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ENCLOSURE (B) 30

STUDIES ON METHODS OF TESTING THE OILINESS OF LUBRICATING OIL

by

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LIST OF TABLES AND ILLUSTRATIONS

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SUMMARY

The authors constructed several oiliness testers, and measured the oiliness of various kinds of mineral and fatty oil with the object to establish a simple method of testing oiliness.

1. The machine constructed were two special four ball oiliness testers and a pendulum oiliness tester, and the latter was the most suitable for routine testing.

2. The numerical values of the coefficients of friction of the same lubricating oil obtained from different machines were not the same, but from the relations between the values obtained by each machine, we could determine the oiliness of a sample oil by one of the machines.

3. In the case of well refined mineral oils there was a rough parallelism between the coefficients of friction and their viscosities.

4. The coefficients of friction of fatty oils had intimate relations to their acid values as well as their viscosities.

I INTRODUCTION

In the zone fluid film lubrication, the most effective property of oil in lubrication is the viscosity and in the boundary condition, it is the oiliness of oil. The lubrication conditions of the aero engines and other machines had become more and more severe, especially in regard to the master rod bearing, and the oiliness of lubricating oil had become the most important factor. Therefore, it was necessary to establish a simple and proper method of determining it. Many reports about various types of oiliness testers are found in the literature — static, and kinetic friction tester, point and line contact type, for example, Deeley machine, Ref. (1) Timken machine, Ref. (2) four ball machine, Ref. (3) pendulum machine, Ref. (4). From 1933 to 1934 we constructed some special types of oiliness tester referring to the literature with the object of obtaining the most simple and proper oiliness tester.

II DETAILED DESCRIPTIONS

A. The Test Apparatus and Test Procedure

1. Four Ball Tester A. It consists of three steel balls (dia ½ inch) tightly packed in a oil cup and a rollable ball (dia ½ inch) on the former, such as the one constructed first by O. Boeck with the object of testing high pressure lubricants. The schematic view of the apparatus is shown in Figure 1(B)30.

B, C, D. are packed balls, A is a rollable ball to which a weight carrying body E is attached, H is a mechanical device to circulate the oil, J is a heater and G is a hook for direct measurement of the frictional resistance.

a. Direct measurement of the frictional resistance: The lower part of the apparatus is revolved by a motor at a constant velocity, and the friction is measured with a spring balance or by means of a string balance device shown in Figure 2(B)30, the calculation principle is as follows:

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From the balance of force at point A

$$\frac{W}{\sin\theta} = \frac{a}{\sin(\pi-\frac{\theta}{2})}; \text{ or } a = \frac{W\sin(\pi-\frac{\theta}{2})}{\sin\theta} = \frac{W\sin\frac{\theta}{2}}{\sin\theta} \quad (1)$$

From the balance of force at point B

$$f = a\sin\frac{\theta}{2} \quad (2)$$

From (1), (2)

$$f = \frac{W\sin^2\frac{\theta}{2}}{\sin\theta} = \frac{W\sin^2\frac{\theta}{2}}{2\sin\frac{\theta}{2}\cos\frac{\theta}{2}} = \frac{W}{2}\tan\frac{\theta}{2} = \frac{W}{2}\frac{\cdot}{\sqrt{n^2-l^2}} \quad (3)$$

f is the force of friction, W is the weight.

b. Measurement of the coefficient of friction by means of damped revolution (deceleration method): The lower part of the apparatus is revolved by a motor at gradually increasing velocity, the upper part is revolved with the lower one, and the latter is stopped, then the former begins to revolve at a decreasing velocity. The revolution velocity (deceleration ratio) is measured by means of a stroboscopic device.

The calculation principle is as follows:

It is assumed that

- f : the force of friction,
- γ : the distance between the point of action of the friction force and the revolution axis,
- I : the moment of inertia of the revolving body,
- ω : the angular velocity,
- t : the time of revolution.

$$f \cdot \gamma = I\frac{d\omega}{dt} \quad (4)$$

If n is assumed to be the revolutions per unit time,

$$f \cdot \gamma = 2\pi I\frac{dn}{dt} \quad (5)$$

Assume f' to be the total pressure at the point of contact and the coefficient of friction, and then

$$f = \mu f \quad (6)$$

If θ is assumed to be the angle between the straight line, connecting the center of the upper ball and that of one of the lower balls, and a plane rectangular to the revolution axis, and M to be the mass of the upper body, g to be gravity constant.

