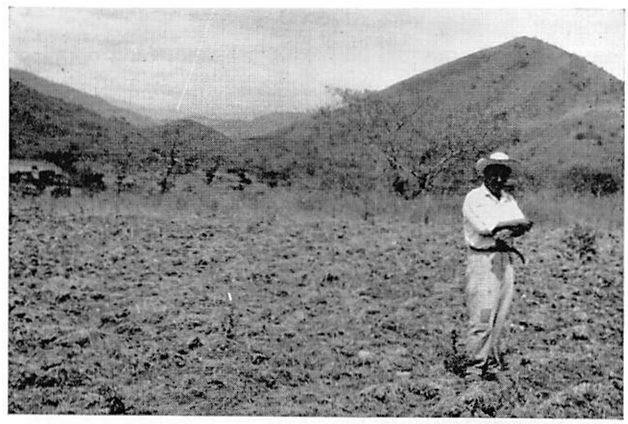

FIG. 6 : The sort of tilth needed to prevent wind erosion. Guatemala.

Bringing clods to the surface is only a temporary or emergency method because surface clods readily weather down to erodible particles. Living or dead vegetation must be depended on for permanent control (Fig. 6).

Re-vegetation

Decomposing vegetation produces materials that bind the soil particles together to form water-stable non-erodible aggregates. It is important, therefore, to keep adding fresh organic matter to the soil and to keep it on the surface where it decomposes least. Thus, vegetative cover, not just organic matter, is the key for controlling wind and water erosion, as well as for conserving water. The black soils in the Cambridgeshire Fens are an example of this ; they are rich in organic matter, but when bare of vegetation, dry and finely tilled, wind erosion is not uncommon on them.

CONTROL MEASURES

Wind erosion control measures are :

1. Roughen the surface to slow down wind velocity and trap drifting soil ;
2. Produce or bring up from below clods large enough that cannot be moved by wind ;
3. Establish barriers and trap strips at intervals across the field to reduce wind velocity and avalanching ; and

4. Protect the soil surface with vegetation or vegetative residue.

The principles of control apply everywhere, but the effectiveness of each depends on local conditions. Usually a combination of methods is the best.

In very high winds and extreme drought some erosion may occur, despite the best control measures, but it will be much less than if no controls are established.

Permanent methods of control include stubble mulching, cover crops, strip cropping, crop rotations, proper choice and use of tillage, planting, and harvesting implements, wind barriers, shelter-belts and permanent re-grassing and reforestation.

Stubble Mulching

A growing crop provides cover during part of the year and, if managed properly, the residues left after harvest continue to protect the soil for a considerable time thereafter. The degree of protection depends on residue quantity quality and orientation.

In the United States of America a silt loam soil having 25 per cent. non-erodible fractions needs 750 lb. of standing wheat stubble or 1,500 lb. of flattened wheat stubble per acre to control erosion, and 1,750 lb. of standing or 3,500 lb. per acre of flattened wheat stubble are needed on a loamy sand. Long is more effective than equal quantities of short stubble, and leaning is better than flattened stubble.

The more erodible soils should never be without cover. Continuous cropping increases the hazard of crop failure, but assures reduced erosion.

Over-grazing of pastures and range fires have often led to depletion of native grasses and intrusion of less desirable species. Proper stocking and good management are essential. In some sandy and dry areas, vegetation is so sparse that any grazing increases wind erosion and can result in soil drifting to more productive lands.

Cotton, tobacco, sugar beets, peas, beans, potatoes, peanuts, asparagus and market garJen crops in general leave little cover on the land and contribute to erosion by both wind and water. Whenever possible, these should be grown in strips between protective barriers or strips of erosion-resistant crops, such as small grains and others that are closely planted which cover the ground rapidly. Widely-spaced crops, like maize and sorghum, are intermediate in their resistance to erosion. Fallow is most susceptible to erosion, but where moisture is limited it is essential, so wherever possible fallows should be in strips between protective barriers and as much crop residue left on the surface as possible.

The finer textured residues like wheat straw seem to afford more protection than equal quantities of coarse-extured residues, such as sorghum s tubble.

Standing crop residues are usually planted at right-angles to prevailing winds. Portable wind tunnel tests with 9 in. high sorghum in rows 40 ins. apart show that soil losses are about three times greater when parallel with the wind than at right-angles.

Cover Crops

In some areas of the Canadian Prairie Provinces, spring wheat is planted on fallow in the late summer and, depending upon growth, pastured in the autumn. If moisture is adequate, this effectively protects the soil dring the following spring period of high winds, until spring wheat is planted for harvest.

Late summer or early autumn-sown wheat, although not planted as a cover crop, gives protection from wind erosion during the critical period the following spring (Fig. 7).

FIG. 7 : This winter wheat planted with semi-deep furrow drill in rows 12 ins. apart is an effective cover crop. The wheat including crowns amounts to about 700 lb. per acre of dry matter above the surface. The soil is sandy loam highly susceptible to wind erosion, yet virtually no soil movement occurred during an exceedingly dry and windy spring.

The combination of a good stubble mulch and autumn growth made by winter wheat is very effective. If it fails to germinate or provide sufficient cover in the autumn, severe erosion may occur the following spring unless protected with residues from the previous crop. If these are insufficient, the land should be roughed and made as cloddy as possible as a temporary expedient.

Sorghum is sometimes planted on the more erodible soils of the Great Plains of the United States solely as a protective cover during the following spring erosion period. It is seeded at any time during the summer and is often left unharvested.

Strip Cropping

This does not require any change in cropping. It merely involves subdividing the farm into alternate strips of erosion-resistant crops and erosion-susceptible fallow or crops. The crops and the fallow are rotated each year on the strips.

There are two general types : (1) Wind strip cropping, in which the strips are straight and run as nearly as possible at right-angles to the prevailing winds, and (2) contour strips, in which the strips follow the land contours. Which is used depends on the relative severity of wind and water erosion. Wind strip cropping is generally best for controlling wind erosion (Fig. 8).

Strip cropping reduces soil avalanching, which increases with width of field. Therefore, the narrower the strips the more effective they are. In western Kansas, erosion-susceptible strips with a 1 ft. stubble to windward are 20, 25, 80, 100, 150, 280, 350 and 430 ft. wide to control wind erosion on sand, loamy sand, granulated clay, sandy loam, silty clay, loam, silt loam, clay loam, and silty clay loam, rsepectively. The widths would have to be narrower or wider where wind velocities are respectively higher or lower than in western Kansas. Adequate quantities of crop residues are required in strip cropping as an additional protection. The narrower strips are less easy to work with standard machinery.

The more the wind deivates in direction the narrower the strips should be. Topography influences the effectiveness of strips and should be considered when designing such a system.

FIG. 8 : Wind strip cropping with strips 254 ft. wide on loam soil in rotation with fallow, wheat, and sorghum with proper residue management has given adequate protection.

Crop Rotations

Crop rotations help to control erosion. The inclusion of lucerne with sugar beets and potatoes in rotation or the application of farmyard manure is quite effective in reducing soil losses from wind erosion in Nebraska. Tests showed that 12 tons per acre of farmyard manure for 40 years reduced the soil loss from about 37 tons per acre to about 1·5 tons per acre. Comparable plots in the lucerne rotation had soil losses averaging about 0·5 tons per acre.

The bulk of the dryland areas in the United States of America subject to wind erosion follow wheat-fallow, wheat-wheat-fallow, and wheat-sorghum-fallow rotations, which are readily adaptable to strip cropping. The longer rotations which include perennial crops also work well in a strip crop system.

Machinery for Wind Erosion Control

Tillage machinery and tillage practices have played an important role in both aggravating and alleviating wind erosion in North America. The mobility, adaptability, speed of operation, and size of present-day equipment has worsened matters by enabling man to put more highly erodible land under cultivation, but constant improvements in machinery and tillage methods help to control erosion.

Machinery used to control erosion includes just about any implement that stirs the soil. Certain types of tools, however, are better than others. The specific implement and method of use depends on such factors as :

(*a*) The job being done ; *i.e.*, is it regular tillage to prepare a seed bed and to sow the seed, or is it an emergency operation where the only purpose is to stop existing erosion ?

(*b*) The condition of the land at the time of tillage.

If crop residues are heavy, sub-surface sweep tillage, which leaves a good cover on the land, is effective, but if there is little residue on the surface it is better to use a plough, a lister or a chisel implement to ridge the land and bring clods to the surface.

Tillage implements can be classified into three broad categories :

1. Those that turn a layer completely over.
2. Those that mix or stir the surface soil.
3. Those that cut underneath the surface, but neither mix nor turn the tillage layer.

The mouldboard plough is an example of the first, the disc harrow of the second, and the sub-surface sweep of the third.

Mouldboard and Disc Ploughs

The mouldboard plough was used extensively by early settlers in nearly all parts of North America. To-day, however, it is limited principally to sub-humid and humid regions and to irrigated lands and special conditions in the arid regions.

The main objections to ploughing are the burial of crop residues and the relatively high cost of operation.

Despite the disadvantages, the plough is useful for killing tough, deep-rooted weeds and producing cloddy surfaces. New tillage techniques, in which combinations of implements plough, work down the soil, seed, and apply fertilisers and herbicides all in one operation, have extended the use of the plough.

One of the main advantages of the disc plough is the lower draught, so it is particularly useful in ploughing hard, dry soils or for " deep ploughing " in sandy areas to bring up clay and bury sand. The disc plough will also cut through heavy stubble or trash without choking and will scour better in heavy, sticky soils than the mouldboard plough.

Listers

The lister was primarily developed as a combination

FIG. 9 : A 14 in. lister bottom which does an excellent job of emergency tillage to control wind erosion.

furrow-opener and planter for sorghum and maize. The lister bottom consists of two opposed shares and mouldboards which throw the soil in two opposite directions. The most common size is the 14 in., shown in Fig. 9. The lister provides good protection against wind erosion, because it leaves the land ridged and rough (Fig. 10).

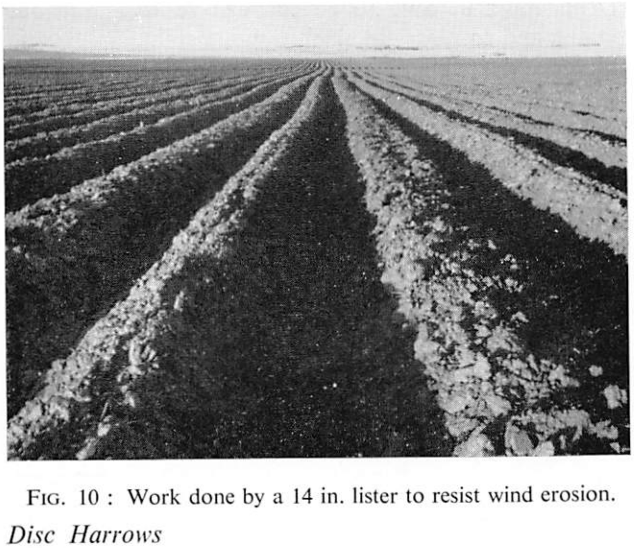

FIG. 10 : Work done by a 14 in. lister to resist wind erosion.

Disc Harrows

The three types of disc harrows commonly used in North America are the single disc, which obtains penetration by angling the discs, the offset disc and the tandem disc.

Disc harrows should not be used on bare, erodible lands in dryland areas, because they pulverise the soil and leave the surface smooth, fine and loose. They are not very effective for destroying weeds (Fig. 11).

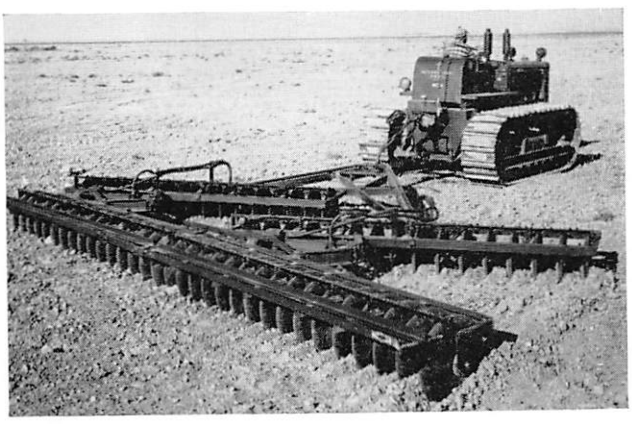

FIG. 11 : This is a good example of what not to do on dry land subject to wind erosion.

Spike and Spring-Tooth Harrows

The spike-tooth harrow should not be used where there is a wind erosion hazard. In the past, it probably caused far more erosion than it prevented. It is effective in packing soil in early spring after ploughing, and it will kill a few very small weeds.

The spring-tooth harrow is a somewhat better implement. It penetrates deeper, brings some clods to the surface, causes some ridging, and destroys small weeds prior to planting. It cannot be used on heavy residues because of clogging, and is a poor implement where wind erosion is serious.

Duck-Foot Cultivator

The duck-foot cultivator having shovels 12 ins. or less across the wing tips is used extensively in the semi-arid and arid areas of North America for cultivating fallow land, for seed-bed preparation, and to a limited extent for emergency tillage. It is effective in destroying weeds if residues are not so thick as to clog the shovel shanks. It leaves a rough, ridged surface.

Chisels

Chisel tools usually have rather heavy curved or straight shanks and are trailed or mounted on a toolbar. Chisel points vary in width from 2 ins. upwards and are of many shapes.

These implements were developed primarily to break hard soil and for sub-soiling, but are also much used for emergency tillage, although they have no value as regular implements for wind erosion control (Fig. 12).

When used for emergency tillage the chisel is set at depths just sufficient to bring up compacted clods.

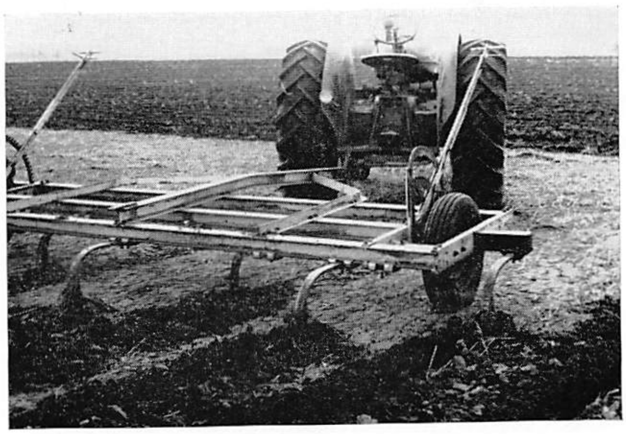

FIG. 12 : The chisel point cultivator (chisel) does a good job on fine-textured, compacted soils by bringing clods to the surface to resist wind. It is not very suitable for loose, sandy soils.

One-Way Discs

The one-way disc was an early step away from the mouldboard plough and toward stubble mulch farming. It has large closely-spaced concave discs and is pulled at an angle that moves the entire surface soil approximately at right-angles to the direction of travel. It destroys weeds and will leave about half the residue on the surface after one bout, but it pulverises the soil and leaves it susceptible to erosion if residues are meagre (Fig. 13). The one-way disc should not be used for more than the initial tillage and only if the residues are heavy. A sequence of one bout with the disc followed by sweeps and rod-weeding on land having fairly large amounts of residue is recommended.

The amount of rsedue burial can be controlled to some extent by angle and depth adjustment and by speed. The implement can be adapted for emergency tillage by removing every other disc, thus forming ridges similar to a lister, or by using eccentric discs which give a pitted surface to the field.

Sub-surface Tillers

The many types of sub-surface implements are designed to undercut with a minimum disturbance of surface residues. They are recent developments and have been largely responsible for the stubble-mulch type of farming. Their chief advantage is that they leave as much as 80 to 90 per cent. of crop residue on the surface (Fig. 14). One disadvantage is that they do not bring clods to the surface.

FIG. 13 : One-way discing immediately after harvest to destroy weed growth and to put soil in a condition to absorb moisture.

The blades on heavy-duty tillers range from 5 to 7 ft. in width, either straight or V-shaped. Lighter types have V-blades 12 to 36 ins. in width (Fig. 15), and they differ from the duck-foot cultivator, in that the blades are wider, shanks fewer and longer for greater clearance, and they usually have rolling coulters ahead of each shovel to prevent clogging.

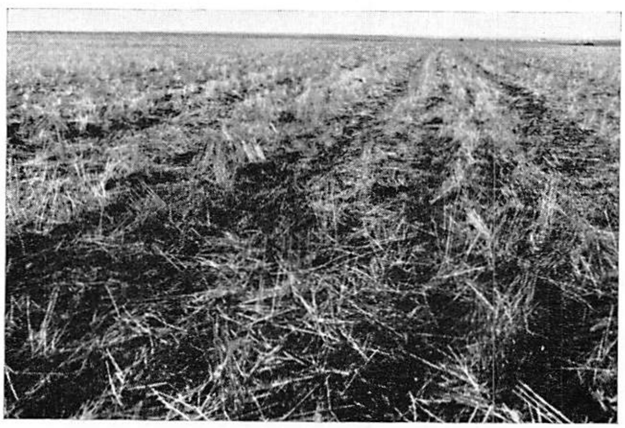

FIG. 14 : Over 80 per cent. of wheat stubble mostly standing was left above the surface after one operation with a sub-surface tiller with two 7 ft. V-type sweeps. The land is well protected from wind erosion.

Rod-Weeders

A rod-weeder consists of a long, horizontal bar, square or triangular on section, which rotates 2 or 3 ins. below the soil surface. The rotation of the power-driven rod deposits some clods and residue on the surface while tending to move the fine soil downward. It is good for destroying weeds, but it clogs in heavy residue, and repeated use at the same depth will pack the soil.

Miscellaneous Tillage Tools

On some soils rotary hoes can be used, provided there is plenty of crop residue on the surface. These implements have gangs of spiked or curved-tooth wheels, and are effective for distributing residue before seeding.

Drilling Machinery

Drills must be able to go through residues without clogging and to place the seed in moist soil.

Single and double-disc drills with 6 or 7 in. spacing for wheat can only be used where residues are light. Deep-furrow disc or shovel drills with 14 in. spacings are preferable for wind erosion control.

For sorghum, a shovel-type drill, a 14 or 8 in. lister, a furrow-opener planter, or seeding attachments on a chisel cultivator all leave a rough surface and place the seeds where they germinate readily.

Windbreaks and Shelter-belts

Shelter-belts of trees are an effective means of controlling wind erosion, but they have certain limitations and disadvantages. One limitation is that the climate, soils, and water-tables in the dry-land erosion areas of North America are not favourable for trees. A disadvantage is that a shelter-belt will protect only a limited area. Still another objection is that trees sap moisture for some distance, thus reducing crop yields.

