Mineral Oils—	Average Specific Gravities
American Light Machinery Oil	.860—.923
American Heavy Machinery Oil	.872—.947
Russian Light Machinery Oil..	.898
Russian Heavy Machinery Oil	.907
Russian Extra Heavy Mach. Oil	.911
Scottish Shale Lubricating Oils	.865—.895

The viscosity of an oil is a measure of its molecular cohesion, and is usually expressed in terms of the time in which a given quantity will flow through a standard aperture at a measured temperature. As a large number of "standard" viscometers are in use in different countries, it is usual when stating the viscosity of an oil to state also the name of the machine the viscosity was measured in. To get over the confusion arising from the lack of a universal standard of viscosity measurement, Archbutt and Deeley have devised a method of, and have worked out a formula for, reducing the records of all viscometers to a common standard, known as the "Absolute Viscosity," but this method has not yet been adopted for commercial work.

In Great Britain "Redwood's" is the standard viscometer; in the United States "Saybolt's Viscometer" is in most common use; while on the Continent of Europe "Engler's" is the instrument with the greatest vogue.

The principal features of such instruments are: the oil container, with stoppered efflux aperture at the bottom; the water or oil jacket surrounding the container; the heating arrangements; the thermometers for the container and water jacket; and the flask for receiving the oil while testing.

When a sample of oil is to be tested, the temperature of the water or oil jacket is first raised to the required point, and the oil is raised to approximately the same temperature, and poured into the container to the height marked by the fixed indicator. The liquids should both be stirred until both are of the desired temperature, when the efflux valve is opened, and the time taken to run off 25, 50 or 100 C.C. is carefully noted. This time measured in seconds is the "viscosity" of the oil sample according to the instrument used.

Several viscometers, of which Doolittle's and Peters' are examples, give results which are based on the retardation of fan blades in motion in the oil sample.

The Coleman-Archbutt Viscometer is a glass instrument, on the same principle as those already described. Some results of its readings are set out in Table 3, which follows:—

Table 3.—Efflux Valves for 100 C.C. in Seconds.

Coleman-Archbutt Viscometer.

Oil.	Efflux time @ 60°	Densities @ 60°	Efflux time @ 100°	Densities @ 100°	Efflux time @ 150°	Densities @ 150°
Sperm Oil ..	240.4	.8783	111.7	.8637	62.1	.8455
Olive Oil ..	539.2	.9159	208.2	.9011	93.3	.8826
Rape Oil ..	615.8	.9150	242.3	.9004	111.1	.8821
Castor Oil ..			1433.0	.9473	321.2	.9234
Scotch Mineral Oil (.865)	90.7	.8683	52.0	.8533	38.2	.8347
American Spindle Oil	256.2	.8884	99.2	.8700	52.2	.8521
American Light Machinery Oil	619.5	.9008	193.0	.8867	75.5	.8690
Russian Medium Machinery Oil	1955.0	.9096	417.0	.8957	115.4	.8784
Galician Heavy Machinery Oil	695.0	.8961	205.0	.8822		

In the above table it will be noted that the viscosity falls in all cases with rise of temperature, the density falling also. The loss of density is proportional to the temperature rise, but the viscosity falls much more rapidly than the density. For the most part the mineral oil viscosity values are lower than the fatty oil values at the higher temperatures.

The viscosities of oils may be compared by means of a glass pipette, but some means must be adopted of keeping the temperature of the samples uniform during the test.

The flash point of oils is chiefly considered with respect to cylinder oils, but for safe work no ordinary lubricating oil should have a flash point that does not approximate to 350° F. The flash point of an oil may be simply ascertained by means of a small vessel, preferably of copper, about 2in. diameter by about 2in. deep, in which the oil should stand at a height of about 1½in. The vessel should be heated on a Bunsen flame, and the oil should be stirred with a thermometer. As the probable flash point of the oil is approached, a small gas flame about the size of a sweet pea seed should be passed across the upper part of the dish at short intervals, say once for every three degrees rise of temperature. When the temperature has risen to the flash point of the oil, a blue flame will flash across the surface of the oil. The temperature recorded on the thermometer should then be noted as the flash point of the oil. If the heating of the oil is continued, the blue flame will appear each time the jet is brought near its surface. Eventually a temperature will be reached at which the flame will become permanent, and the oil will burn. This temperature is the burning point or "fire test" of the oil.