$$f' = \frac{Mg}{\sin\theta} \quad (7)$$

from (5), (6), (7)

$$\mu = \frac{2\pi \sin\theta}{Mg\gamma}\frac{dn}{dt} \quad \text{............(8)}$$

or

$$= \frac{2\pi \sin\theta}{Mg\gamma} \cdot \frac{n_1 - n_2}{t_1 - t_2} \quad \text{.....(9)}$$

2. <u>Four Ball Tester B.</u> The construction of the main parts is the same as the four ball tester A, but the weight is applied by means of a lever and it is suited for the measurement of so-called film rupture strength. The schematic view of the apparatus is shown in Figure 3(B)30.

a. <u>Direct measurement or the coefficient of friction</u>: The plug K and the plate L are removed, the upper part is revolved, and weight F is applied, the force of friction is measured by means of a hook G and a spring balance. H is a ball bearing device to decrease undesirable friction.

b. <u>Measurement of the film rupture strength</u>: The plug K and the plate L are placed in position, and the upper part is revolved and weight F is gradually increased until the film rupture occurs.

3. <u>Pendulum Oiliness Tester</u>. The pendulum oiliness tester is one of the most simple of the various friction testers and T. E. Stanton,[5] J. W. Donaldson[5] used this. We made some devices for shortening the pendulum stem, as shown in Figure 4(B)30. The upper test pieces were steel balls (dia. ½ inch), and the lower was steel, white metal, or Cu-Pb alloy. The calculation method was mathematically derived by S. Kyropoulos[6] and is as follows:

$$\frac{\mu}{1+\mu^2} = \frac{A\cos\theta}{\gamma} \cdot \frac{\cos\alpha_{\gamma+1} - \cos\alpha_\gamma}{\frac{3}{2}(\alpha_{\gamma+1} + \alpha_\gamma) + \frac{3}{4}\sin 2\alpha_{\gamma+1} - \frac{1}{4}\sin 2\alpha_\gamma - 2\cos\alpha_\gamma \sin\alpha_{\gamma+1}}$$

μ: the coefficient of friction

a, γ, θ: shown in Figure 5(B)30.

$\alpha_\gamma \cdot \alpha_{\gamma+1}$: the amplitude of γth, γ+1th oscillations.

In the present experiment, $\alpha_\gamma - \alpha_{\gamma+1}$ 0.0135 radian, and the following equation was practically satisfactory:

$$\mu = 4.90 \times (\alpha_\gamma - \alpha_{\gamma+1})$$

B. <u>Results</u>:

We measured the oiliness of various kinds of mineral and fatty oils. Some physical and chemical properties and the test results are summarized in Table I(B)30.

The measuring conditions are shown in Table II(B)30. The following general views could be deduced, from the above experiment.

1. <u>Relation Between Viscosity and Oiliness</u>: The graphical representations of the relations between the oiliness (Coef. of friction and film rupture strength) and the viscosity are given in Figure 6

(B)30, 7(B)30, and 8(B)30. In the case of mineral oils, the relation between oiliness and the viscosity was roughly represented as a curve, and that of fatty oils of low acid value was also roughly on a curve lying in the zone of higher oiliness (Figure 7(B)30.). The fatty oils of high acid value were far better in oiliness, and were plotted but they did not fall on the curve for low-acid fatty oils. If we get these curves, the oiliness of any oil will be estimated from the displacement of the point for the oil from the curve. An Average of 3 or 4 determination would be required.

2. Comparison of the Data Obtained From Each Machine: The numerical values of the coefficient of friction of the same lubricating oil obtained from different machines (or from different procedures, at different conditions, with different test pieces) were not the same, but a rough parallel relation was present as shown in Figure 7(B)30 and 8(B)30, that is to say, an oil which had good oiliness by one measurement procedure also had good result in another test procedure.

3. Comparison With The Data Obtained From Deeley Machine: The data obtained from each machine had a parallel relation with that obtained from Deeley machine.(cf. Table I(B)30.)

III. CONCLUSIONS

There was a relation between the coefficients of friction obtained from various oiliness testers.

To determine the oiliness of a lubricant, only one of the machines need be used.

For simple measurement, the pendulum machine is the most desirable, but for the testing of high pressure lubricants, the four ball tester B. must be used.

References

(1) Archbutl, L., and Deeley, R. M. Lubrication and lubricants. London: Griffin, 1900;451

(2) Kadmer E. H. Schmierstoffe u. Machinenschimierung (1940) 306 etc.