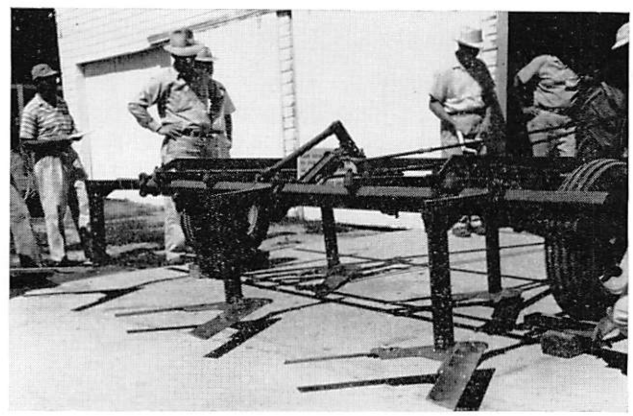

FIG. 15 : A sub-surface tiller with 3 ft V-type sweeps.

Nevertheless, shelter-belts are an important method of wind erosion control in many areas of North America.

Factors affecting Shelter-belt Effectiveness

The effectiveness of any shelter-belt depends on such factors as wind velocity and direction, and shape, width and porosity of the belt.

The closer to leeward of the belt the greater the reduction in wind velocity. Velocity reductions with winds at right-angles to the belt range from 70 to 80 per cent. near the belt, about 20 per cent. at distances equal to 20 times the height of the belt, and zero reduction at about 30 belt heights to leeward. These reductions remain constant, irrespective of wind velocities, but the belt will not provide the same extent of erosion control with a 50 mile per hour wind as it will with a 20 mile wind. For example, the minimum velocity to start soil movement on most soils is between 12 and 15 miles per hour. A 50 per cent. reduction in a 20 mile wind would reduce it to 10 miles per hour, thus providing full protection, but a 50 per cent. reduction in a 50 mile wind would reduce the velocity to only 25 miles, which is not sufficient to stop soil blowing.

Shelter-belts should be oriented to catch prevailing winds broadside on. Generally, a streamlined or a very abrupt vertical belt provides less protection than one having a triangular-shaped top surface.

Density or porosity is determined by the species and number of tree rows within the belt. Some porosity, especially near the ground, is desirable, but too much causes air-jetting, which results in serious erosion immediately to leeward.

There is lack of reliable experimental data as to what degree wind erosion can be controlled by use of shelter-belts having different porosities.

Emergency Tillage

When vegetative cover becomes depleted, emergency tillage should be done which will create a rough, cloddy soil surface. It is, however, only a temporary expedient, because clods readily disintegrate under the influence of the weather.

It is much better to use emergency tillage before erosion has started than after.

Implements and Methods

Some of the most effective implements are listers, narrow and heavy-duty chisels, and duck-foot and wide spade shovel cultivators.

The method depends on the seriousness of possible erosion, soil texture, and whether or not a crop is involved. If erosion is expected to be serious, tillage with a lister will be necessary, but in mild cases chisels and cultivators may be all that is required.

Sandy soils are by far the most difficult to hold. At best, any emergency measure in sand is short-lived, and it is far better to keep such soils permanently covered with vegetation.

It is easier to produce a rough, cloddy surface in fine and medium textured soils, and chisels are usually effective for the purpose.

The existence of a crop affects the choice of tillage methods. A wheat crop may be too sparse to hold against erosive winds, yet there is some hope of saving part of it. In these cases, tillage in strips with a chisel implement or complete coverage with widely-spaced tines might suit the condition.

Factors Governing Effectiveness of Emergency Tillage

Tillage at right-angles is more effective than tillage parallel to the wind. Depth of tillage must be sufficient to bring clods to the surface. This is usually 3 to 4 ins. on clays and 6 or 7 ins. on silty loams. Tilling at speeds of 3·5 to 4·0 miles per hour produces the most effective surfaces.

With chisel implements, 24 in. spacing of tines provides good protection. With a 14 in. lister, 42 in. spacing is effective, and 20 to 24 in. spacing with 8 in. listers. On spring-tooth harrows the spacings should be 8 or 9 ins. Where there are crops and complete coverage is not desirable, 54 in. spacing will provide some protection and leave part of the crop.

Reclaiming Wind-Eroded Sands

Reclaiming dune sands is best done during rainy periods and when winds are high. The deep-furrow cultivator is satisfactory in shallow accumulations where some clods can be brought to the surface. The lister is better on deeper deposits. Work should begin to windward.

On very deep accumulations the whole surface should be covered with anchored straw, brush, or similar materials, and the work should begin on the windward side.

Suitable grasses, shrubs, or trees should then be planted. For humid and sub-humid regions, European beach-grass (*Ammophila arenaria*), American beach-grass (*Ammophila breviligulata*), Volga wild rye (*Elymus giganteus*), and sea panic-grass (*Panicum amarum*) are suitable. For dunes of the Great Plains, broom corn (*Sorghum vulgare, var. technicum*), Sudan grass (*S. vulgare, var. sudanese*) or small grains can be used as a temporary cover. Species such as Indian grass (*Sorghastrum nutans*), switch grass (*Panicum virgatum*), sand bluestem (*Andropogon hallii*), western wheat grass (*Agropyron smithei*) are suitable for permanent vegetation.

Shrubs such as ephedra (*Ephedra viridis* and *E. sinica*), dune broom (*Parryella filifolia*), sand plum (*Prunus angustifolia*), sand cherry (*P. pumila*) and snowberry (*Symphoricarpos spp.*) are some of the many species suitable for permanent stabilisation (Fig. 16).

FIG. 16 : Drifting sand on a beach in Australia is first stilled by the brush fence, then covered by the tufty Marram grass growing near the fence and finally made permanently stable by the turf-forming grasses shown on the right.

Careful management is necessary when stabilised sand-dune land is used. Roads through loose sand should be covered with non-erodible materials, houses should not be built, and the whole stabilised area should be guarded from fire, over-grazing, or excessive cutting of trees ; in fact, most of it should be used only for recreational purposes, and managed for the protection of more valuable adjacent agricultural land.

The reclamation of parts of the Norfolk brecklands, which are largely wind-eroded sands, has followed rather a different pattern because the conditions are not identical, but similar principles are involved.

WIND EROSION IN THE LESSER-DEVELOPED COUNTRIES

The Extent of the Damage caused by Wind Erosion

With the expansion of agricultural production in lesser developed countries in recent years has come a fuller appreciation of the damage that has been done by wind erosion, and surveys indicate that it is far more widespread than is commonly believed. Many countries in South America, North Africa, the Middle East and Asia report wind erosion and damage to cultivated lands by sand " creeping " from previously eroded areas.

Measures being taken to control water erosion are also helping to check erosion by wind, but, unfortunately, wind erosion is often not taken seriously.

Climatic Conditions

Throughout the regions mentioned there are large semi-arid areas where the rain, often very heavy, falls in the winter and is followed by a dry period of six months or more. Annual cereals and forage crops are grown. The soil and climatic conditions in many of these countries are more favourable for annual cereal production than the dry-land areas of North America and Australia, but lack of knowledge and of the equipment needed for dry-land farming has held back cereal production.

Local Methods

Arable crops—particularly cereals—are combined with sheep and goats on rough grazing and cereal stubbles. The natural pastures produce very little herbage during the dry season, and this is over-grazed (Fig. 17). The stubbles, too, are eaten right down to the ground and even pawed up, leaving no vegetative protection whatever. The treading of the dry soil by the flocks leaves it in a very fine erodible condition.

The frequent severe dust storms in these regions are largely a result of this over-grazing.

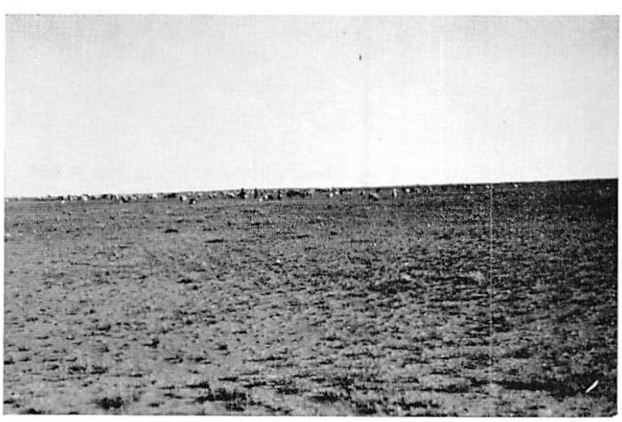

FIG. 17 : Typical over-grazed land in the Middle East.

The Implements Used

The basic tool, the animal-drawn wooden plough, modified but little through the centuries and often criticised and held to ridicule by " modern " farmers, has much to commend it for the local conditions (Fig. 18). It does not invert the soil or bury surface residues. It works only to a shallow depth, leaving the soil in cloddy low ridges. Despite the over-grazing and soil pulverisation that is common, some protection is given, and it is true to say that had inversion ploughs been used continuously instead very little land would have remained in production.

FIG. 18 : An indigenous plough at work in Iraq.

Expansion Programmes and Power Machinery

The need for increased production has led many governments to introduce tractors and power implements and to progressively reduce animal power and indigenous tools.

Mouldboard and disc ploughs, disc and spike-tooth harrows and narrow spaced drills, all most suitable in temperate humid climates, did initially increase crop yields, but in the long run their continued use accelerated wind erosion by burying the organic residues and leaving the soil in a fine, smooth condition.

Power machinery has also brought under crops large areas which previously could not be cultivated with indigenous implements. But much of this marginal land requires skilled management, because it has increased the potentially erodible areas.

The Present Position

The present position is serious, but not alarming. In many of the countries there is a growing awareness that soil conservation must play an important part in agricultural programmes. The work on wind erosion control done in North America and Australia is becoming known and the methods and machinery used are being adapted to meet local needs.

The Future Prospects

The more rapid working of " stubble mulch " implements, as compared with inversion ploughs, is attractive, even if they do not offer the advantages of improved soil and moisture conservation, so they will probably be increasingly used.

In many of these cultivated areas, however, the greatest problem is still that of providing sufficient fodder for livestock so as to check over-grazing. Unless stubble grazing is stopped, there is little point in introducing stubble mulch methods.

Haymaking is virtually unknown in most of these regions, although conditions are often excellent for the purpose. The introduction of suitable fodder plants could contribute greatly to overall agricultural production and assist considerably in preventing wind erosion on arable lands. Once these plants are established, the equipment for efficient hay and silage making will undoubtedly be made available.

It is fortunate for the lesser-developed countries that many of the practices and machines essential for increased production under dry-land conditions are identical with those needed to control wind erosion.

In the immediate future it is therefore expected that the trials being conducted will show that expansion programmes will not be threatened from the wind erosion that in the past resulted in so great a loss of agricultural land.

SUMMARY

Erosion of soil by wind is due to depletion or destruction of natural vegetative cover. Whenever possible, this cover should be restored.

A thorough understanding of the processes of soil denudation, erosion, and stabilisation is a pre-requisite for developing effective methods of control.

The principles of wind erosion control apply everywhere, but the relative importance of each depends on local conditions. Usually a combination of practices will be most effective.

These have been effective :

1. Land covered with sufficient vegetation or vegetative residue resists erosion. Only implements that leave plant residue on the surface should be used.
2. A cover crop will give additional protection.
3. Strip cropping, especially if supplemented with vegetative cover, is very effective on fallowed land. It does not require any change in tillage and cropping practices.
4. Rotations that provide a high level of soil fertility, substantial cover, and favourbale soil structure decrease wind erosion.
5. Sandy lands not suited for cultivation should be seeded to grass or planted with shrubs or trees.
6. Lands that are too dry, if they cannot be irrigated, should be seeded permanently to grass and properly pastured.
7. Windbreaks and shelter-belts greatly aid in controlling wind erosion. They should be placed at intervals across the farm.
8. Artificial barriers, such as wood lath fences and paper strips, control wind erosion on peat and sandy soils growing vegetables. Temporary strips of Sudan grass, sunflowers, sorghum, or other tall plants at right-angles to the wind are also successful.
9. Community action is necessary for proper erosion control.
10. Under exceptional conditions emergency action may be necessary, such as scattering organic residues on the land or tilling it to create a rough, cloddy surface which will resist the wind.
11. The basic principles of indigenous ploughs used in lesser developed countries should not lightly be discarded in favour of more modern implements.
12. Over-grazing is a major contributing factor leading to wind erosion in a number of semi-arid regions.
13. Conditions are suitable in many of these lesser-developed countries for fodder crops.
14. The cultivation of hay and silage crops will lead to a demand for harvesting and handling them.

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DISCUSSION

DR. ALEXANDER MUIR*: The question of erosion is, of course, an ancient one. I was surprised to find that the Paper did not start with somebody like Plato and his description of Greece and of the terrible calamity which overtook the country, which once used to be forested. However, the numerous references from ancient times can be used to show that erosion has long been with us, and, of course, we have the geological record as well.

I was interested to read in an American journal recently of an example of buried soil from Devonian times. Here we have had a soil born during a hot, probably tropical, climate, completely buried by the sands of Devonian times. So even before man's existence, we certainly had soil erosion in quite a big way.

Mr. Neal and the Paper have definitely combed America and Australia for information on this subject. What surprised me was that there was no reference to the U.S.S.R., because the problems of erosion there are quite as great as anywhere else in the world. Interestingly enough, the Russians started at about the middle of last century to devise means of control, when the planting of shelter belts in Southern Russia was instituted in an effort to stem the soil erosion, which was extensive even then. They still do quite a lot of work on protection from erosion.

Mr. Neal has mentioned one or two instances in this country and, of course, we are not troubled on any great scale. My first view of soil erosion was in parts of Yorkshire where one can see saucer-shaped fields with stagnant pools in the middle, the sand having been built up nicely round the edge. This example may not be of soil erosion in the ordinary sense, but it provides an excellent example of what strong winds can do in moving material about.

Mr. Neal would, I think, like to disclaim the reference from Dr. Sinkhovitch which starts the Paper. It is certainly one to which I would take very strong exception.

There is not the slightest doubt that the greater part of the eroded and derelict land in the Middle East results really from the conflict between the pastoralist and the settled agriculturist. In other words, it is a continuation of the biblical story of Cain and Abel, and I am afraid that this trouble still goes on.

While it may be a good idea at the moment, in North America at any rate, to bury weeds in preparing the land for a crop, I think it is certainly not so in the Middle East. It is undoubtedly the case that in this area, with the hordes of sheep and goats, plus cattle and the nomadic camels, one needs the weeds that follow the cereal crops as fodder. There is simply no other food as such for these animals. So in the methods of improving agriculture in these countries one must keep in mind this social side.

It is a very different matter from North America or Australia, where the people have already inherited our method of agriculture. One has to go well back in our history, at least to Elizabethan times, to find that stubble was one of the main sources of fodder for the animals.

I was pleased to hear Mr. Neal's remarks concerning the primitive ploughs in these countries, because I am convinced that from the technical viewpoint they are a good thing. If modern machinery is to be introduced, it must be machinery that will do much the same thing as these primitive ploughs. In other words, what is necessary is largely a scratching effect, by which a fair amount of the crop residue is left on the surface. There is no point in taking out big caterpillar tractors and heavy implements, because they would ruin the soil still further. It is, therefore, the light machinery that is needed for the dry land type of cultivation.

The areas of irrigation are quite another matter. With some of the soils in the irrigated areas, one would certainly need larger implements.

When considering soils in general, one is up against

* *Head of Department of Pedology, Rothamsted Experimental Station.*

a double problem, and in saying this I am thinking in terms of the Middle East again. There is not only the problem of erosion as such, but the concomitant problem of soil salinity.

In the Spring, I had the opportunity of visiting Turkey and seeing something of Central Anatolia and also the southern coast. It is obvious that in a great part of Central Anatolia, irrigation agriculture is almost out of the question, although dry-land agriculture is altogether an extraordinarily precarious business. One sees square mile after square mile where the vegetation has been eaten off completely by the small cattle, goats and sheep, and there is nothing left on the surface but stones. It is almost impossible to do anything with the land. There is no water, and in any case the configuration of the land would make it very difficult to irrigate.

On the other hand, it seems to me that in areas like the south coast of Turkey, where there are many opportunities for irrigation from the big streams, there must be some attempt at adjustment. In other words, one type of agriculture should be developed in one area, and a totally different type in another area.

I once visited the Nebraska sandhills area, where under controlled grazing there seems to have been astonishing recovery of the vegetation. One would not expect it to be lush, but I was assured that there is far less erosion now under controlled grazing than when the Red Indians held the country. A practice like that might be very usefully adopted in some of the Middle-Eastern countries. It certainly would lead to far greater protection of the soil.

PROFESSOR F. A. BROOKS*: I have been interested in the discussion, although it is not exactly in my line as I am not on the mechanisation side. I am here on short sabbatical leave at Rothamsted with Dr. Penman in the Soil Physics Department. He arranged a trip for me to go to Scotland which included visiting the Culbin Sands area, where such a good job has been done on reforesting an area that was denuded in, I believe, 1684. So I have seen very successful work on soil erosion that is being done here in Britain, and I am becoming interested in the subject in California, not so much for soil conservation as for reduction of a public nuisance.

That may be a little strange for agricultural production people, but actually the townspeople outnumber the agriculturists very greatly in California. The blowing of the peat dust, a dry black organic soil, from the reclaimed areas in the Sacramento Delta has been such a nuisance to the City of Stockton that legislative action has been threatened which might abolish farming the reclaimed tide lands.

There are some thousand miles of dykes in the reclaiming system of this valuable land, but one proposed solution was simply to permanently flood it all. That, of course, would reduce productive food acreage which we need and of which we are getting short. In spite of our wheat surplus, the United States is not running far ahead on its food production programme—the excess is only about 7 per cent. ; so with an ordinary variation in the weather, we could quickly be suffering a squeeze, except for wheat.

* *Agricultura Experimental Station, University of California.*

There is one thing which I do not understand about the Paper. I know Dr. Chepil and Mr. Woodruff personally, and I think that in meeting the editorial policy of the F.A.O. there has been a drastic reduction of the original reports. Can we be told what are the future prospects of getting more information published of this nature ?

One phase that you, as engineers, might find worth considering is what happens to the wind at the surface. We have been talking of wind of 12 - 15 m.p.h. Is that measured 3 ins. above the ground, or at a height of 30 ft. ? There is quite a difference in average speeds at the two heights. The wind tunnel which has been used at Kansas is a box affair ; it is taken out into the field and the air is blown through it. Inside a closed channel, therefore, instead of natural gusts there is a different kind of eddy structure. In such a tunnel there are strong, small-scale eddies from all sides and from the top which impinge on the bottom.

We have had considerable discussion in California about whether we can use wind-tunnel results in dealing with problems outdoors, where there is only one surface and there is no enclosure. I believe it is Professor Batchelor, of Cambridge, who pointed out that it is inherently wrong to expect closed-channel tests to be comparable to outdoor results. There has been a change in wind-tunnel practice because of that difficulty, and now, at the Colorado State University, Dr. Cermak is building a wind tunnel 40 ft. long from the entrance to his test sections. This will give him an opportunity to develop a boundary layer 20 ins. deep and still have a free-stream zone above. Under these conditions, using small-scale models, we might make some good tests in a wind tunnel comparable with outdoors.