The cold test of an oil is sometimes known as its setting point. It is that temperature at which an oil commences to solidify. It is best measured by first cooling the oil sample down below its setting point and then heating it, stirring the mass with a thermometer and noting the temperature at which it again becomes completely fluid. This test is of value in cold countries, in connection with locomotive lubricants; also in relation to machinery in any really cold situation anywhere.

Special instruments have been devised for ascertaining the setting points of oils. They usually consist of an ice chamber, with external insulating walls, an inner chamber for the oil container, a thermometer, and an observing window.

Table 4.—Approximate Cold Test of Oils in Degrees Fahrenheit.

Oil	Setting or Freezing Points
Castor	14° to 0°
Cotton Seed	39° to 32° and less
Lard (oil)	42° to 25°
Linseed	3° to —17°
Neatsfoot	50° to 32°
Olive	50° to 21°
Rape	28° to 10°
Sperm Oil	32°
Scotch Shale	32°
American Machinery	generally about 25°—32° rarely to 0°
Russian Machine	0°

Color tests of oils are made with both reflected and transmitted light, but they have no serious bearing on the lubricating properties of oils.

In the volatility test a weighed quantity of oil in a small shallow vessel is exposed in an oven for a fixed period, and is then re-weighed. For ordinary lubricating oils there should be a loss of not more than ½ per cent. in 24 hours at a temperature of 212°. Oil for steam cylinders tested at a temperature of 350° should not lose more than 5 per cent. in 60 hours.

Mineral oils do not decompose on evaporation, but the fixed oils do; consequently vegetable and animal oils cannot be used where gumming is likely to be a serious matter.

Greases are tested for their melting points in specially constructed instruments, but approximate results may be obtained with improvised apparatus. It is advisable to make more than one test with any particular grease. The average melting point of tallow is 114° Fahrenheit, of lard 97°, of palm oil 95°, of spermaceti 110°,and of petroleum jelly 98°. Greases are also tested for consistence.

It will be impossible to discuss here the chemical testing of lubricants. It will be sufficient to state that such tests are designed to discover the faults rather than the virtues of oils. A large number of machines have been designed for the mechanical testing of lubricants. These machines measure the temperature and friction resulting from varying conditions of speed and loading; they compare the effects of various viscosities, and the results of different systems of lubrication; and they measure the co-efficient of friction between various metals. Sir Boverton Redwood, in calling attention to the somewhat unsatisfactory results obtained with testing machines, points out that the most valuable result of the experiments made with such machines has been the demonstration of the close relation which exists between viscosity and lubricating power; from which it follows that the determination of the viscosity of an oil affords the most valuable test of lubricating qualities that we have at our disposal.

Professor Thurston thus summarises the characteristics of an efficient lubricant:—

1. Enough body or combined capillarity and viscosity to keep the surfaces of the bearing separate under maximum pressure.

2. The greatest fluidity consistent with the above.

3. The lowest possible co-efficient of friction under the conditions of actual use.

4. A maximum capacity for receiving, storing, transmitting and carrying away heat.

5. Freedom from tendency to decompose, by gumming or otherwise.

6. Entire absence of acid or other properties liable to produce injury of materials or metals with which they may be brought in contact.

7. A high temperature of vaporisation, and a low temperature of solidification.

8. Special adaptation to the conditions as to speed and pressure of rubbing surfaces.

9. Freedom from grit and from all foreign matter.

The first three of these conditions are the most important. Boiled down, they insist on just so high a viscosity as is necessary and as much fluidity as possible. The chosen viscosity, therefore, should be just sufficient to keep the opposed surfaces apart under the maximum load and temperature. In a journal under the conditions of perfect lubrication, where the load is borne entirely by the lubricant, the friction is proportional to its viscosity. The friction should also be proportional to the speed; but, as pointed out by Osborne Reynolds, that is not so, on account of the loss of viscosity that follows on the increase of temperature due to the viscous friction of the lubricant itself.

In principle there is little to add to Thurston's summary noted above. In practice it is very easy to go astray in the selection of lubricants suited to the work to be done. Factories where the consumption of lubricating oils is large, should be equipped with a good testing apparatus. In smaller factories, engineers may make approximate tests with improvised apparatus, but small consumers must rely largely on the advice of their oil suppliers.