(3) Boelarge G. O. Engg. (1933)(1937): Beeck O. Proc. Roy. Soc. 177 190 (1941)

(4) Stanton T. E. The Engineer 135 (1923): Donaldson J. W. T. Soc. Chem. Ind. 52 (1933)

(5) Stanton T. E. The Engineer 135 (1923): Donaldson J. W. T. Soc. Chem. Ind. 52 (1933) 151

(6) Kyropoulos S, Rev. Sci. Instr. 8 (1937) 151

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Table I(B)30
SUMMARY OF THE TEST RESULTS

No.	Four Ball Tester B			Pendulum Tester									Deeley Machine		
				Steel on Steel			Steel on Brass			Steel on Copper					
	Temp.*	Viscosity (S.U.S.)	Film Rupture Strength (kg)	Temp.* (°C)	Viscosity (S.U.S.)	Kinetic Friction Coef.	Temp.* (°C)	Viscosity (S.U.S.)	Kinetic Friction Coef.	Temp.* (°C)	Viscosity (S.U.S.)	Kinetic Friction Coef.	Temp.* (°C)	Viscosity (S.U.S.)	Static Friction Coef.
1	24	[illegible]	15	23	5000	0.086	21	6000	0.082	21	6000	0.064	25	4400	0.096
2	24	[illegible]	13	24.5	5900	0.092	22	2250	0.087	22	2250	0.083	25	1550	0.097
3	22	[illegible]	9	24	1100	0.103	26	990	0.101	26	950	0.098	24.1	1100	0.118
4	24	[illegible]	7	24	450	0.115	22	525	0.111	22	525	0.109	25	430	0.121
5	24	[illegible]	6	20	105	0.179	25	92	0.124	26	92	0.116	24	94	0.135
6	23	[illegible]	20	19	9900	0.062	26	440	0.052	24	3350	0.046	25	3600	0.096
7	[illegible]	[illegible]	18	28	3600	0.070							17.5		0.080
8	[illegible]	[illegible]	13 29	21	470	0.080	24	418	0.079	24	418	0.072	24.5 25.0	403 400	0.111 0.109
9	[illegible]	[illegible]	11 30	21	[illegible]	0.079	24	338	0.073	24	338	0.065	23.2 30	342 265	0.106
10	[illegible]	[illegible]	[illegible]	24.5	[illegible]	0.084							17.4 25.0	345 262	0.066 0.111
11	[illegible]	[illegible]	[illegible]	24	277	0.084							15.5 25.0	312 230	0.070 0.115
12	[illegible]	[illegible]	30	21.5	215	0.079							16.3 25.0	280 210	0.061 0.112

Table I(B)30 (Con't)

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Table I(B)30 (Con't)
SUMMARY OF THE TEST RESULTS

No.	Samples	Viscosity (S.U.S.) 100°F	Viscosity (S.U.S.) 210°F	Viscosity index	Acid Value	Four Ball Tester A Direct Method: Temp.* (°C)	Four Ball Tester A Direct Method: Viscosity (S.U.S.)	Four Ball Tester A Direct Method: Kinetic Friction Coef.	Four Ball Tester A Revolution Method: Temp.* (°C)	Four Ball Tester A Revolution Method: Viscosity (S.U.S.)	Four Ball Tester A Revolution Method: Kinetic Friction Coef.
1	Aeroengine oil #120	1468.5	111.4	99.4		23	5000	0.101	27	3800	0.091
2	Aeroengine oil #80	781.0	81.0	95.5		24	1400	0.105	27	1550	0.095
3	Turbine oil	414.4	50.8	99.3		24	1100	0.110	28	820	0.097
4	Mobile oil	210.6	45.8	77.5		24	450	0.121	28	360	0.107
5	Spindle oil	67.0	37.8	152.6		24	94	0.140	28	85	0.117
6	Castor oil	1271.4	100.6	95.3	0	25	3600	0.078	27	3200	0.073
7	Polymerized Soya bean oil	1994.0	219.0	132.8	3.67				28	2600	0.069
8	Rape seed oil	242.4	60.8	153.0	0	24	419	0.092	28	360	0.087
9	Camellia oil	200.6	55.6	155.3	3.53	24	338	0.089	27	300	0.068
10	Cotton seed oil	167.4	53.0	163.2	0.34	28	228	0.091	29.5	122	0.101
11	Shark liver oil	149.4	51.7	161.2	4.28	29	200	0.089	28	210	0.072
12	Cod liver oil	139.7	51.4	169.3	4.48	28	190	0.089	29.5	220	0.073

*No additional heat applie

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Table II(B)30
CONDITIONS FOR MEASURING OILINESS
FOUR BALL TESTER