In our outdoor investigations of wind erosion of peat soil the essential feature is the measurement of where the bottom of the natural wind-velocity profile comes. We know very well that if we have a standard wheat or barley 30 or 40 ins. high, the wind above it acts as if it had a bottom that was well above ground, but below the top of the grain. We have, therefore, a displacement height factor. Our particular problem with dust blowing concerns the height of this equivalent zero plane. We have learned that by interplanting between the asparagus hills, with the ridges 7 ft. apart, we can change the displacement height measured above the top of the ridges from -10 cm. to $+20$ cm. In other words, the natural wind can be lifted by interplanting. That kind of concept might be useful in a great many of these studies.

MR. G. G. WHEELER*: Being concerned principally with the supply and selling of machinery, naturally one has to look at this problem more from the viewpoint of the equipment we have to choose from. There is, of course, the other problem of what the farmer will accept. My best plan is probably to quote one or two small examples, and to direct some questions to Mr. Neal and our learned friends who are present, asking what they would recommend in certain circumstances where wind erosion is a big problem.

* *Regional Sales Manager, Near East, Massey-Ferguson, Ltd.*

Many of the areas where I have responsibilities are a part of the vast semi-arid areas of the world, which are generally subject to wind erosion in one form or another. A large part of this zone is suitable for agricultural development and offers a vast potential machinery requirement.

These areas lend themselves to machinery more than, say, the humid or high rainfall areas of West Africa, because, being semi-arid and low rainfall areas, there is insufficient water to support large populations of people or livestock. Therefore to develop food production, power equipment is essential. Some success has been achieved to date in certain areas, particularly in the Sudan.

Those acquainted with the Sudan will know that the Sudan Government has allocated vast tracts of land to farmers in parcels of 1,000 acres ; this is the minimum size of farms in the development areas—some farms are in multiples of these units and must be considered large by any standard. These areas are being developed particularly for growing a local type of millet.

On the economic side, the gross return per acre is about £8, calculated at local grain price. The total cost of production, including the cost of machinery, fuel, seed and harvesting, etc., is about £6. One aspect to note is that the cost of the tractor is written off from the first year's crop, there being no income tax to control or guide depreciation rates as in this country.

This low cost of production is possible only by utilising minimum tillage methods. The ground is usually gone over twice, or three times if virgin land. Seeding is included in the last time over the land—a grain box is mounted on top of the harrow. This is all a large, fast operation—based on Western Canadian practice of wheat growing.

These Sudan areas are large clay-plains, which are not generally subject to erosion—they being virtually always covered—either by crops or weeds. Livestock are present only in relatively small numbers—there being only two or three months' rainy season with the area becoming arid and dry for the rest of the year with little domestic water available.

In making use of difficult areas, cultivation systems such as that described would not be possible if the land were light or unlevel ; in these latter circumstances erosion would present a problem necessitating the adoption of additional or more costly operations such as those listed in the Paper. These would increase the cost of production, which in all probability would exceed the gross return per acre.

My first question, therefore, is whether any economics have been worked out for the various forms of cultivation for erosion control as listed in the Paper ? Is there any hope that Governments will set up demonstration farms to explain and show methods that local people can adopt ? Certainly, even with the best farming principles, the farmer himself must show a profit at the end of the year—if inadequate control shows a better return, even if only in the short run, such methods will inevitably be adopted.

In many countries where the land is highly susceptible to wind erosion, there is little popular demand for implements that would regard as most suitable to reduce or prevent the erosion. In view of this altitude, I wonder whether, in countries where erosion is a very real problem, the F.A.O. has been able to persuade Governments to legislate for the type of implements which could be imported and sold to the farmers ?

How many years does it take to overcome the inbred conservation of farmers in their choice of types of implements ? My experience of this problem in Libya, where erosion is a big problem—in the olive groves, large trees can be buried by blown sand overnight. The majority of farmers are Italian and use equipment and implements similar to those used in their homeland.

After detailed discussion between ourselves, our agents and the F.A.O. machinery adviser for the territory, our distributor imported a selection of suitable Australian implements—judged suitable by all concerned for the type of cultivations required, size of farm and principally the land, in that they would reduce wind erosion. A large-scale demonstration was provided and full publicity given. Everyone regarded it as a wonderful idea and much favourable comment received from all quarters. Unfortunately, however, after all the trouble, all the implements were returned to the distributor's store. Everyone thought they were excellent, but nobody bought any. What is the answer to this problem ?

MR. M. E. B. NEAL : In reply, first to Professor Brooks' enquiry, the Paper which I have just read is only a very brief summary of the material which has been received to date by F.A.O. for a publication which will be put out in 1960. Acknowledgment will be given to all contributors from the many countries concerned, and the list of bibliography which will be included will name all of the workers whose work is referred to. I have a list of this bibliography, and this leaves no doubt as to the tremendous amount of work done by Dr. Chepil and his colleagues. When this Paper was first thought of, it was difficult to collect information. Now we have a great deal of detailed information coming through from Russia, Australia and Canada, and other countries, and the original estimate of 20,000 words seems inadequate.

Professor Brooks mentioned the wind height and the effectiveness of the wind tunnel. I would not attempt to argue or disagree in any way that this may be ineffective.

PROFESSOR BROOKS : I did not say " ineffective."

MR. NEAL : Let us say " inaccurate." As yet, however, it is the only thing we have. Perhaps, when the Colorado work is reported to us, we may find that there is some difference. So far, however, this is the only information we have on work with wind tunnels, and it is only right that we should give it to you.

Mr. Wheeler has asked some rather awkward questions. Most of the dry-farming practices which are being recommended to-day are also practices which are effective in controlling wind erosion. Economically, the use of these special machines in wind erosion control in America has been extremely successful. Dr. Muir referred to the sandhills of Nebraska, an area in which there are many arable farmers. Particularly in the

Horse Shoe Loop, there are some wonderful examples of how the use of these special implements can result in what we would call absolutely unfarmable land being cropped year after year, the crops being produced economically and doing extremely well.

The difficulty in the under-developed areas with which Mr. Wheeler is dealing is not so much the economics of using the implements as the mere fact that the farmers do not have the money to buy them. That is one of their big problems. They simply cannot afford to scrap their existing implements and buy new ones straight away. This is a common complaint in Tunisia. On the whole, however, there can be no doubt about the economics of these methods. Production can be considerably cheapers by using these machines, which are also the machines required for dry farming.

I was asked whether any of the countries had legislated for the right type of machines to be imported. F.A.O. has made many recommendations to individual countries concerning legislation for farm machinery. Some Governments have been advised that certain machines are not suitable for their country, and this practice is being continued. As to the length of time that it takes to overcome tradition and to change methods, this depends upon the tradition and upon the method.

Libya was quoted as an area in which there was a disappointing sales experience. In that same country, however, a modified version of the local native wooden plough is now being manufactured and is doing extremely well. The local farmers are taking to it. It is simply a modification of their existing plough, which can be used with one or two animals. It can be used for ridging, for sub-surface tillage and for " breaking-in " their initial work and for wheat planting and covering the seed. It has been used for the last three or four years, and the local farmers say that they have seen a noticeable stopping of the drifting of the sand dunes. It is a successful small tool which is within the means of the small farmer.

Dr. Muir mentioned the conflict between pastoral and arable agriculture. This is the main problem that we are up against. The Paper refers to the question of providing stock with alternative fodder to stubble and weeds. This will be done and it will be the biggest change of all. I think that in many cases it will be possible to grow annual forages instead of having the fallow following the wheat. Once this change comes about, these methods will slowly begin to take effect.

MR. R. M. CHAMBERS : Page 3 of the Paper contains the statement that—

> " The mobility, adaptability, speed of operation and size of present-day equipment has worsened matters by enabling man to put more highly-erodible land under cultivation."

It then qualifies that and retracts from the rather severe statement about machinery by saying that—

> " constant improvements in machinery and tillage methods help to control erosion."

The Gobi Desert, the Sahara, the Sind and the Western Desert in Australia were not created by mechanisation. Therefore I, as a member of the I.B.A.E., feel that that statement is not sufficiently complimentary to machinery, and I would like to ask Mr. Neal whether he is prepared to say that the machines are already available for controlling erosion and that it can be controlled by the " mobility, adaptability, speed of operation and size of present-day equipment " if people in erodible areas use it correctly.

MR. NEAL : Concerning the point about the machinery being responsible for erosion, let us be quite frank. There has been a terrific amount of erosion in the past which has not had anything to do with the use of agricultural machinery. In the majority of cases, agricultural machinery has been used in the rural areas probably for only thirty years. In some of those areas, the machine has been directly responsible for the erosion in the last thirty years. At one time, we were afraid that the introduction in these semi-arid areas of machinery suited to humid-land farming would have the same effect and that there would be dust bowls all over the world as a direct result of bringing in powered equipment to these areas. Obviously, mechanisation had nothing to do with the Gobi Desert.

Concerning the availability of the machinery to control erosion, I am at present trying to buy some, but the only place where I can buy it is Canada and the United States, and the price is very much beyond the means of the people whom I am trying to help. Possibly, English manufacturers might give some attention to this if the market is as good as Mr. Wheeler thinks. It may be that they will consider it worthwhile making these special machines and going out after that market.

In America, the number of firms making the special equipment is not very great, but it is very noticeable how the small local manufacturer has set to in order to meet this need. In Texas, Kansas and Nebraska there are small firms—small by our standards—who are producing these special machines. One of the most successful machines introduced in the United States has been the big, wide sub-surface sweep which is called the Noble blade. Mr. Noble was once a farmer in Canada working his own land, but now he is supplying blades to the whole of the 'States.

MR. WHEELER : Actually, similar types of equipment, which largely are copies of the American, are made also by a number of firms in Australia and South Africa.

MR. NEAL : The sub-surface sweep machine of this type has not gone well in Australia.

MR. WHEELER : I refer to the type which is up to 36 ins. wide.

MR. NEAL : They are not popular. The Australians are still unable to use sub-surface sweeps in many areas and are still mainly making narrow tined stump-jump equipment.

DR. P. C. J. PAYNE*: I wonder whether Mr. Neal can clear up an apparent anomaly. We read and hear that

* *Lecturer in Farm Mechanisation, Wye College, University of London.*

a turbulent wind is far worse at causing erosion than one of more streamlined flow. At the same time, we know that roughness of the surface, or trash, or anything else which is bound to cause turbulence near the surface, is good at preventing erosion. Is this apparent anomaly a question of scale ? Perhaps a 6-in. layer of turbulence is a good thing, but a really turbulent wind caused by bushes or convection currents or something of that nature is a bad thing ? Would this be the explanation : the question of scale ?

MR. NEAL : To be frank, I do not know. One obvious relation of the effect of standing stubble would be to reduce wind velocity and create turbulence. I think, however, that turbulence is created above the level of the stubble or of the vegetation, in which case it may actually assist in slowing down the velocity at ground level. The creation of a cloddy surface also has a slowing-down effect on wind velocity in the area behind the clod.

MR. N. M. GARRARD : I would like to know whether Mr. Neal can tell us anything of the results of the corrective measures in the way of large-scale contour planting now taking place in Australia.

MR. NEAL : I have quite a lot of information on the Australian practice. The contour ploughing is concerned mainly with the prevention of water erosion. Strip ploughing, ploughing in straight strips and seeding, at right angles to the wind, is being used for wind-erosion control in Australia ; but the contour ploughing is designed more for the control of water erosion that of wind erosion.

MR. E. R. FOUNTAINE : I would like to revert to the area in California referred to by Professor Brooks because it is comparable with the Fenlands in England. Although Mr. Neal has hinted that the Americans have all the answers, it is certainly obvious there that they have not put them all into practice. I think that at least 200,000 acres of fenland in that area are subject to erosion so serious that when driving through the area in the middle of the day it is sometimes necessary to use headlights on motor vehicles.

Although the inter-row planting of asparagus with barley is one answer to the engineering problem, the main problem is a social one. Most farmers are crop-sharing tenant farmers and have no long-term interest in the land.

When this trouble was first studied, shelter-belt planting was suggested as the solution. The really keen farmers tried this method, but they suffered heavily because all the soil blowing about in the area was encouraged to fall on their crops and buried the whole lot. However, the introduction of barley planting between the rows does provide a method which benefits directly the farmers who use it.

PROFESSOR BROOKS : I agree completely. It is difficult to get the practice established. Not all of the rows are cross-wise to the wind. The problem is really economic. The trouble is not so much that we have tenant farmers as the fact that it is possible to make about 10 per cent. more by growing white asparagus instead of green asparagus. The white asparagus takes more rebuilding of the hills to keep it buried. The slight extra price that can be obtained for the white asparagus makes it worthwhile to keep the earth stirred up the whole time. One answer, possibly, is to persuade the public to prefer green asparagus.

The barley does not represent a gain to the grower. The self-seeding of the barley makes the ground bad for the following year. Four or five cultivations are necessary to get rid of the volunteer barley. Strenuous efforts are now being made to find a plant which can be put in and which is not self-seeding.

MR. J. M. CHAMBERS : I should like to refer to the implement side of the problem. We, the agricultural engineers, have always considered the plough a good machine for burying crop residue plus weeds and all unwanted material which remains on the surface after harvest. We have regarded the plough as ideal for that purpose. Apparently, the plough would also be a very desirable implement from the viewpoint of soil conservation if it did not bury the crop residue.

With that specification of requirement, I am quite sure that we could design something which would prevent the burial of the crop residue, but which would give the result of ploughing in other ways. I am not promising to do anything like that. I merely say that now we know the requirement, we can do it if it is of any advantage.

A young farmer from Kansas once told me that he had seen the top soil in one of his father's fields when it was wet, too wet to walk upon, blow away in a cold, dry wind. The ground remained wet under the very thin layer of dry soil on top which, as it dried, blew away. His father usually took emergency tillage operations in the form of disking when he found that there was a blowing wind. He disked not the complete field, but strips. But on the occasion when he lost the top soil of all the ploughed land of a 40-acre field, the ground was so wet that he could not get on to it. Has Mr. Neal any experience of that type of erosion ?

MR. NEAL : I understand that in areas where wind erosion is likely to occur, the Soil Conservation Service will advise farmers that there are likely to be high winds and serious erosion during the year. People in these areas are advised to carry out emergency tillage, using specified tools. The S.C.S. now has a very big staff of 14,000 workers, with five or six men to each district. The wind-erosion districts do not comprise the whole of America, but merely special areas. Cost-sharing payments are made through the Agricultural Conservation Service offices, and I heard no complaints of delays.

Mr. Chambers spoke of wet soil and the wind drying out the top surface and blowing it off. I have not seen this happen, but I can well understand that it may happen. If it is a common occurrence, the answer might be to grass it down.

COLONEL N. BATES : Do I take it that this afternoon's Paper refers entirely to temperate-zone farming, or are we talking about tropical and sub-tropical soils also ?

MR. NEAL : Practically all the wind-erosion areas are arid or semi-arid areas which are mainly sub-tropical.

COLONEL BATES : I am thinking of areas like the Deccan, where there are long, dry periods followed by enormous deluges of rain. Can Mr. Neal make any suggestion concerning areas which have a double problem of that nature ? If people are working on wind erosion and bring up their plants and lay them across the direction of the wind, that direction may well be across the slope of the ground. When the heavy rains come afterwards, all the channels are immediately erosion courses down which the water would pour.

MR. NEAL : One soil-conservation measure cannot be regarded in isolation. We are up against this problem wherever there are these torrential rains in wind-erosion areas. The answer may be terracing, or it may be other cropping. We cannot consider these things simply one at a time. The Paper refers only to wind erosion, but it cannot be dealt with in isolation.

MR. R. M. CHAMBERS : Has any work been done on stabilising the soil surface ? I remember an article on the spraying of a starch solution on to fenland soils that were blowing, in an effort to stabilise. I wonder how this has progressed ?

MR. NEAL : It has not progressed. It has been regarded as an uneconomical venture. When tried, it gave only temporary protection. Work is, however, still being done with various " stabilising " or " binding " agents.

MR. E. S. BATES : Why only temporary protection ?

MR. NEAL : Because it was a soluble starch and it did not remain long enough on the surface to give a binding effect. It was only a mild binding starch.

MR. E. S. BATES : That is obviously a lead to methods of coagulating particles so that they cannot become windborne. Has any other attempt been made to do this ?

MR. NEAL : The attempt is being made all the time in an economic way by putting organic matter there. This is the cheaper way.

MR. R. M. CHAMBERS : If it is effective as an emergency measure even for 24 or 36 hours, in certain conditions it can obviate the damage that is caused to plants in sand-drifting conditions.

THE PRESIDENT : Mr. Neal emphasised that living or dead vegetation must be depended upon for permanent control. From that, I suggest that thought can be given by the soil scientists and by those who specialise in the development of grasses for special applications. From my own experience, I know that in the work of reclamation in Holland the Dutch Government have been able to overcome a lot of their soil-erosion problems by developing and using these special grasses.

ELECTIONS

Effected by Council at its Meeting on the 10th November, 1959.

ASSOCIATE MEMBER

Reynolds, G. L. .. .. .. Beds.

ASSOCIATES

Byerley, G.	Northumberland	Jones, B. H.	Yorks.
Byerley, W. A.	Northumberland	Sutherland, J. B.	Northumberland
Cooper, D. J.	Glos.		

GRADUATES

Barnett, E. B.	Lincs.	Sims, D. A.	Somerset
Fraser, C. B.	Warwicks.	Warner, D. A.	Mon.
Hobbs, G. R.	Surrey	Weir, J. A. C.	Devon
Pollard, R. G.	Sussex	Wood, E.	Yorks.

STUDENTS

Carpenter, J. L.	Northumberland	Jamieson, M.	Northumberland
Geeson, A.	Lincs.	Webb, D. G.	Oxon.

DEVELOPMENTS IN TRACTOR TRANSMISSION SYSTEMS AND THEIR LUBRICATION

by E. S. Bates, M.I.Mech.E., M.I.Agr.E., F.Inst.Pet.

Presented at an Open Meeting on 9th December, 1959.

THIS Paper briefly outlines the principles involved in the lubrication of the various types of gearing employed in agricultural tractors. Transmission gear oils are described and classified, and developments in the use of thinner oils in tractor transmissions embodying hydraulic lift systems are recorded. The trend towards incorporating a higher degree of torque at low speed not only in industrial applications but also in agricultural machines, produces a demand for a stall-free transmission system which depends to a large extent on the use of hydraulic oils. From this point there is a logical step towards the tractor of the future with infinitely variable speed/load characteristics derived from hydrostatic transmission.

Hydraulic oils for these systems are described, but are not, as yet, classified, except by certain equipment manufacturers' tests. As the systems themselves develop, commensurate technical improvements in hydraulic oils will be made.

Introduction

Up to and including the last war one make of British tractor alone accounted for approximately three-quarters of the U.K. tractor population.