In the ordinary factory the machinery itself is a good guide to the lubricant required. For light pressures and high speeds light oils of low viscosity are suited; for light pressures and low speeds, an oil of medium density and viscosity; for moderate speeds and pressures, and for high speeds and high pressures, heavy oils; and for high pressures and low speeds, extra heavy oils, or greases. In choosing between mineral oils and animal or vegetable oils, it must be remembered that the two latter cannot be used in any places where gumming or acidity is either harmful or dangerous. In steam engine cylinders, for instance, no animal or vegetable oil or fat should ever be used. In the "Autoclave" process the fatty oils are broken up into their constituent parts by the action of steam under a pressure of 125 lbs. per square inch. The conditions, therefore, that obtain in the ordinary steam cylinder, are such as will cause the formation of fatty acids, whenever fatty oils are introduced as lubricants. In view of this fact, the far too common practice of using tallow as a cylinder lubricant is most surprising. Formerly the cylinders of all South Australian locomotives were lubricated in this way, and, as a result, it was possible to cut away parts of the cylinder faces by means of an ordinary penknife. Speaking of prevention of corrosion of boilers, L. E. Bertin says (in "Marine Boilers"): "The use of tallow, or vegetable oils for the lubrication of the cylinders should be strictly prohibited; none but mineral oils should be allowed, and even of these only the absolutely necessary minimum should be permitted." Elsewhere, on the subject of priming, he draws attention to the danger following on the introduction into the feed water of fatty acids from the cylinder lubricants.

For steam cylinder lubrication, the chosen oil should have a high viscosity at 100° Fahrenheit, and should have a vaporising temperature of well over 300°, and a flash point of not less than 350°.

For internal combustion cylinders, the practice is to use a compounded oil containing about 10 per cent. of a fixed oil: the mixture having a viscosity approximating to that of rape oil at 60° Fahr. In a semi-Diesel engine, whose makers advised that only olive oil should be used for the cylinder, the author has had excellent results from the use of a pure mineral oil.

In the crank-chambers of motor cars, the best results are obtained from an oil, preferably a high-class mineral oil, that will not easily dissociate under the influence of heat, of high flash point and good viscosity, and which, at the same time, is capable of being completely consumed in the combustion chamber.

In cases where the oil is constantly being filtered and recirculated, the presence of fixed oils in the lubricant is out of the question, owing to the accumulation of the products of decomposition.

In many bearings the use of plastic lubricants is necessary, but in cases where the horse-power available was only just sufficient to drive the plant, factories have been stopped as a result of the general substitution of grease for fluid lubrication. A good grease, however, is an economical lubricant at low speeds. As compared with oil, the resistance to shear of grease is considerable and, generally speaking, it should not be used for anything but low speed lubrication, or where oil can not be employed to advantage.

Solid lubricants are not without value, and such substances as soapstone, mica, French chalk, sulphur and graphite are often added to greases.

Graphite is the most valuable of solid lubricants. It is usually applied in a state of suspension, in oil; but it has been supplied in a dry state by inhalation into internal combustion cylinders. The office of graphite is not so much to lubricate as to reduce friction by increasing the smoothness of bearing surfaces—that is, by filling up the minute depressions that always exist on such surfaces. Ordinary graphite is apt to settle out of its fluid carrier, and causes trouble by accumulating in bearings, also by quenching the spark in oil engines.

Deflocculated graphite, as discovered by Dr. Acheson, has the useful property of remaining suspended in oil or water for an indefinite period. In a bearing under a pressure of 70 lbs. per square inch, and lubricated with aqueous deflocculated graphite, a co-efficient of friction of .01 was maintained over an extended trial. Its discoverer, experimenting with a Panhard car, claimed that the addition of his graphite to the cylinder oil reduced the oil consumption from 1 gallon per 200 miles to 1 gallon per 750 miles.

Further experiments with this lubricant may be looked forward to with interest, especially as it promises to assist in the solution of the most difficult of all lubricating problems, the lubrication of the cylinders of internal combustion engines.

Bibliography:—

(a) *Lubrication and Lubricants*—Archbutt and Deeley.

(b) *Lubricating Oils, Fats and Greases*—Hurst.

(c) *Petroleum and its Products*—Sir Boverton Redwood.

Discussion.

MR. A. W. TOURNAY-HINDE (in proposing a vote of thanks to the lecturer) said: I feel sure that all of us have listened with very much interest indeed to Mr. McEwin's paper on lubrication. Lubrication, although it is a subject to which every engineer has, necessarily, to give attention, is probably one of the most vexed and most discussed subjects amongst us. So far as my know-