	Film rupture strength (Tester B)	Direct friction Measurement (Tester A)	Damped Oscillation method (Tester A)	Deeley Machine
Load (kg)	0 – 400	1.0077	1.0077	0.452
Sliding speed m/sec.	0.1226	0.0072	0.034	0.0362
Ambient Temperature	Room	Room	Room	Room
Test Temperature	Not controlled	Not controlled	Not controlled	Not contro

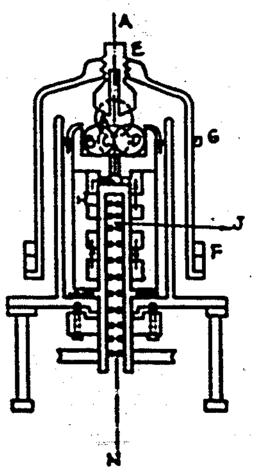

Figure 1(B)30
FOUR BALL TESTER A.

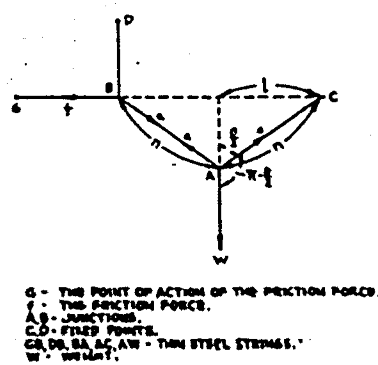

Figure 2(B)30
STRING BALANCE DEVICE FOR THE DIRECT MEASUREMENT OF KINETIC FRICTION COEFFICIENT.

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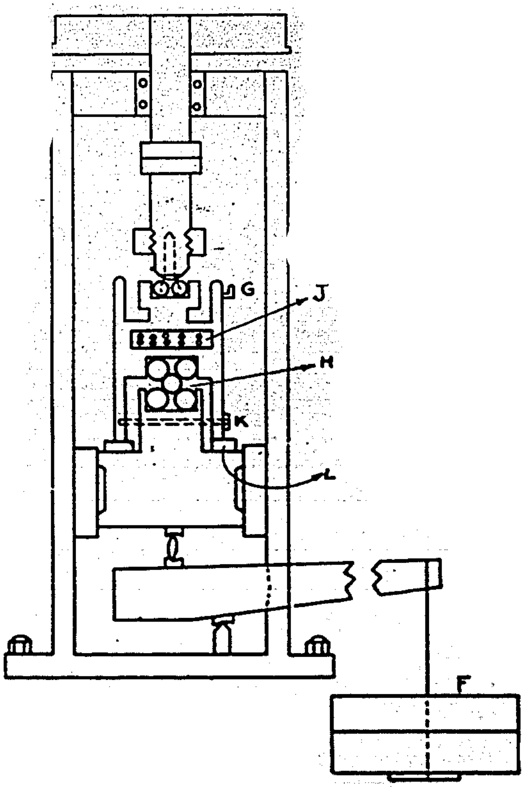

Figure 3(B)30
FOUR BALL TESTER B.

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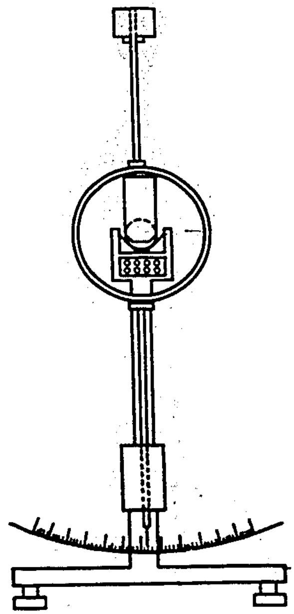