In 1920 the engine of this tractor developed 20·8 h.p. at 1,000 r.p.m. With an all-up weight of 2,660 lb. on a 63-inch wheelbase, it was capable of pulling two furrows on heavy land. Transmission was worm and wheel final drive, and the gearbox with three forward and one reverse ratio gave maximum speeds in the gears from 1·5 to 6·75 m.p.h. In 1959 the same tractor develops 51·46 h.p. at 1,600 r.p.m. The all-up weight is now 5,072 lb. on an 80-inch wheelbase, and the tractor can pull four furrows. The final drive is changed to pinion and wheel, and the gearbox has six forward and two reverse ratios, giving maximum speed in the gears from 2·07 to 13·16 m.p.h. This tremendous improvement in the technical specification of the tractor will most certainly have been achieved without any loss of reliability since the transmission, which includes the T-structure, is expected to last the total life of the machine without replacement.

Transmission Requirements

A number of factors concerned with the usage of tractors differ so distinctly from road vehicles that they have an important effect on transmission design. To begin with, the vehicle on the road has a rolling resistance of up to 40 lb./ton, whereas a tractor off the highway regularly experiences rolling resistances from 5 to 10 times[1] higher than this figure. Furthermore, the draught or working load on the tractor is usually applied in such a way that when the clutch is disengaged the tractor will almost immediately come to a standstill. For this reason the gearbox is not fitted with synchromesh or other devices as the selection of gears is effected at a standstill and the gear trains consisting of spur gears will either be constant mesh or sliding gears. In the gearbox there will also be either bevel or spur gears used as auxiliary drives for belt, power take-off and hydraulic lift pump. Ball races and ball thrust races take the reaction loads.

In the right-angle drive and differential-drive unit which follow immediately on the output shaft from the gearbox, the right angle will almost certainly be a spiral bevel pinion and wheel with a ratio between 3·5 : 1 and 6 : 1. The majority of differential units consist of straight toothed bevel gears mating with similar gears on the axle half-shafts. A heavy-duty taper roller bearing will at one and the same time support, locate, and absorb thrust on the pinion. Manufacturing technique is most important at this point so as to ensure correct tooth alignment of pinion and wheel. The worm and wheel final drive, although containing two important advantages, (*a*) ability to step down 20 : 1 in ratio and (*b*) absorb a higher load factor than the spiral bevel, is rarely accepted nowadays by tractor designers because of the difficulty of obtaining accurate tooth machining and gear location without incurring excessive cost. In addition, there are lubrication problems specifically related to worm drives. The same applies to hypoid gearing.

By employing the spiral bevel pinion and wheel in the right angle, the final drive which follows it might step down as much as 20 : 1 in ratio. This is necessary to obtain the required gearing between engine and ground components which in an agricultural tractor might be 19·4, 34·8, 48·6, 68·4, 87·3, 132 to 1, compared with an engine of similar power in a goods vehicle where the overall gear ratios would be 6, 8·3, 12·1, 21·6, 39 to 1. This multiplication in torque combined with shock loading produces loads up to 20,000 lb. on the teeth of the spur gears in the final drive, so that material selection and choice of hardening treatment have to be right in order to ensure a satisfactory life. Mechanical design is more effective than lubricant quality at this point. Either heavy-duty ball or taper roller bearings are necessary to withstand the combined transmitted and shock loads. Whilst the outer races may be grease packed, the inner races and the final-drive gears are splash lubricated in common with the rest of the transmission. Heavy-duty ball bearings are also needed to support the inner ends of the axle half-shafts against the bending moments applied by the rear wheel extensions—*i.e.*, widening the track for row-crop work.

The designer's choice of gear ratios can either make or mar a tractor for a given application. Added to this, the number of ratios available will influence the economy and rate of working. There are two means of improving the situation, (*a*) the two-speed reduction gearbox and (*b*) the torque multiplier gearbox, either of which are additional to the conventional system just described. The first method is little more than an added complication for the driver, but the mechanical torque multiplier can be brought into action instantaneously to increase the torque at an obstacle without having the engine stall or stopping the tractor to select a lower gear ratio. It need only be used for this purpose, thus it does not add to the transmission losses, but rather tends to reduce overall fuel consumption by enabling a high gear ratio to be selected. This is a relatively new device in so far as it has been applied to agricultural tractors and may well prove to have great benefits. The lubrication of such a gearbox follows conventional practice.

MECHANICAL DRIVE

Gearing

The gear forms most common in tractor transmissions are spur, helical, bevel, spiral bevel. They are all cut from blanks of cylindrical form, and the axes of a pair of mating gears lie on the same plane. Their appearance is conveyed by Fig. 1. The worm is generated in the same way as the others, but is rarely found in tractors to-day

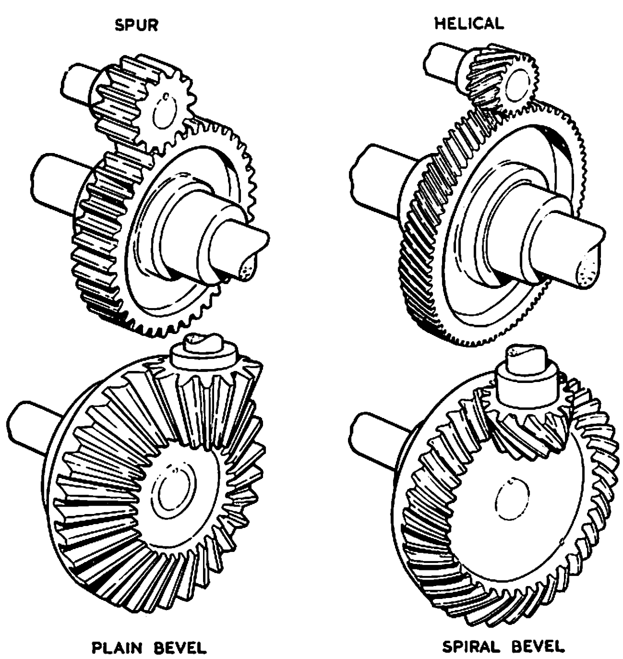


FIG.1.

because of higher manufacturing costs in relation to life expectancy. The hypoid gear differs from all the foregoing types in that the axes of the gears are on two different planes. Its special attributes for road vehicle designers are not essential, even if not a drawback, to tractor designers. The worm and the hypoid are depicted in Fig. 2.

The tooth form—*i.e.*, outline of tooth seen in section, is the same for all gears, being an involute or nearly so. The point of contact of the pitch circles of two opposing gears is known as the pitch point, and when the teeth of two opposing gears touch each other on this imaginary point they are in fact in contact on their pitch lines. The

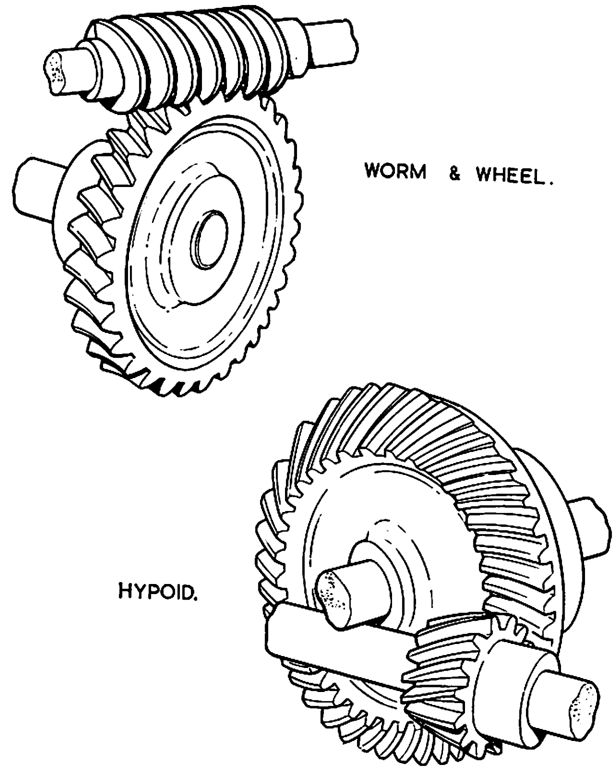


FIG. 2.

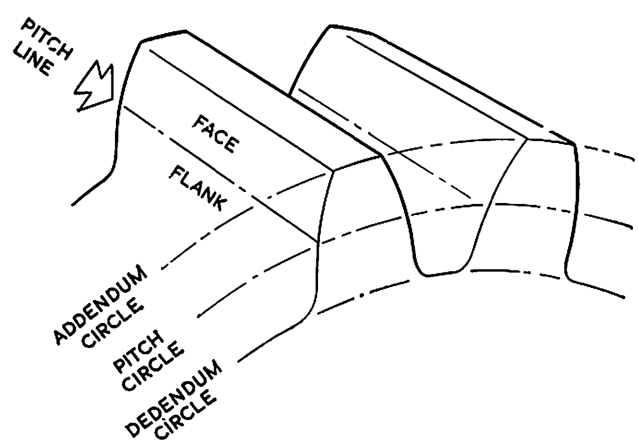


FIG.3.

face of a gear tooth lies on the addendum side of the pitch line and the flank is below it. Fig. 3.

Lubrication

As a pair of opposing teeth come into mesh, the teeth not only roll round each other like the cylinders from which they originated, but the teeth relative to each other's face and flank slide over one another until their mesh is complete and the two teeth are touching on their pitch circles. At this moment they are equivalent to cylinders and can only roll over each other, there being no sliding. Theoretically they touch all along the face of the tooth so that instead of point contact it is line contact—*i.e.*, pitch line. Theoretically the pitch line should be infinitely thin, but plastic deformation of the tooth face occurs under pressure and contact is made along a line with finite width. When the teeth progress out of mesh sliding begins once again.

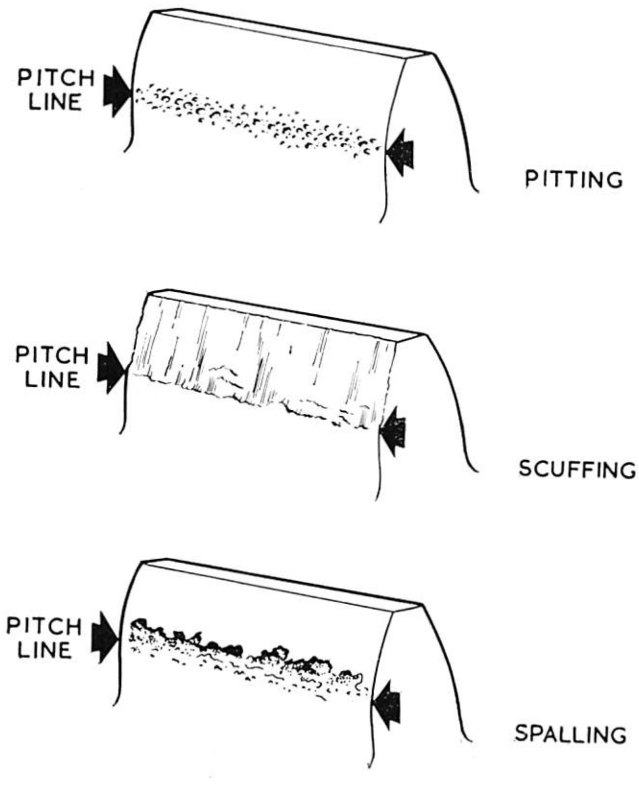


FIG. 4.

It is this sliding which promotes lubrication of gear teeth. In spur and helix gears, either straight or bevelled, the line contact sweeps across the surface of the tooth from root to tip. Wedge action induces a flow of oil into the space between the teeth. It is easier to maintain a wedge of oil under these conditions when the direction of sliding is at right angles to the line of contact. Worm and hypoid gears, due to their shape, have a direction of slide approaching or coinciding with the line of contact under which condition it becomes practically impossible to maintain a wedge of oil. Thus where hydrodynamic lubrication gives way to boundary or film lubrication it is usually necessary to fortify the mineral oil with an extreme pressure additive.

However, not only the quality of the lubricating oil, but gearbox housing design, choice of gear material, hardness and surface finish of the teeth all play their part. In a properly lubricated gear the metal surfaces are separated by a film of oil—but the thickness of the oil layer must be measured in molecules. Deformation due to strength of materials or roughness of surface finish can cause rupture of the oil film and point to point contact providing a momentary surge of temperature up to the melting point of the metals involved.

Even then no great harm may be done since initially at any rate such metal-to-metal contacts are minute in area and the loading on the tooth may subsequently be spread out over a larger area. But if conditions either of load or insufficient lubrication are so severe that this condition is aggravated to the extent where the metal flows to a considerable degree, or even breaks away in minute fragments, then a series of faults can develop. Experts can identify twenty types of tooth failure, but these can be readily grouped into :—

(*a*) Destructive pitting.
(*b*) Scoring or scuffing.
(*c*) Flaking or spalling and breakage.

It is not necessary for the tractor user to be more precise than this. To him all twenty mean some fault in either lubrication or gear material which should not have happened. Fig. 4. What we want to see is a polished tooth face and flank with the machining marks still left on the " coast " side of the tooth. Fig. 5. Pitting, however, does not always lead to destructive pitting, and in certain instances even acts as a corrective to boundary lubrication. Only an expert can predict what a pair of mildly pitted gears is going to do. Worm gears are particularly susceptible to pitting under high-temperature conditions, as may be seen from Fig. 6.

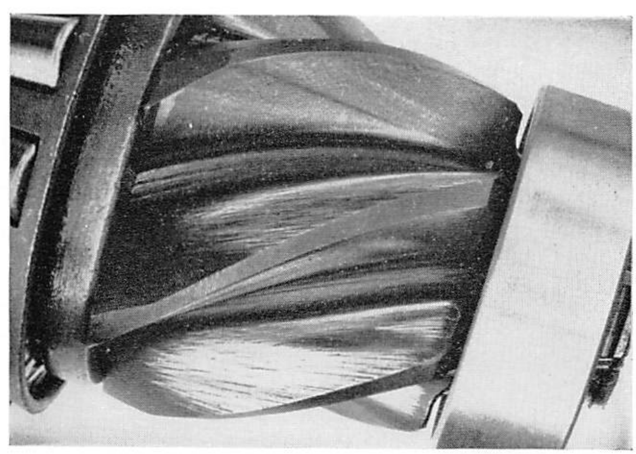


FIG. 5. Tractor test, Algeria, June 1959.

Bearings are an essential part of the transmission. The taper roller bearing supporting the spiral bevel pinion of the right-angle drive shown in Fig. 5 is sensitive both to lubricating oil quality and to design of mounting. Any movement here due either to wear of the race or fretting of the housing upsets the mating of the gears. The plain bearings of the differential drive bevel pinions are also sensitive to oil quality because of a mechanical design problem. Usually these bearings rely on adventitious lubrication by the splashing of oil, thus oil viscosity and load-carrying ability have to be nicely balanced to meet the demands of these bearings as well as the rest of the gear train. Fig. 7.

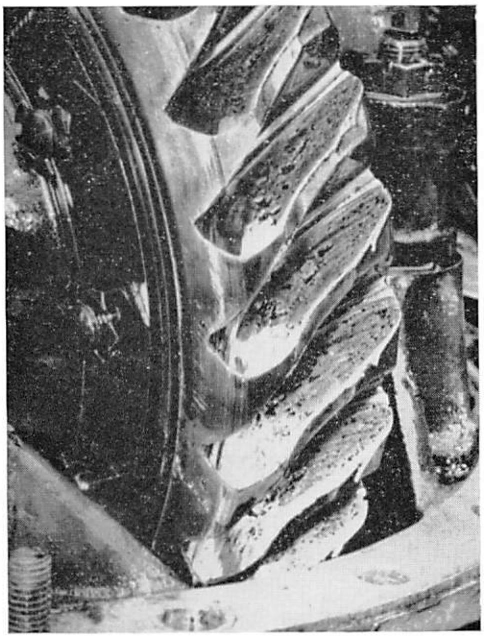


FIG. 6. Road Vehicle Test, Algeria, June 1959.

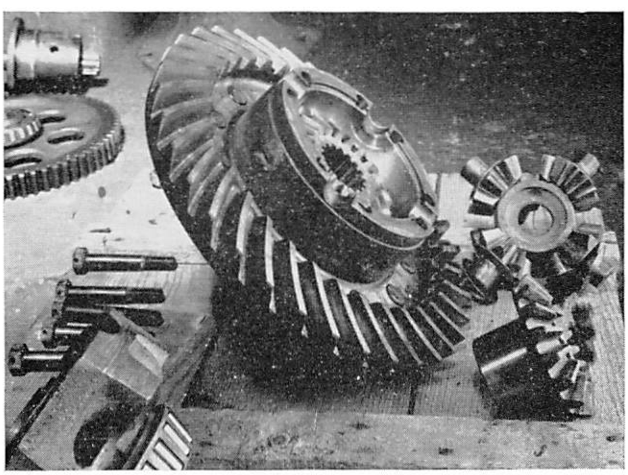


FIG. 7. Tractor Test, Algeria, June 1959.

Gear and Lubricant Testing

Both sides of industry—gear makers and oil suppliers—recognise that the problems of the one affect the solving of the problems of the other, but so far no methods of evaluation common to both have been achieved. Actual gears are often used to evaluate lubricants from the point of view of load-carrying ability, pitting and scuffing. All major tractor manufacturers—as well as aviation and automotive—have their own rigs and field tests—*e.g.* :—

(*a*) Tractor figure eight turn test—to load differential gear bearings.

(*b*) Three-point linkage test—to load hydraulic pump and gear drive.

(*c*) Shock-bump drive test—to produce gearbox tooth rattle whilst all oil suppliers possess individual designs of laboratory test rigs for evaluating film strength, etc. Time permits mentioning only the best known of these :—

(i) I.A.E. (formerly Institution of Automobile Engineers), U.K.[2]

(ii) Ryder, primarily aviation turbines, U.S.A.

(iii) F.Z.G., of the Technical High School, Munich, Germany.[3]

(iv) U.S. Army and Ministry of Supply hypoid axle tests to MIL-L-2105 specification, etc., U.S.A. and U.K.

which help to set standards in lubricating oil quality (load carrying). By testing competitors' oils in these rig and axle tests and by having reference oils " good " and " bad " in quality made freely available some measure of uniformity in quality standards is in fact achieved. To develop oils for new conditions of gearing design and/or operation recourse must be had to a variety of smaller test rigs—*e.g.*, Shell Four Ball, Timken machine, etc., which may indicate in which way the development is progressing before submitting them to one of the standard tests shown above. There is also a special taper roller bearing test rig for assessing wear in bearings similar to that supporting the pinion in a spiral bevel right-angle drive. Even then it is necessary to submit oils to practical field tests extending from 12 to 24 months' duration before being satisfied with their quality.

Choice of Lubricants

Transmission oils are blended from mineral oils which have received the same careful refining treatment accorded to high-class crankcase lubricants. Under average circumstances it is of no importance whether the oil is derived from naphthenic or paraffinic base stock. It is only important that in either case the refining treatments for extraction (of asphaltic matter) and dewaxing (as the name implies) should be neither too severe nor too mild.

Transmission lubricants are classified on a basis of viscosity and load-carrying ability.

Viscosity

The viscosity classifications are S.A.E. 75, 80, 90, 140, 250.

TABLE 1

S.A.E. 75.—15,000 S.U.S. at 0° F.
S.A.E. 80.—15,000/100,000 S.U.S. at 0° F.
Minimum viscosity at 0° F. can be waived provided viscosity at 210° F. is not below 48 S.U. secs.
S.A.E. 90.—75/120 S.U.S. at 210° F.
Maximum viscosity at 210° F. can be waived if extrapolated viscosity at 0° F. not greater than 750,000 S.U.S.
S.A.E. 140.—120/200 S.U.S. at 210° F.
S.A.E. 250.—200 S.U.S. minimum at 210° F.
Viscosity at 0° F. by extrapolation from 70° and 140° F.
S.U.S. = Saybolt Universal seconds.

The viscosity-temperature characteristics of conventional gear oils are shown in Fig. 8, which is drawn to the same scales used in a previous Paper.[5] A comparison will be of interest to the reader.

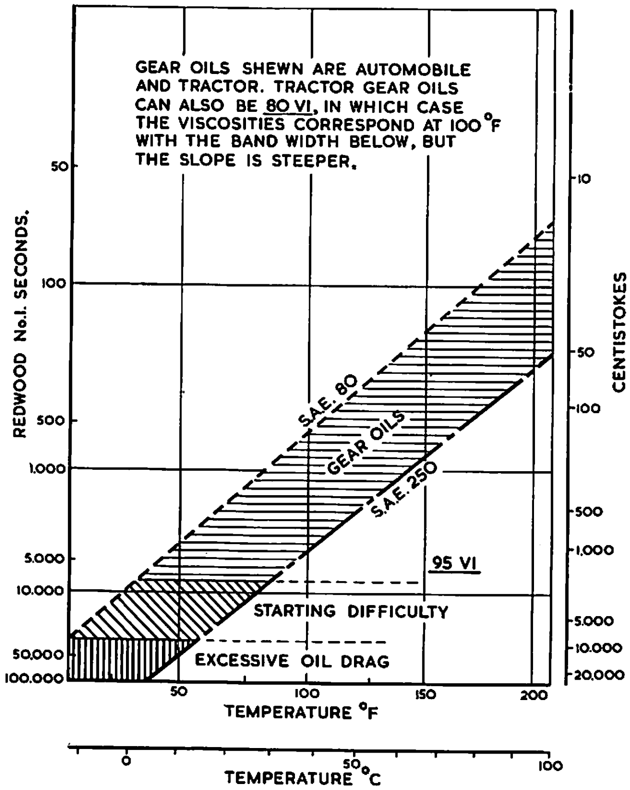


FIG. 8.

Load

The load-carrying ability is indicated by nomenclature thus :—

Type	*Classification*
Straight Transmission Oil	None
Transmission Mild E.P.	None
E.P. Transmission Oil	MIL-L-2105, etc.

E.P. means " extreme pressure " after the use of extreme-pressure additives in these oils. The E.P. oil is for use in hypoid axles, but as hypoid axles are not used in tractors it is not proposed to describe these specification tests which are live axle tests in which reference oils are used for rating. Do not use E.P. oils unless cleared for use by the tractor manufacturer, as some E.P. additives attack certain materials under certain conditions of temperature and pressure. The mild E.P. oils are classified by nomenclature only and they may not necessarily use the same additives as in the full E.P. oil, even in reduced quantity. The responsibility for choosing a mild E.P. oil should be left to the tractor manufacturer or the lubricant supplier. There is no specification live axle test for mild E.P. oils, but in terms of rig tests this oil has better load-carrying ability than a straight mineral oil—*e.g.*, results of I.A.E. Gear Test.[2] :—

S.A.E. 80 Straight Oil—scuffing load—*i.e.*	60 lb.
S.A.E. 90 Straight Oil—before oil breakdown begins	69 lb.
S.A.E. 140 Straight Oil	100 lb.
S.A.E. 90 Mild E.P.	121 lb.

Note : Test repeatability ± 7·5 lb. Average of four results inside repeatability factor.

But it is not necessary for the oil supplier to give such information, and unless the details of test are also understood the information has little value to the purchaser.

Viscosity and Load

A comparison of the straight transmission oils indicates that viscosity has some effect on load-carrying ability also. Nevertheless there is nothing to be gained by increasing viscosity too far because the gears rely on splash lubrication and a thinner oil is also a better coolant. A thinner oil also reduces transmission drag and avoids " channelling " at low temperatures.

Pour Point

Channelling describes the action of the gears cutting a path in the non-fluid oil, thus leaving the teeth exposed and unlubricated. A mineral oil loses its fluidity at a temperature known as the pour point. Generally, naphthenic stocks have a low pour point and paraffinic stocks a higher pour point. It is necessary to dewax paraffinic stocks before blending to make them suitable for most winter climates and then add pour-point depressants[4] to suit them for especially cold conditions.

Oxidation

Because transmission oils remain *in situ* for long periods and are continuously agitated in the presence of air they must resist oxidation. Oxidation not only thickens the oil, but combined with water renders the oil acidic in nature. From this corrosive pitting of gear teeth can occur. It is sufficient to give the base oil a thorough refining treatment, but in cases where high bulk temperatures—*e.g.*, above 200° F. or 90° C. are experienced an anti-oxidant additive[4] can be added with great efficacy.

Viscosity Index

Necessary refining treatment referred to above produces a majority of transmission oils with 80–95 VI.

E.P. Additives

Under circumstances where destructive pitting, scoring or scuffing are occurring additives such as VI improvers[4] and anti-oxidants are useless. The instantaneous temperatures and pressures experienced are so high that only extreme pressure additives may prove effective—if not, then redesigning is involved. But there are often incipient cases due to surface finish, for example, where a mild E.P. additive treatment is sufficient to ensure satisfactory running-in, and it is not unusual to find such oils used as factory fills. These oils do not, however, prevent wear in the accepted sense related to engine wear, so that once a transmission has been run-in and can run satisfactorily on straight mineral oil then that is the correct quality to use thereafter. The way in which an E.P. additive acts is so problematical that an explanation will not be attempted. An E.P. additive suited to hypoid gears may not prove effective in worm gears.

Oil Change Period

The quality of a transmission oil is destroyed by a combination of water, dirt and oxidation. In climates where extremes of temperatures are experienced—*e.g.*, North Africa, rapid oxidation during summer will thicken the oil sufficiently to be noticed in winter and demand an oil change. Under such circumstances an anti-oxidant additive will increase the oil change period. The products of oxidation are acidic in the presence of water and either directly attack yellow metals or mixed with dirt form a sludgy jelly which interferes with the movement of sliding gears or selectors and blocks oilways.

Generally, tractor transmission systems should be drained every 1,000 hours, or annually, when using a straight mineral transmission oil. If special circumstances dictate the use of an E.P. oil, then individual consideration will have to be given to determine the oil change period.

MULTI-PURPOSE TRACTOR OIL

1 Development

British tractor manufacturers differ from nearly all others by incorporating the hydraulic lift in the transmission system. The requirements of a fluid for a hydraulic lift system are :—

(*a*) Flow freely at low temperature.
(*b*) Be viscous enough at high temperature not to leak too easily.
(*c*) Not to attack rubber seals.
(*d*) Not to attack copper.
(*e*) Not to foam.
(*f*) Not to rust nor emulsify with water.

A high quality straight mineral transmission oil can meet these requirements of course, but there is a great deal of room left for improvement. In this context viscosity alone is much more important to the tractor user than has previously been recognised. It will be seen from Fig. 9 that at 20° F., for example, the viscosity of oil A is 4,500 Red. secs. and that of oil B is 70,000 Red. secs. Not only the difference in viscosities (65,000 Red. secs.), but the actual values are important. The tractor with thicker oil not only takes longer to do certain jobs, but even may not be capable of doing them at all until the ambient temperature increases. This is because the transmission oil is too thick to flow at an adequate rate through the valves and porting of the hydraulic lift system. Now one of the most important advantages of mechanisation is the freedom that it gives the farmer to plan work ahead and keep to a reasonable time-table. As the cost of labour goes up it is increasingly necessary for farmers to give thought to reducing working time by working at the highest practical working speed. In this matter hydraulic lift systems play a very important part. Referring again to Fig. 9, we see that at 125° F.—a common bulk oil temperature for transmissions in U.K. summertime—the viscosity of oil A is 190 Red. secs. and that of oil B 460 secs. The oil will flow readily past ports and valves in both cases, but the important thing is that oil A is not thin enough to leak past valve seats, sealing rings, etc., and so the hydraulic lift will not let-down under load. This is a very important safety feature.

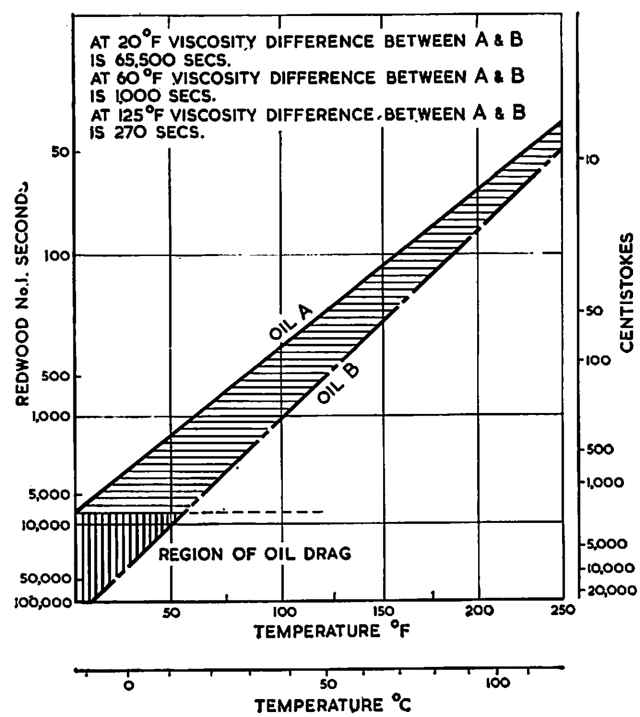


FIG.9.

Tests conducted in Sweden between 20th November, 1958, and 13th January, 1959, in three makes of trailer and front-end loader, on three grades of transmission oil, formed the basis for the following results :—

(a) Number of Tests Conducted

Tractor Makes	*Front End Loader*	*Tip Trailer*
X	194	30
Y	248	36
Z	270	36

The total number of tests was 814. A large number of repeat tests are desirable so as to average out differences in driver technique. In cold weather the time for an operation with the hydraulic lift is dependant on on engine speed, but if engine speed is too great the hydraulic circuit relief valve will lift, thus slowing down the time for the operation to be completed. This also introduces the variable of oil viscosity, which is dictated by (*a*) oil quality and (*b*) temperature. Thus a large number of results are needed to produce a statistical result.

(b) Range of Temperature

Between 20th November, 1958, and 13th January, 1959, the range of air temperatures recorded was −2° F. (−19° C) to 34° F. (+1° C.). The transmission oil temperature, however, is the significant factor. At the beginning of each test the bulk oil temperature was that of the air. During each test the oil heated up and this was recorded simultaneously with the time for an operation. The highest bulk oil temperature recorded at any time on the Swedish tests was 86° F. (+30° C.).

(c) Performance of Front-End Loader

Fig. 10 summarises the results of this work.

For example, there is 17 secs. difference in time to lower a loaded front-end loader at 20° F., and 1½ secs. difference in time at 60° F., as between oils A and B. This is due to their viscosities at these temperatures, there being a difference of 65,500 secs. Red. viscosity at 20° F., but only 1,000 secs. Red. viscosity at 60° F.

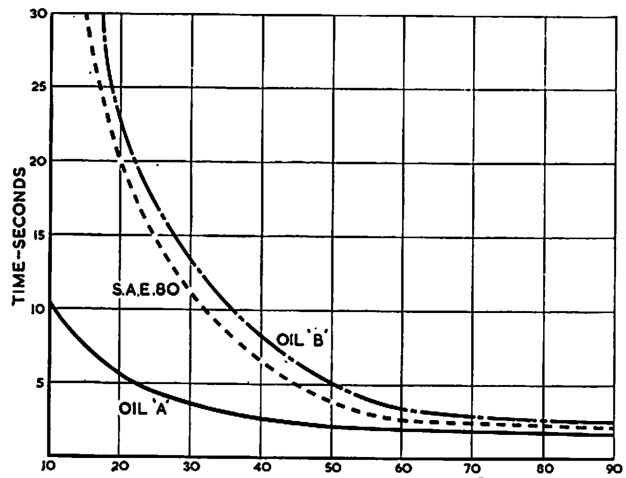


FIG. 10. LOWERING LOADED BUCKET TRACTOR TRIAL, SWEDEN.

Oil A is a multi-purpose tractor oil, S.A.E. 20W/30° V.I. 115, whilst oil B is a high-quality straight-transmission oil, S.A.E. 90, V.I. 90.

(d) Performance of Tip Trailer

Similar shaped curves to that of Fig. 10 were obtained in tractor makes X and Y. In tractor Z only marginal differences in operation time could be recorded, the reason for this being related to the design of the hydraulic ram. However, as even in tractor Z there was no significant difference in let-down times (*i.e.*, leak-by), an important safety feature of the multi-purpose oil was maintained. Results from tractor makes X and Y are as follows :—

Transmission Oil Temperature	*Time to lower trailer with Oil A*	*Oil B*
20° F.	4¾ minutes	infinity
60° F.	2 minutes	7½ minutes

(e) Transmission Efficiency

Temperature data obtained on the Swedish tests predicted advantages for multi-purpose oil in terms of transmission oil friction losses. Drawbar tests conducted by N.I.A.E. in tractor Y employing oils A and B in the transmission recorded a gain of 7% in d.b.h.p. for oil A even after one hour's operation. In both instances the engine contained a thin oil. In one engine the multi-purpose tractor oil A 20W/30, and in the other engine oil S.A.E. 20. The actual drawbar horsepower was 29·75 at 1,300 r.p.m. using oil A.

Obviously the quality of oil alters as service life is extended and one is faced with the question of whether the above performance characteristics will be retained. Extensive field tests show that these characteristics are retained even with physical changes in oil quality so long as the blend of basic oils and selection of additives was correctly made to begin with.

Due to high temperatures, transmission oils are apt to deteriorate in quality more readily in the Sahara than they do in Sweden. Eighteen tractors of six different makes have been on test for more than 12 months in Algeria using multi-purpose oil throughout the tractor, and these tests confirm the views stated above. To quote a few examples only, in one tractor the V.I. of the multi-purpose oil in the transmission was reduced from 115 to 107 in 764 hours' use. In another make of tractor the same multi-purpose oil in the transmission was reduced from 115 to 109 in 1,358 hours of use. In neither case is the let-down rate of the hydraulic lift increased nor leakage from casings increased—a very important safety feature. With transmission bulk oil temperatures exceeding 100° C. (over 212° F.) the oxidation inhibitor has been so effective that a gain in performance of the hydraulic system can be noted in wintertime. In neither case have gears deteriorated, as was shown in Figs. 5, 6 and 7. Successful results such as these have been made possible because we were prepared from the outset to gain the experience required by extensive field tests under true farming conditions.

2 Quality

As was predicted in a previous Paper, multi-purpose oils are now used in transmission and hydraulic systems as well as engines.[4] Thus they must meet the requirements of the transmission and hydraulics already outlined, and in addition the summer and winter requirements of the spark ignition and diesel engine. The diesel engine requires a heavy-duty oil.[4]

Since a multi-purpose oil is required also to stand up to borderline lubrication conditions in the gearing, the load-carrying capacity of the oil must be improved. The additive selected must not damage rubber seals nor copper piping in the hydraulic system, nor must it have any undesirable effects when used in the engine. In this respect the additive must also be " water-resistant " because some additives which might appear inert in fact break down in the presence of water and then attack on copper, etc., begins. At the same time thought must be given to choice of an anti-foam additive. Whilst the straight transmission oil does not require it, it is more than likely that the multi-purpose oil which also contains detergent, anti-oxidant and V.I. improver additives for the engine will foam at the entry to the gear pump of the hydraulic system if without anti-foam additive. For obvious reasons this is undesirable.

The foaming test as conducted on the finished oil in the laboratory is a guide only and field tests in a variety of tractor makes should be conducted to verify that foaming at the hydraulic circuit gear supply pump is not detracting from performance.

The rubber test is also conducted in the laboratory on the finished oil in accordance with a prescribed test method. Cross-sections of typical seals used by tractor manufacturers are immersed in the finished oil for 38 days at 180° F. The samples are measured for swelling, shrinking, hardening or softening. Lubricating oil from Middle East crude is particularly good in producing only slight hardening and neither swelling nor shrinking. Generally, naphthenic stocks cause swelling and paraffinic stocks shrink seals to an undesirable extent—*i.e.*, more than 6% volume.

The viscosity index will hardly alter in use in the engine thanks to improved additives available to-day, but the high rates of shear experienced in the sliding of gear teeth (up to 6,000 ft./min.) will cause loss of V.I. effect in the transmission. Although this does not matter to the gears, it is desirable to have a stable V.I. improver additive. A shear test rig in which the additive is circulated through an injection system to provide a high rate of shear is employed for this selection.

The finished oil will also be engine and gear rig tested in the laboratory before going to a field trial period of from 12 to 24 months' duration without transmission oil change. A satisfactory multi-purpose oil gives an I.A.E. gear test result of 105 lb., which places it higher in rig test value on average than the heaviest grade straight oil currently recommended.

The field trials by extending engine oil change periods will determine the efficacy of detergent, anti-oxidant, V.I. improver, load improver and anti-foam additives in combination with selected base oil blends in the engine.

HYDROKINETIC DRIVE

Although tractor and equipment manufacturers have concentrated on crop production and barn machinery, there is much other useful work to be done on the farm which is left undone because of the high cost of hand labour. Earth-moving operations in connection with soil and water conservation, the building and maintenance of roads and yards and trenching are some examples. To do this type of work it is necessary to attain sufficient traction to transmit large horsepowers at low forward speeds over a variety of soil conditions. As more knowledge of this subject is brought into practical application in tractor design[5] means will be found to assist the driver to obtain stall-free transmission for high-torque low-speed conditions, and at the same time reduce driver fatigue and expedite work by enabling gear changes to be made under constant load conditions. There is an increasing possibility that the fluid coupling and/or torque converter may find acceptance in the more powerful farm tractors of the future.