Figure 4(B(30
PENDULUM TESTER

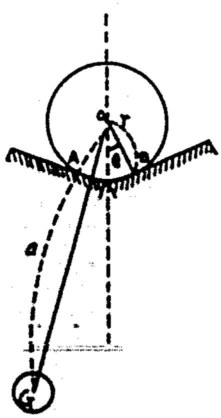

Figure 5(B)30
MAIN PARTS OF THE PENDULUM TESTER

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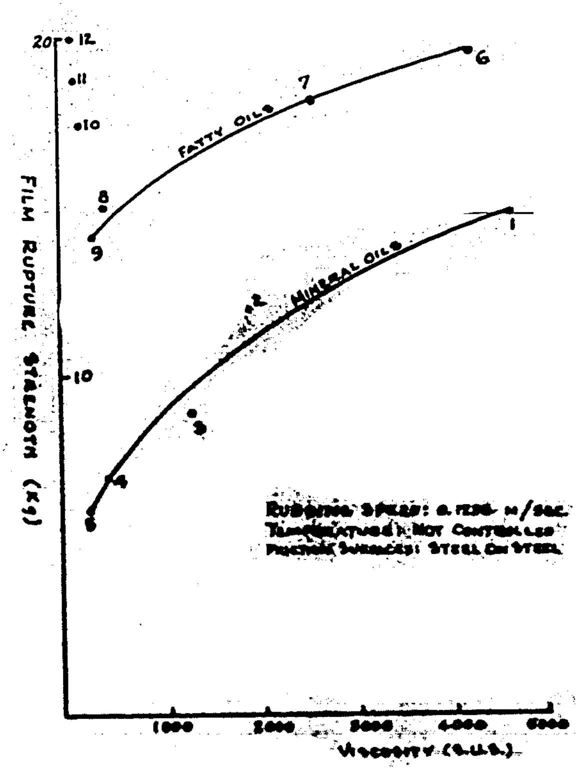

Figure 6(B)30
FILM RUPTURE STRENGTH
BY FOUR BALL TESTER B

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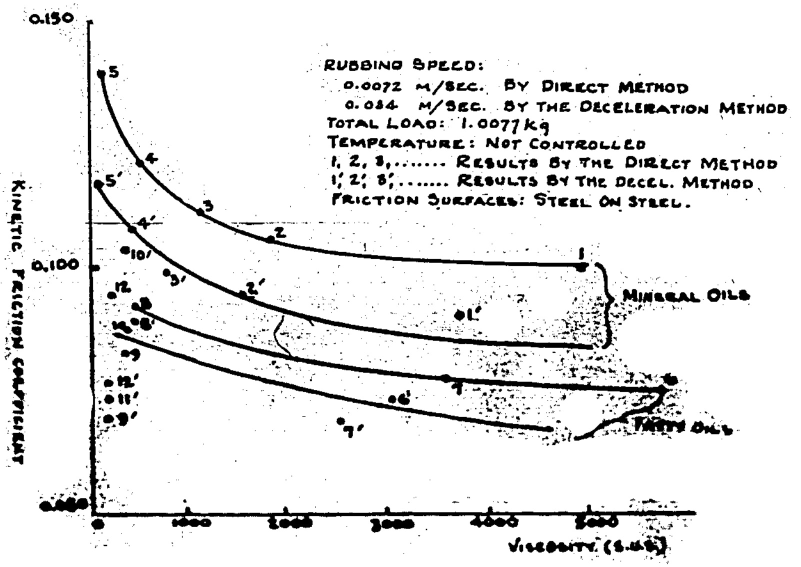

Figure 7(B)30
KINETIC FRICTION COEFFICIENT
BY 4-BALL TESTER A

ENCLOSURE (B)30

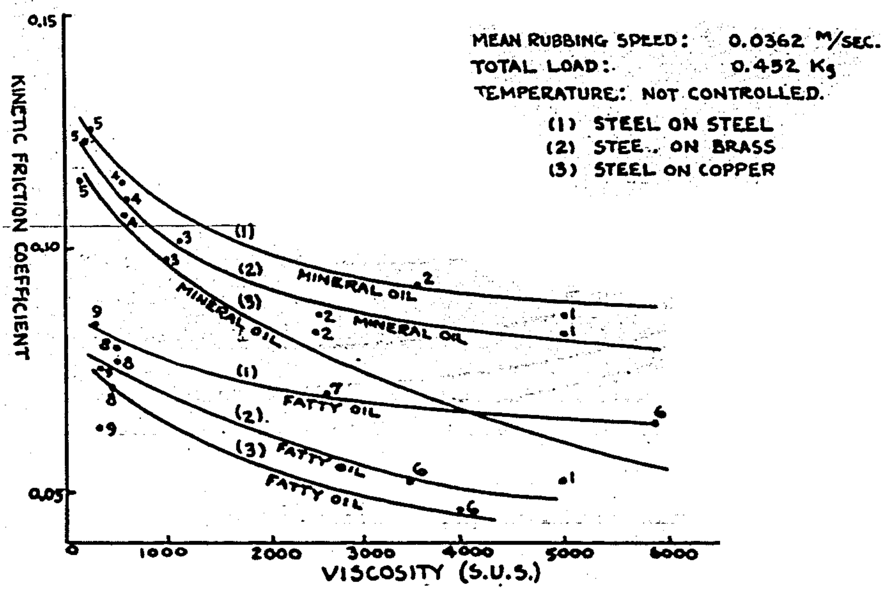

Figure 8(B)30
KINETIC FRICTION COEFFICIENT
BY PENDULUM TESTER