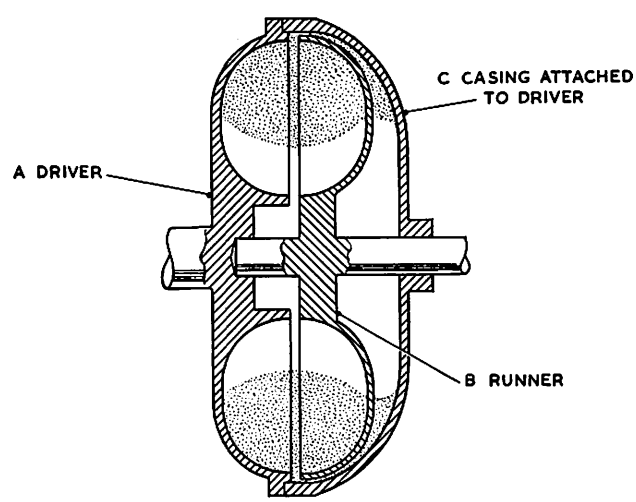
Hydraulic Couplings

If we take as our yardstick the same make of tractor with which this discussion began, the trend for increased torque even for ordinary farm duty is clearly shown in the following table :—

Year	*No. of Gears*	*Engine*	*Lb. ft. Torque at r.p.m.*
1920	3	V.O.	95 at 1,000
1947	4	V.O.	116·5 at 1,200 and 133·5 at 760
1957	6	Diesel	133 at 1,600 and 140 at 1,150
1959	6	Diesel	171·5 at 1,600 and 180 at 1,150

Another thing we learn from the table is the need to increase the number of gears (*a*) to enable the driver to use the low-speed torque without stall and (*b*) to smooth out the transmission steps between the low-ratio starting gear and the maximum speed of the tractor, so as to get good economy and handlability. With increasing torque stronger clutch components are necessary. Altogether these trends make the fluid coupling—which can now be produced in large quantities at reasonable cost—a serious competitor of the single-plate clutch and multi-stage gearbox. In its simplest form the single-stage sealed fluid coupling is partially filled (to allow for expansion) with engine oil or similar high specific-gravity light mineral oil possessing good stability. Temperatures up to 300° F. can be experienced, but as the fluid operates in a sealed atmosphere the fluid rarely requires replacement due to deterioration.

Alternatively the fluid to the coupling is supplied under pressure by an external pump, and this enables a cooler to be put in circuit. Even though temperatures may be lower in the completely filled coupling, nevertheless under adverse conditions high temperatures can be achieved, and in the presence of oxygen give rise to difficulties with sludge and varnish if a highly-refined, inhibited oil is not used. Fig. 11 is a sketch of a single-stage fluid coupling.



FLUID COUPLING

FIG. 11.

The action of the fluid coupling is for the driving member, to which is attached the casing and impeller, to rotate and fling the oil in the casing into the runner cups. As the runner cups are directly connected to the output shaft and so through the gearing to the ground components nothing will happen until the resistance against which the tractor is operating has been overcome. To do this the governor can increase or modify the engine speed corresponding to maximum torque and simultaneously the throttle opened to produce maximum torque. The impeller meanwhile is acting like a centrifugal pump, transmitting power to the runner cups by virtue of the kinetic energy of the oil in the circuit. Eventually sufficient energy is developed by the engine to overcome the resistance against it, the runner rotates and the tractor moves forward against full load.

As the efficiency of transmission is an important factor in fuel economy, it is worth noting that with correct matching of engine and coupling at maximum torque there is about 8% loss, but at a more normal operating output this loss becomes negligible—*i.e.*, 2%. See Fig. 12. The loss due to the subsequent mechanical drive must, however, be added to this.

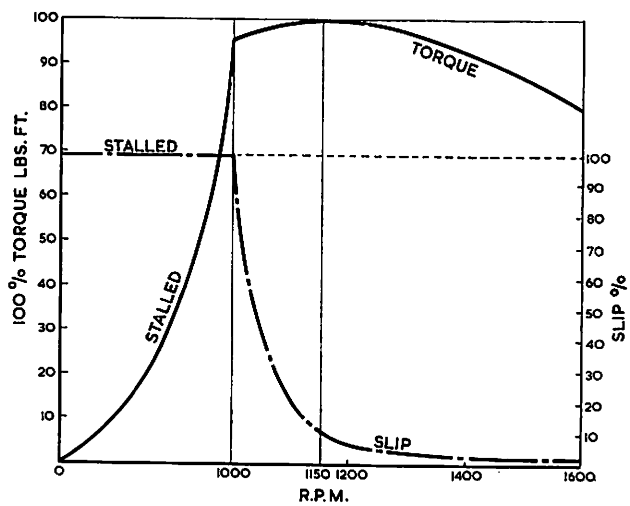
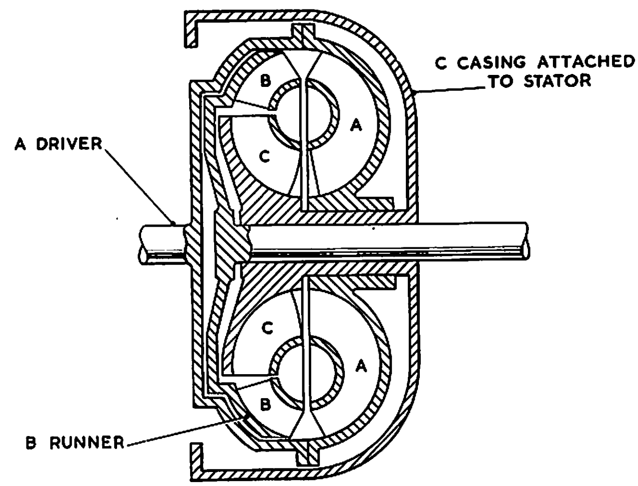


FIG.12. FLUID COUPLING PERFORMANCE

Torque Converters

In the coupling described above, the torque on the driven shaft is the same as the torque on the driver. By inserting a set of stationary vanes known as the stator the torque on the runner can be multiplied. The reaction to the torque on the impeller is taken by the engine, and if there is to be additional torque on the output shaft means must be provided for taking the reaction due to the additional torque. The stator takes this reaction, and in a single-stage converter will multiply the input torque about three times with the runner stalled. Alternatively the converter can be filled and emptied of fluid by a pump and a cooler incorporated in the circuit—as a converter runs with a fair degree of slip over part of its speed range and this wasted energy is taken out in the form of heat. The maximum transmission efficiency of a converter is about 86%, occurring at a point equal to 40% of the speed range, but as the speed of the runner approaches the speed of the impeller the efficiency falls away to zero. This is the exact opposite of the fluid coupling. Accordingly, when a speed of about 60% maximum is reached the converter action must either be cut out, and a friction clutch employed to give positive drive, or else the converter must be transformed into a fluid coupling by permitting the reaction member to free wheel. Fig. 13 is a sketch of a torque converter.



SINGLE STAGE TORQUE CONVERTER

FIG. 13.

In combination with hydrokinetic drives a variety of mechanical drives can be arranged so as to give the best form of power the job demands. The most up-to-date of these systems in the tractor world provides a slow, smooth, heavy starting torque, reserve torque to apply as needed in any gear range, and ability to operate in higher gear with converter reserve (for fuel economy). This drive, besides employing a single-stage torque converter filled by pump, has a lock-up on the drive from the engine through a single-plate dry clutch, and the gearing is selected by means of a multi-disc clutch hydraulically operated.

The torque converter is always sensitive to oil quality since surging and cavitation in circuit give rise to foaming, which is especially prevalent when a detergent engine oil is used. Ideally, an inhibited highly-refined mineral oil of very low viscosity is best suited to this application.

Hydraulic Oils

Unlike transmission and crankcase oils, there is no standard classification of hydraulic oils, nor is there any standard nomenclature to define the quality. Laboratory tests are conducted to confirm their suitability in terms of anti-foam, anti-rust, demulsability and freedom from rubber attack ; some of which tests have already been mentioned. The majority of hydraulic oils are 95–100 V.I., with one or two special brands at 140 V.I. The range of viscosities available is shown on the Fig. 14. Generally, they are produced from mineral oils, highly refined to achieve good demulsability and a high level of oxidation stability, by means of clay treatment and solvent extraction processes. Thus they are straight mineral oils for the most part, with perhaps some anti-foam additive. A satisfactory pour point is also achieved without the use of a depressant by careful selection of base stock. On account of the bearing surfaces involved, oil must be a good lubricant.

Obviously hydraulic oil for coupling or converter must be fluid down to the lowest temperature at which the tractor may be operated—say, −30° F., and it must withstand temperatures up to at least +300° F. in the converter.

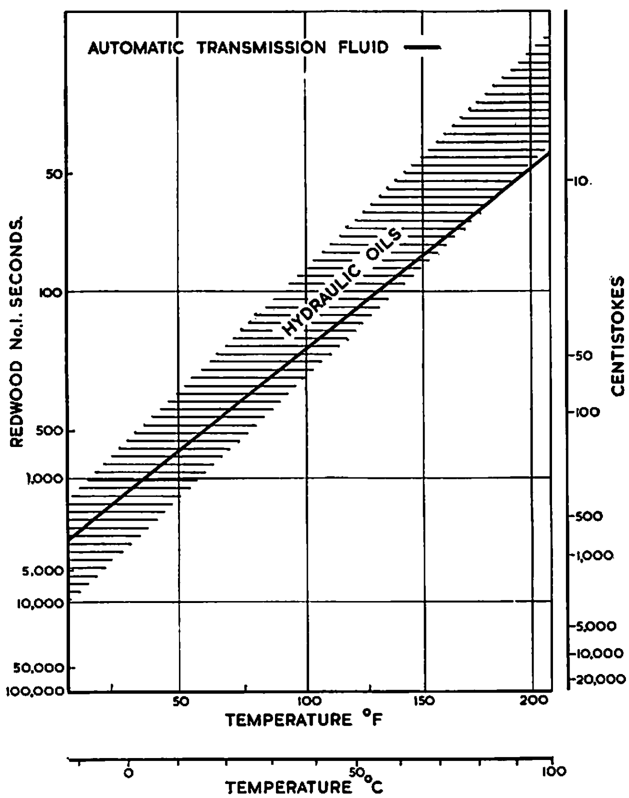


FIG. 14.

Automatic Transmission Fluids

Now that automatic transmissions are becoming standard fitments to motor cars, standardised test procedures for oils are being evolved by manufacturers, and when finalised will be accepted by oil suppliers. The specification requirements of Automatic Transmission Fluid, Type A, Suffix A, of Armour Research Foundation has wide acceptance in English-speaking countries.

This specification is designed to obtain a highly-refined mineral oil containing detergent, anti-oxidant, V.I. improver and anti-foam additives, with oiliness agent and pour-point depressant if needed. The high temperature in the presence of air in the torque converter coupled with the small capacity of oil in circulation produces the need for detergent and anti-oxidant combinations. The V.I. improver is needed to cover the temperature range quoted above as there are bearings to be lubricated also. The fact that these additives are present will also promote foaming, and as foaming produces loss of transmission efficiency an anti-foam additive is imperative. Finally, of course, the finished oil must be non-corrosive, non-rusting and not attack rubber.

By submitting the fluid to a heating test not only the efficacy of the additives in preventing precipitation and sludge is noted, but also evaporation of the fluid due to its volatility.

In addition to the laboratory tests, the transmission fluid is tested on the road for 2,000 miles and also in a car installed in a cold chamber.

It is interesting to see how the development of multi-purpose tractor oils and automatic transmission fluids have followed similar paths, in that they both rely on field tests to finally approve the combination of additives in mineral oil—many of which they have in common.

Oil Change Period

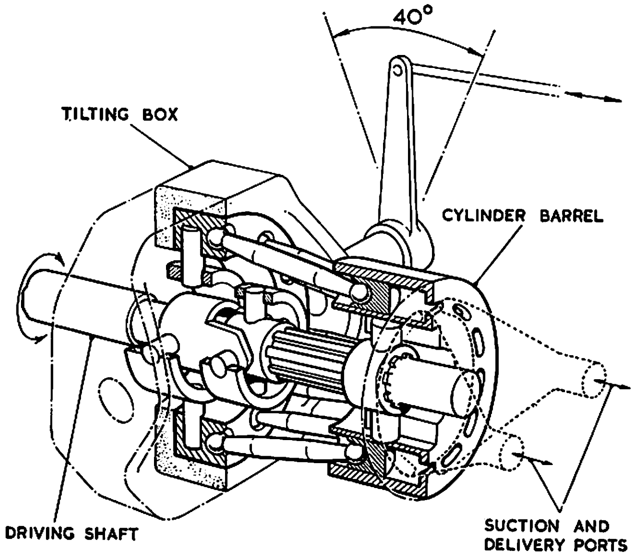
To date no definite period for oil change of automatic transmissions has been decided upon, due to the variety of designs available not having a common factor in their rate of oil oxidation. The oxidation rate varies with transmission design, oil capacity and oil quality. It will not, however, be difficult to determine oil-change period once a given design has been established in farm practice.

HYDROSTATIC DRIVE

The discussion so far has indicated immediate future developments. In the longer term the incremental effect of a depleted agricultural labour force will mean even more complex machinery being utilised to take the place of human skills. Higher wages will be demanded, thus increasing the incentive of the farmer to expedite the work of the farm with the least loss of time and in the most efficient manner. These factors in themselves will focus the attention of engineers on to hydraulics so that the more hydraulically-operated equipment is brought into use the greater the proportion of installed horsepower that will be expended through the hydraulic medium. Ultimately it becomes logical that all the power needed, including tractor propulsion, will be provided hydraulically.

Hydraulic Pumps and Motors

Hydraulic pumps of a size and weight suited to tractors are invariably high-speed units operating with a multiple number of cylinders and either cylindrical-shaped or ball-shaped pistons. Whilst both types are successful, the cylindrical-shaped piston is the one favoured by U.K. designers following satisfactory wartime service experience in ships and aircraft. The output of the pump in terms of pressure and flow is regulated by speed and variable stroke—this latter being under the control of an adjustable tilting swash plate. Fig. 15. The motor can be a machine exactly the same as the pump, but as it is a slave the aforementioned swash plate is non-operative. Due to the nature of its output, therefore, the hydrostatic drive is stepless and direct reversing (the hydrokinetic drive is not directly reversible). But in a hydrostatic drive the circuit oil is by no means static—the flow rate has to be limited (*e.g.*, 15 ft./sec.)—and turbulence avoided.[6] Turbulent flow and internal slip are the major causes for loss of transmission efficiency, which is, of course, a loss of energy, wasted in heat, and a cause for higher fuel consumption.



HYDROSTATIC SWASHPLATE PISTON PUMP.

FIG. 15.

Transmission Efficiency

The efficiency of a mechanically-geared tractor transmission operating always in the intermediate ratios can be taken as 92%. It will remain 92% from no load to full load, after the oil has warmed up. The efficiency of hydrostatic drive varies, however, from 70% at quarter load to 85% at full load, whilst that of the torque converter will lie between 85% and 92%, depending on the design of the converter and the number of mechanical gears added to it.

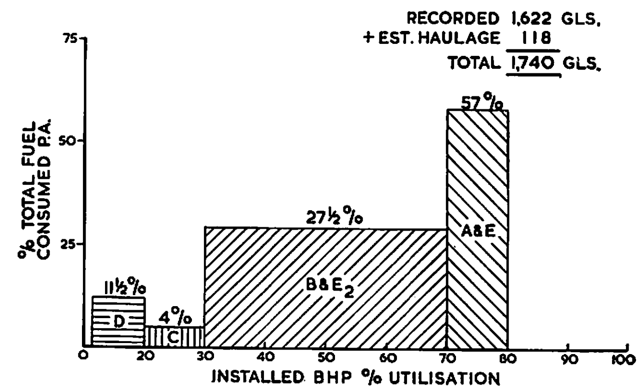
Fuel Consumption

Despite this, it is possible that the hydrostatic-drive tractor will produce a lower annual fuel bill than its competitors, so long as the output of the diesel engine can be so regulated in relation to the output of the pump that it always runs at its optimum fuel consumption. It may be argued that as a tractor is not always fully loaded[7] a difference such as 70% and 92% in transmission efficiency will wipe out the gain in engine fuel economy settings ; but this can be checked in farm practice. A survey was conducted on a 360-acre farm using a conventional diesel tractor weighing 4,755 lb. and engine developing 38 brake h.p. On the belt the engine delivered 35·7 belt h.p. and the maximum fuel consumption recorded was 2·5 gls./hr. and the minimum 0·5 gls./hr.[8] The 16 farm jobs recorded (by Bryan) can be conveniently placed in groups to which has been added haulage (based on the author's own field experiments), in order to round out the normal farming year.

Group A.—Field work, ploughing, heavy cultivation, harvesting standing crops.
Group B.—Field work, light cultivation and root crops.
Group C.—Field work, haymaking and grass cultivation.
Group D.—Haulage.
Group E_1.—Barn work, heavy.
Group E_2.—Barn work, light.

N.B.—The ratios of diesel-fuel consumption in these categories compares closely with similar work done by the author using a V.O. tractor.

Fig. 16 indicates that out of a total annual consumption of 1,740 gls. of diesel fuel, category A and E_1 work, which demand from 80% to 70% installed b.h.p., account for 57% of the total fuel consumption, although the time spent is only 42% of the annual hours. On this particular farm a hydrostatic-drive tractor would therefore be operating for the greater part of the time where its transmission efficiency is highest. Unfortunately we do not know the fuel-economy characteristics of this engine quoted in the Paper, other than that at full-power rated speed its fuel consumption is 0·485 lb./b.h.p./hr. If we accept it as the optimum and presume that this optimum



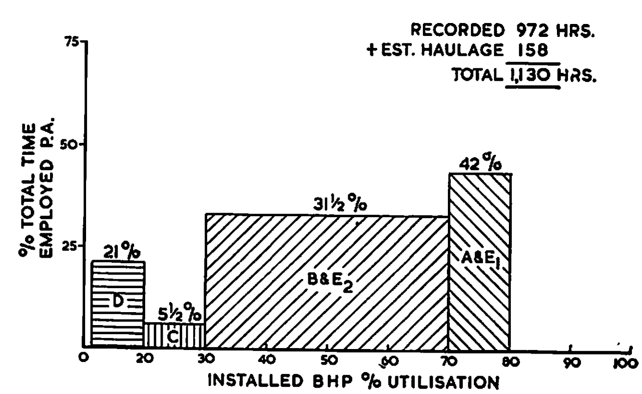


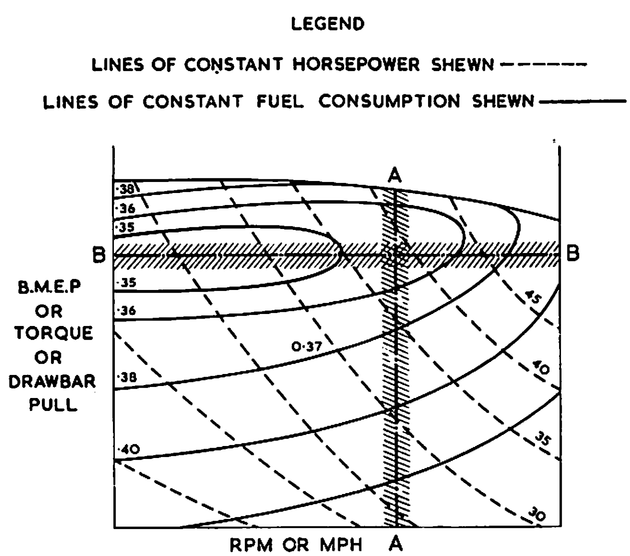
FIG. 16.

figure is maintained with falling engine speed increasing b.m.e.p. down to one-third of installed b.h.p., then so long as the required variable output from the hydrostatic transmission can be obtained by reducing the speed of the engine and maintaining b.m.e.p. fairly constant it should be possible to keep the engine at its optimum fuel setting for a wide variety of farm jobs requiring from 30% installed h.p. upwards. If we make another assumption—*i.e.*, fuel sp.gr. = 0·840, we can calculate what the fuel consumption for the hydrostatic-drive tractor on this particular farm would be, assuming various transmission efficiencies relative to the power output :—

Work Category	*Fuel used by Normal Tractor*		*Fuel used by Hydrostatic Tractor*		*At % Efficiency*
A	886	gls. recorded	870	gls. estimated	82
B	393	,,	320	,,	75
C	71	,,	(65)*	,,	70
D	198	author's estimate	(166)*	,,	67
E_1 and E_2	192	recorded	192	recorded	Belt work
Total	1,740	gls. p.a.	1,613	gls. p.a.	

* Assumed optimum consumption at low engine speed is 0·600 lb./b.h.p./hr.

If these assumptions are considered reasonable, this case shows that the hydrostatic tractor can return the same consumption as a conventional tractor. In fact, if the engine and transmission are correctly matched the hydrostatic tractor may even have a lower fuel consumption. Obviously, engines should be selected for this application which have a very good fuel-economy envelope, with minimum fuel consumption over a wide speed range, and the hydraulic-pump output control design such that it can take full advantage. This is a bigger factor than the transmission efficiency. See Fig. 17. Finally, there is the sobering thought that the stepless drive itself may produce added economies in working cost per acre, and that the overall transmission efficiencies quoted here are extremely conservative.



A = GOVERNED SPEED ECONOMY OF CONVENTIONAL TRACTOR

B = GOVERNED B.M.E.P ECONOMY PROPOSED FOR HYDROSTATIC TRACTOR

FIG. 17.

Not only fuel economy may be beneficially affected, but first cost and replacements by doing away with mechanical gearing altogether in favour of hydrostatic drive. If the pump, controls and motor can be installed cheaper than gears, then replacement life can be the same as ground components and engine. Only the T structure need carry the full life of the tractor. This should help the development of hydrostatic drive.

Lubrication

So far as is yet known, the type of oil required will be similar to those described under hydrokinetic drive. An automatic transmission fluid may prove desirable, because of its suitability for a wide range of temperatures. Much of the future oil quality requirement, however, depends on machinery design. By attention to port, orifice and valve design foaming can be minimised. The size of reservoir plays an important role in releasing foam and in resisting oxidation. The largest possible reservoir the tractor can accommodate is needed to provide a large surface area, longer time for circulation per unit quantity, and also place for a submerged pump, thus obviating the need for a booster pump. In addition, improved cooling of the oil will result, so that longer life can be expected.

CONCLUSION

The type of transmission selected constitutes one of the most important features in the design of any tractor.

The type of transmission selected by the designer constitutes an essential factor in tractor operation to obtain the maximum rate of work with minimum consumption of fuel.

Transmission design is so important in this respect that during the next five years new solutions better adapted to the requirements of farm tractors will make their appearance. Oil technology will make advances commensurate with the requirements of these new machines.

ACKNOWLEDGMENT

This Paper illustrates the importance we attach to the development of lubricating oils in successive but correlated stages—laboratory tests, engine and rig tests, field trials. The work described in the development of a multi-purpose oil for tractors was due to BP Research Centre and the Technical Services Branches of Svenska BP, Société des Petroles BP Algerie and BP Trading, Ltd. I would like to thank the Chairman and Directors of The British Petroleum Company for permission to read this Paper.

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[2] I.A.E. Gear Test—Appendix A.
[3] F.Z.G. Gear Test—Appendix B.
[4] E. S. Bates, *I.B.A.E.*, 1955 : "Technical Developments in the Lubrication of Tractors."
[5] A. Senkowski, *I.B.A.E.*, 1959 : "Ground Adhesion Problems of Wheeled Agricultural Tractors."
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APPENDIX A

Description of I.A.E. 3¼-in. Gear Machine

The I.A.E. 3¼-in. gear machine is used to assess the load-carrying capacity of lubricating oils. It consists of a test gear box and a power return gear box, coupled by torsion shafts in a power circulatory system driven by an electric motor through triple V belts. Load is applied to the spur gears of the test gear box by means of a flanged coupling built into one of the torsion shafts. Before conducting the test, one half of the flanged coupling is fitted with a weight carrier and weights. When the required load has been applied, the two halves of the coupling can be locked together and the weight carrier removed.

A dynamic loading mechanism permits the application of load to the test gears while the machine is running. The mechanism, which is used in a machined casting, is bolted to the bedplate, and replaces the torsion shaft that carries the loaded coupling. The loading torque is applied to the mechanism by means of a handcrank and worm and worm wheel assembly, which drives a pin and roller along helical slots in a hollow bush. The bush is blind at one end to receive the test gear shaft, and as the roller assembly advances along the helical slots, a twist is induced in the drive shaft so that a load is applied to the gears. The load, which is indicated on a graduated scale, can be held at any selected value by engaging a locking lever behind the hand-crank.

The test gear box is a one-piece casting in which a pair of test gears can be mounted on the ends of overhead shafts at 3¼-in. centres. Each gear is located on a spigot and is secured by six bolts. The glass-fronted cover facilitates observation of the test gears, and this can be removed to enable the test gears to be replaced. A small oil jet positioned above the gears feeds the oil to be tested between the gear teeth along a vertical line passing through the pitch point.

APPENDIX B

The F.Z.G. Test and Its Significance

Test Rig

Basically the rig is similar in design to the I.A.E. test rig, the main difference being the method of evaluation. An electric motor drives the shaft, at the far end of which the test wheel is fitted. The latter meshes with the test pinion, which in turn is connected by a shaft and the driving gear to the motor shaft, thus closing the circuit. A coupling in the second shaft is used to provide different torques in the system, varying from 0·34 mkg. for the first-load stage to 54·5 mkg. for the 12th-load stage. Various tooth profiles, materials and operating conditions can be used (see " Test Methods "), but the standard material is case-hardened steel of 800 kg./mm.² Vickers Pyramid Hardness, designated 20 MnCr5.

Tooth flanks and faces are cross-ground to a surface roughness of 0·4 microns maximum with a Maag machine, enabling surface damage to be recognised extremely well.

Standard Test A/8.3/90

Before the test begins, wheel and pinion are weighed to an accuracy of 1 mg. The letter " A " denotes that the gear pair A is used, the tooth profiles being such as to give a relatively high slide/roll ratio (as in hypoid gears, for instance).

The figure 8·3 indicates that the pitch-line speed is 8·3 m/sec. (The standard pinion speed being 2,170 r.p.m.)

The initial oil temperature is denoted by the last figure in the reference—*i.e.*, 90° C. in this case. The temperature rises during the test, but it should not exceed 140° C.

Each load stage is run at constant speed over a period of 15 minutes. The test wheel and pinion are rinsed with C_2Cl_6 and carefully weighed after each load stage before being refitted for the next run at higher torque.

The 10 horsepower three-phase driving motor runs at 3,000 r.p.m., suitable pulleys being provided so that the test gears can be run at speeds of 1,000, 2,000, 3,000, 4,000 and 6,000 r.p.m.

The test proceeds at a given speed in steps of increasing load either up to a predetermined load or to failure. The gears are made from Eh34 steel, containing 2% nickel molybdenum, carburised, hardened and ground. The dimensions are standardised to 26° 19′ pressure angle, 4·769 diametral pitch, and have 15 and 16 teeth respectively. Results are assessed on visual examination of tooth surfaces.

Evaluation of Test

The flanks are inspected and photographed. Slight scratches (depth of damage 1–2 microns), scoring (depth 3–7 microns) and scuffing (depth exceeding 3 microns) are associated with various load stages, depending on the additives present. When scoring or scuffing occurs wear suddenly rises sharply, as indicated by a graph showing weight loss in mg. in relation to the load stages and the corresponding total work transmitted.

The tangent of the curve at any point on the graph represents the specific wear in mg/PSh. A lubricant is considered to have passed a certain load stage if the curve has remained relatively flat and if the specific wear remains low. Considerable importance is ascribed to the point at which the wear curve suddenly begins to rise steeply (" limiting scuffing load " or " region of high wear "). The test results depend, of course, on the conditions chosen.

Test Methods and Their Significance

A/8·3/90. As explained above, this is the Standard Test using gear pair A with the highest slide/roll ratio. This is the test usually adopted by motor-car manufacturers in Germany.

A/16·6/90 is a special test carried out at twice the speed of Test A/8·3/90, all other conditions being the same.

T0e special test B/.... is no longer used ; it lies between tests A and C, which have been found sufficient to cover the conditions required.

Special test C/.... uses gears of a different tooth shape, giving a low slide/roll ratio. This test corresponds more to requirements of industrial transmissions.

A further special test which was developed from special test A/16·6/90 employs gears with a tooth width reduced by 1/2 so that, using the same torques, stresses are practically doubled. This test has, however, not yet been published.

APPENDIX C

The author is keenly aware that next-to-nothing has been said in this Paper about the *fundamental* problems in gear lubrication ; but space does not permit, when it is equally desirable that the results of research should be recorded. To help those interested in this subject and that of transmission design, the following reading is recommended in addition to the References [4], [5], [6] quoted.

(*a*) Institution of Mechanical Engineers, London : International Conference on Gearing, September, 1958.

(*b*) American Society of Lubrication Engineers : 1st Gear Symposium, January, 1959.

(*c*) Institute of Petroleum, London : Gear Lubrication Symposium, 1952.

(*d*) A. J. BOZZELLI : " Designing an Automatic Transmission Fluid," *S.A.E.*, January, 1959.

(*e*) Armour Research Foundation of Illinois : National Conference on Industrial Hydraulics, 1953.

(*f*) K. L. MAGEE : " A New Concept in Tractor Transmission," *S.A.E.*, September, 1958.

(*g*) S.A.E. National Farm, Construction and Industrial Machinery Meeting, Milwaukee, September, 1959, S.A.E. Transactions.

(*h*) HAMBLIN : *Journal of Agricultural Engineering Research*, Vol. 2, No. 1, 1957 : " Motive Power of the Future."

DISCUSSION

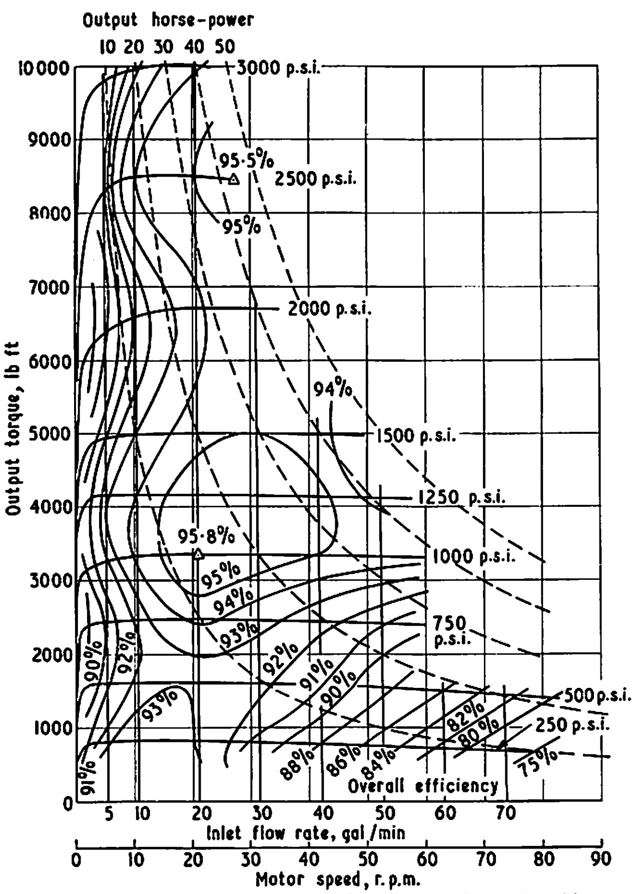
MR. H. J. HAMBLIN* : I congratulate Mr. Bates on a most interesting and useful Paper, which was extremely well timed in its presentation.

I will start the discussion by giving the author a little support in the data shown in Fig. 16. Those figures were taken from an American publication, and I had naively thought that if I looked up some British figures I would be able to " sink " the author in the discussion, so I had looked up an N.I.A.E. Farm Trials Report, and of the four groups—A & E_1, the American figure was 42 per cent. and the British figure was 41·7 per cent. ; B & E_2, the American figure was 31·5 per cent. and the British figure was 26·9 per cent. ; C, the American figure was 5·5 per cent. and the British figure was 9·2 per cent. ; and D, the American figure was 21 per cent. and the British figure 22 per cent. So in spite of the fact that Mr. Bates had used the American figures plus a little wangling to bring in the haulage which they had not got, he had obviously finished up with something which was very germane to conditions over here.

One could only agree wholeheartedly with the stark realism of the figures which the author had taken for

* Head of Mechanical Engineering Dept., N.I.A.E.

efficiencies of 60, 67 and 82. It was no good working out this sort of thing on optimistic figures, but at the same time I do not think one should accept transmission efficiencies of that order as inevitable with a hydrostatic transmission, and I have brought along a slide which showed the results of a prototype commercial motor test at the N.I.A.E. They were, of course, the efficiency curves of a motor only, whereas Mr. Bates had been dealing with a complete transmission. It would probably be agreed that starting with such a motor one ought to finish up with a transmission quite a bit better than Mr. Bates' very conservative figures (Fig. 18).



Performance of Commercial 7-cylinder Hydraulic Motor
Inlet oil temperature: 110±6°F *Viscosity: 84 centistokes

FIG. 18

Next, I want to ask Mr. Bates a question about oils for hydrostatic transmissions. I have no exact data, but my personal impression after the hot summer following some quite cold weather was that the slope of the viscosity curve of modern hydraulic fluids was really too steep even for operation in a temperate climate. It would be interesting to know whether Mr. Bates agreed that flatter viscosity curves were needed.

Lastly, I wish to take exception to Mr. Bates' final paragraph on lubrication. Mr. Bates apparently wanted a large reservoir, and my own view is that on tractors one could not afford to have a large reservoir because the space was too valuable. With hydrostatic transmission a lot of space could be saved, but it should not be thrown away again by putting in a large reservoir. My own experience shows that one could get away with an extremely small reservoir, and also I do not agree with Mr. Bates wanting to throw away the booster pump, because that would make the design of the high-speed main pump difficult. It was very difficult to get the oil into that pump without a booster. Mr. Bates' final sentence was : " In addition, improved cooling of the oil will result, so that longer life can be expected." How long a life did Mr. Bates expect to get with oils in hydrostatic transmission ? I would like to start the bidding by suggesting that the figure should be 5,000 hours between changes.

MR. T. P. GREGORY* : In the first place, I did not think the author has been nearly complimentary enough about universal oil in its solution to the farm problem of storing well. If one wanted oil in good condition, one had to store it in fairly small bulks ; on the other hand, if one wanted to buy cheaply one had to buy in large quantities, and if there were four or five varieties there was a tendency to get in a muddle and quantities of oil were not turned over at all. I have now changed to universal oil and found it most advantageous.

My second point refers to the advantage of a thinner oil. We are now engaged in making silage and the time factor is very important indeed. If it is possible to do five loads an hour cut, loaded into the trailer, dumped at the storage point and off again, then the time spent in getting a trailer up and down again is of considerable importance, and even a minute makes a lot of difference in a twelve-hour day. Thus an increase in the speed of the hydraulic tippers was of immense value, and naturally in cold weather it was tremendously helpful.

Thirdly, I wish to ask Mr. Bates about hydraulic motors. Mr. Paterson has experimented at home with a piece of machinery he is now operating with a tiny 2-h.p. motor. I am attracted by the size of the quite tiny 35-h.p. motors—about 1 ft. long, 18 ins. wide, tremendously attractive—and I would like to ask the author whether he thought one single oil in the sump of a tractor would give an external tapping which would give 35-h.p. outside the tractor, it being understood, of course, that it left enough inside to get the tractor along !

I am very interested indeed in the hydrostatic drive. If one was going to rely on the driver so to adjust his ground end engine speeds that his tractor was running at its most efficient level, one was doomed to disappointment in a major way, and I feel sure that the control lever which does everything—put the tractor engine at its optimum level and at the same time arrange the tractor speed—would have to be introduced before any advantage at all would arise from the fuel consumption point of view.

* Director, Rex Paterson Farms.

MR. C. H. HULL* : This Paper is a most timely one, particularly as the present stage was one of transition both in the approach to providing lubricants for tractors and in the development of transmissions for tractors.

I must disagree with Mr. Bates' comments on worm gearing. My parent company is primarily a gear cutting company, and they would not like to think that the manufacture of accurate tooth forms for worm wheel gearing presented great difficulty in this day and age. However, I would agree with the author's general conclusions that the primary reason for the discontinuance of the worm wheel final transmission for tractors was that its load-carrying capacity was inclined to be somewhat unpredictable because of the high position in the location of the two wheels required relevant to one another, and the problem both of initially getting them adjusted correctly and of maintaining that correct adjustment.

I should have liked to have heard a little more about the properties of oils as coolants. It was just touched on in the Paper, where reference was made to the fact that the thinner grade oils made better coolants, but my own view is, particularly relative to bearing applications, that although the oiliness and load-carrying capacity of lubricants were important, often it was equally important as a coolant, in that if one did not carry the heat away from the bearing, no matter how oily it might be, ultimately that bearing would fail.

At the present time there was a widespread introduction of lighter grade oils and oils of much higher viscosity index, which led to the ability to be able to use one grade of oil throughout the tractor. A great deal of most careful and co-operative work had taken place, both within the oil industry and with the tractor industry itself, and remarkable things had been achieved. However, I wish to sound one note of warning in case people, reading such a Paper, might think that they could use those types of oils in any tractor. Some disappointment had been experienced by people with what might be termed quite old machines, in that frequently the stage was reached where the oil seals had got very considerably worn and, in fact, what was really making the seal was an accumulation of dirt and deposits of old oil debris around the seals, and there then could arise the condition where the universal oils, which were very searching, were liable to penetrate the debris and clear it out, and there would then be a spate of oil leaks which had not previously been experienced. I would recommend that those types of oils should be used only in new and relatively new tractors.

With reference to the development of transmissions, the first type mentioned in the Paper were hydrokinetic. In my view, any transmission in which one of the first things which had to be put into the circuit was a cooler was an admission of defeat on the part of that transmission. If it had to be cooled it was wasting too much power. Of course, there were applications for tractors which were not just for routine agricultural use or even the routine earth-moving applications. There were applications where it was more important to get a stall-free smooth control of the pull or push than it was to get either speed or high efficiency or the normal engineering aspects of the application.

I have had experience during the war years with aircraft-towing tractors. When trying to tow an aircraft which was bogged down in an airfield, it was more important to be able to apply a pull to that tractor and smoothly pull the aircraft away than it was to have a high transmission efficiency while the towing was actually going on. Equally when using a tractor for winching operations, a hydrokinetic tractor enabled one to manoeuvre the load on the winch merely by varying the engine revs., and that aspect of the operation became more important than all the other engineering aspects.

My view is that relative to agricultural applications generally, and many earth-moving applications, the hydrokinetic converter had the inherent disadvantage that as the load went on or off the tractor its speed changed very appreciably, often at a most inappropriate moment.

On the question of hydrostatic transmission, I think the point brought out in the Paper could well be underlined—namely, that control was going to be one of the main problems to be solved. Up to the present there had been a quite remarkable development of plants and motors, and the transmission efficiencies which were being achieved were quite reasonable from the application aspect, but the control aspect did not appear to have been thoroughly explored as yet. There were two aspects of the matter. One was that if one gave the tractor driver a speed control with which he could either stop or rapidly change the forward transmission ratio or the reverse transmission ratio, the rate at which he could move the control if it was high meant that he was changing very rapidly from a very low ratio to a very high ratio, and the tractor could not respond anything like so rapidly, firstly because of the inertia, and secondly the load on it due to the tool it was operating, so that the driver was being given a means of building up very high shock loads and stresses in the race of the transmission.

The other aspect of the control problem was that either it had to be treated as a machine with a constant governor speed, where the forward speed of the tractor was varied with the transmission control, or the driver was left with the problem of juggling both controls to achieve the optimum, and the danger was that if he was running the engine at a high speed and only lightly using it by using a low forward speed, he was then running the engine under its most inefficient conditions. Therefore, it seemed that the controls would have to be inter-linked to ensure that the engine was running at an economical load and to ensure that comparable or better overall transmission efficiencies were being achieved, so that one got both more work per gallon of fuel burnt and less fuel used for the equivalent amount of work done.

MR. E. S. BATES : I should like to thank the opening speakers for their kind expressions of opinion about the Paper and also for the trouble which they have taken in preparing their own contributions. As each is an expert in his own right, I do not intend to take up the cudgels

* *David Brown Industries Ltd.*

against them, but would only attempt to answer the queries which they have raised.

In replying to Mr. Hamblin I shall, in fact, be answering Mr. Gregory regarding the quality of oil for external hydraulic motors. As I see the situation, the oil world has come to the threshold of a new development in producing not simply an automatic transmission fluid adapted for use in hydrostatic machines, but in finding the correct solution for the hydrostatic pump motor systems of the future. I feel confident that as that was done in terms of oil there would also be found the right type of oil for the external hydraulically-driven motor. It is essential to combine the ability to operate through a very wide range of temperatures with the ability to work at extremely high pressures through small clearances. So far as possible, an attempt has to be made to avoid the deposition from the oil of its natural constituents under extremely high pressures working through very small clearances. It is always possible to mop up undesirable deposits by the use of additives, but who is to say that simply by throwing in additives for that purpose the right thing was being done ? A great deal of development work lies ahead. Because of that, I am unable to give Mr. Hamblin an answer as to how long the oil would last.

As regards Mr. Hull's comment relating to oil as a coolant, that is a very important factor, and it is a slight hindrance that there is no up-to-date information on the rate of heat transfer of oils containing those blends of additives. When I mentioned the thin oil as being a better coolant I was thinking in another context. It is known that with regard to the rate of heat transfer there is very little difference between naphthenic stocks and paraffinic stocks, or blends of the two, but when the oil is relatively thin it is a better coolant because it poured so much more easily ; it is splashed on to the outer casing of the gearbox and therefore transmits more heat through the surrounding casing. In a much earlier Paper I quoted the temperatures in gearboxes carrying out various farming operations throughout the U.K. agricultural year on a typical farm.

MR. E. H. BOWERS* : There are one or two things in the Paper with which I do not agree. At one point the author says that the efficiency of mechanical gearing is 92 per cent. from no load to full load. I do not think that is right. There were losses which were in many cases simply proportional with r.p.m.

With regard to the hydrostatic tractor, one has been operating in my organisation on farm work, and it has been found that the fuel consumption was quite often higher than with the mechanical transmission, for the simple reason that with the hydrostatic transmission during heavy work it was possible to use the full power of the engine continuously by selecting exactly the right ratio for the job in question. With tractors and locomotives it has been found that, although on a daily basis the fuel consumption might be higher, on the basis of acreage ploughed or per ton mile it was the same or slightly lower than that of a mechanical transmission.

As far as controls were concerned, I feel quite sure the single lever control will come, but it has been found that drivers who were not particularly interested in hydrostatic transmissions tended not to run the engine any faster than necessary, simply because it made a lot of unnecessary noise and fuss, and the driver could manage quite simply with two levers, one controlling displacement and the other the engine speed.

My own view is that the hydraulic engineer does not get enough information from the oil companies in general. Hydraulic engineers know something about oils ; they know the sort of problems they are up against, and in fact many of them were evaluating oils. I do not think the S.A.E. specifications could be called specifications—in fact, I think golden syrup would probably conform to S.A.E. 40 ! There are many additives for various purposes which Mr. Bates has mentioned, and yet there seems to be little information about their incorporation in proprietary oils, or, more important, the improvements effected by them. Although the author has said there is a good deal of controversy over the type of tests which could be used to evaluate oils, surely controversial figures would be better than no figures at all. The oil companies have spent a lot of time disseminating information about hydraulic equipment ; was it possible for them to give a little more data on their products and what they were doing themselves ?

* Dowty Hydraulic Units, Ltd.

MR. PAWLING* : I feel the author's task of selecting the qualities of a universal fluid would have been eased if he had been able to draw upon some standards. Unfortunately, in the hydrostatic world these standards do not exist.

In the days of low-speed, low-pressure hydraulic equipment the problems involving the hydraulic fluid were not so great. But the introduction of a high performance hydrostatic drive which had so many advantages for agricultural and similar machinery perforce involved very high rates of shear and very high rates of pressure change in the fluid ; for example, shear rates of approximately 1,000,000 reciprocal seconds and pressure changes from 5,000 to zero p.s.i. in a few milliseconds.

The introduction of standards which had taken these factors into account would be of use not only to oil companies but to the hydraulic industry as a whole. At the moment, a lot of money and time had to be spent on the full-scale testing of every fluid. If standard tests could be introduced as preliminary coarse " screen," they would go a long way towards increasing the rate and reducing the cost of development.

* Dowty Hydraulic Units, Ltd.

MR. C. K. J. PRICE* : In the early part of his Paper, Mr. Bates has rather emphasised difficulties in the use of copper with certain oils, and I wonder whether in future the problem could be avoided by not using copper in hydraulic circuits. The suggestion might betray my ignorance in other respects, but if so I would like to know.

A further point was that in the figures for Algeria only the high viscosity oils were quoted, and I wonder whether there was any significance in that. My firm has used the type A fluids for some time and were in trouble with the viscosity falling quite steeply. It was a problem which had to be tackled. Experience on hydrostatic systems for cars was not particularly helpful, because there oil changes were asked for up to 20,000 miles, and that could be as little as a thousand hours' running, which was a long way from Mr. Hamblin's 5,000 hours.

In the part of the Paper dealing with hydrostatic transmissions not enough emphasis was placed on time on the job. It should be possible to spend less time on the job with this more versatile system.

On the question of inter-linked controls I do not think the case for it has been fully made. I believe there might still be a future in two levers, although it may be that one would be foot operated.

On the further question of sudden application of stress, if hydrostatic transmission came to full fruition it was difficult to see why there should be any anxiety about high stresses occurring.

MR. A. SENKOWSKI : Basically, what engineers would like to have is a fairly low viscosity fluid which still lubricated adequately. I know it is impossible, but when the developments had been carried on I had rather a suspicion that different oils for engines and transmissions might again prove to be advantageous.

Another point concerns the characteristic curve for the engine used by Mr. Bates, which I do not consider to be representative of really recent English engines. These diesel engines have somewhat different characteristics to those shown, and they boil down to the fact that there is an optimum speed range for optimum fuel consumption. That speed range is between two-thirds and one-half of the maximum rated speed, and within a band there is quite an amount of freedom to vary either the speed of the engine or the load with surprisingly small, if any, differences in the specific fuel consumption.

Finally, with regard to the gear testing machine I have understood that it sprayed the oil into the mesh, but that was not what I was taught in school ! On high performance gears it is usually the other way round, but the author might be fully justified, because that was a machine used for special oil tests. It would be interesting to hear Mr. Bates' comments.

MR. BATES: The point has been made by two speakers that the oil companies are not up and coming with information. I really do not know how to reply to that criticism because, of course, I am not in contact with them over that matter. I have never been approached for information, and I can only bear it in mind.

There is a new project coming forward for the examination of hydraulic oils under extreme pressure conditions, and any information which was obtained would undoubtedly be published and made available to anybody who wanted it. I can only apologise to the two gentlemen concerned if the oil industry appears to be niggardly with its information. There is no such intention. Of course, it could be that the oil industry did not have the information they wanted, which I believe was far more likely !

With regard to the S.A.E. numbers,a comment has been made about one specification, but, after all, that was a very long-standing specification and had been evolved many years previously, and it was intended quite specifically for crankcase oils and gear oils to determine their viscosity/temperature relationship and nothing else.

As regards the use of copper, speaking only in very general terms, copper can certainly be a bugbear in circuits where mineral oils are being used at relatively high temperatures and suffering oxidation in the process. Copper is a very active catalyst indeed, and in many circumstances, such as heavily-rated turbines in marine applications, a special request is made that copper should not be used for pipework.

The fact that I have only quoted the use of high viscosity index oils in Algeria has no significance whatever. I have merely been reporting work whihc has been going on in that country.

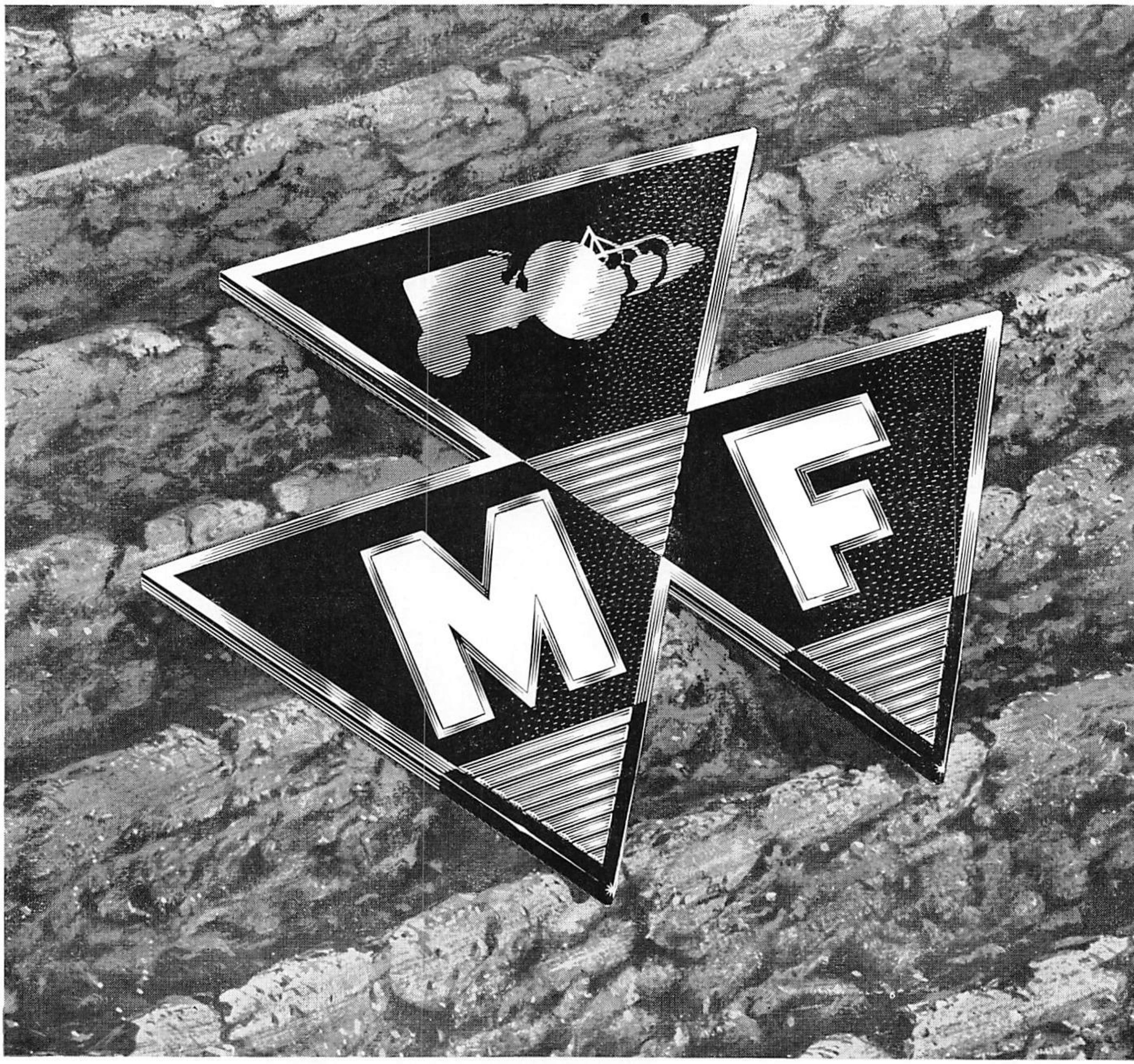
I am not in the least surprised that the viscosity index fell during use in some types of hydrostatic machines. It was obviously due to the high shear rate on the oils, and as I have said they were on the threshold of developing oils specifically for hydrostatic drives.

As regards the I.A.E. gear machine, the purpose of spraying the oil in between the teeth was in order to obtain repeatability of test.

MR. BOWERS : I wish to apologise if I have given the impression that the oil companies do not co-operate and give all the information for which they are asked. My feeling is that the industry got answers to specific questions, but there was a lack of general published information. One had to ask specific questions over a very wide field in order to get the answers because they were not readily available.

THE PRESIDENT : The time is approaching when it will be desirable to strengthen the relationship between engineers on hydraulic equipment and engineers representing the oil industry. I believe there is some scope at the present stage and I appeal to those concerned with development to bring the oil industry engineers in at the earliest possible moment. A further point which will emerge in good time is that the automotive industry has its own oil specifications. In fact, every diesel engine supplier would demand a specification which was internationally known. Surely the day is approaching when hydraulic engineers, by close co-operation with everybody concerned, will have their own oil specification. I believe when that day came they would all be making progress.

* Chief Engineer, Joseph Lucas (H. & C.E.), Ltd.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OPEN MEETINGS

LONDON

MEETINGS AT 6, QUEEN SQUARE, LONDON, W.C. 1, AT 2.15 P.M., UNLESS OTHERWISE STATED.

March 8th, 1960

PAPER : " Equipment for Milking and Milk Handling," by H. S. HALL, B.Sc., National Institute for Research in Dairying.

EAST MIDLANDS BRANCH

March 7th, 1960

(Joint Meeting with West Midlands and Yorkshire Branches)

DAY VISIT to Massey-Ferguson, Ltd., plant at Manchester, followed by a Paper, " Ground Adhesion Problems of Wheeled Agricultural Tractors," by A. SENKOWSKI, M.S.A.E., A.M.I.Mech.E., M.I.Agr.E.

March 23rd, 1960

PAPER : " Aircraft in Agriculture," by a speaker from Crop Culture (Aerial), Ltd., Isle of Wight. Meeting at 7.30 p.m. at the N.F.U. Offices, Park Street, Lincoln.

NORTHERN BRANCH

MEETINGS IN THE NORTH-EASTERN ELECTRICITY BOARD'S LECTURE THEATRE, CARLIOL HOUSE, NEWCASTLE-UPON-TYNE, AT 6.45 P.M.

February 15th, 1960

PAPER : " Agricultural Aviation, with Particular Reference to Aerial Spraying," by Dr. D. B. BLACKETT, Chief Advisory Officer, Pan Britannica Industries, Ltd., Waltham Abbey, Essex.

March 14th, 1960

ANNUAL GENERAL MEETING.

WESTERN BRANCH

March 14th, 1960

PAPER : " Grain Damage in Combining," by F. MITCHELL, B.Sc., National Institute of Agricultural Engineering. Meeting to be held at The Lackham School of Agriculture, Lacock, Wilts.

EAST ANGLIAN BRANCH

FEBRUARY 15th, 1960

OPEN MEETING in King's Lynn : " Modern Trends in Soil Cultivation."

February 24th, 1960

ONE-DAY CONFERENCE in Norwich : " Fodder Conservation."

YORKSHIRE BRANCH

March 7th, 1960

(Joint Meeting with the East Midlands and West Midlands Branches)

DAY VISIT to Massey-Ferguson, Ltd., plant at Manchester, followed by a Paper, " Ground Adhesion Problems of Wheeled Agricultural Tractors," by A. SENKOWSKI, M.S.A.E., A.M.I.Mech.E., M.I.Agr.E.

SCOTTISH BRANCH

ALL MEETINGS COMMENCE AT 7.30 P.M. UNLESS OTHERWISE STATED.

March 16th, 1960

PAPER : " Bale Drying of Hay," by G. SHEPPERSON, B.Sc.(Agric.), A.M.I.Agr.E., National Institute of Agricultural Engineering, at Glasgow.

March 17th, 1960

PAPER : " Bale Drying of Hay," by G. SHEPPERSON, B.Sc.(Agric.), A.M.I.Agr.E., National Institute of Agricultural Engineering, at Aberdeen.

WEST MIDLANDS BRANCH

March 7th, 1960

DAY VISIT to the Massey-Ferguson, Ltd., Manufacturing Plant at Manchester, followed by a Paper, " Ground Adhesion Problems of Wheeled Agricultural Tractors," by A. SENKOWSKI, M.S.A.E., A.M.I.Mech.E., M.I.Agr.E., at 10.45 a.m.

(Joint Meeting with East Midlands and Yorkshire Centres)

March 25th, 1960

ANNUAL GENERAL MEETING at 6.30 p.m. at the Hotel Leofric, Coventry, followed by the Annual Dinner at 7.30 p.m. for 8 p.m.

IN THIS ISSUE

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