EVALUATION OF THE EFFECTS OF VISCOSITY ON PERFORMANCE OF TURBINE-TYPE FLOWMETERS

by

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INTRODUCTION

Turbine-type flowmeters are designed on the theory of axial-flow turbo-machinery which neglects the viscous influence of the flowing fluid. Generally, flowmeters are calibrated for use with a specific fluid, and accurate measurements of discharge can be made so long as the meter is used with the same fluid. When the meter is used to measure flow of fluids other than that for which it was calibrated, a problem arises in determining the discharge of the different fluids because the speed of the meter rotor, or frequency output of the meter varies with the fluid properties.

The purpose of this report is to determine the effects of viscosity on the performance of several flowmeters of different designs. It is supplementary to Report No. CER58ARC5 previously submitted under Contract DEN-57-10195.

BACKGROUND INFORMATION

The principle effect of fluid viscosity on turbine flowmeters is the variation of internal hydraulic losses associated with the fluid flow. At any given discharge, viscosity variation effects the speed of the rotor, chiefly because of a change in the drag coefficient, in turn, a function of the Reynolds Number of the flow. The fluid viscosity also has a secondary effect on the external hydraulic losses due to a change in the "lubricating" and "non-lubricating" quality of the fluid.

Because of the inherent head losses involved in the flow, a rational approach to understanding the effect of viscosity on turbine flowmeters is best based on separation of the independent losses.

Such studies have been attempted by former investigators on other turbo-machinery without much success (1) (2) (3).* Empirical methods have evolved therefore in attempting to evaluate the effects of viscosity on turbo-machinery where the hydaulic losses could not be separated.

EXPERIMENTAL DATA

The study of viscous effects on flowmeters was made with 3/4-inch size meters manufactured by Potter Aeronautical, Fischer and Porter and Waugh Companies. The kinematic viscosities of the fluids used ranged from 0.56 to 27.5 centistokes. The fluids were medium hydraulic oil (MIL-0-5606) light hydraulic oil (Almag, Code 1514), kerosene and water. Temperatures of the fluids were varied from 60°F to 120°F. Kinematic viscosities of the fluids were measured in the laboratory. The results are presented in the Appendix of this report. The discharge of the flowmeters ranged from 1 to 25 gallons per minute.

PRESENTATION AND ANALYSIS OF DATA

Some experimental data of this study are presented in graphical form in Figs. 1 to 3. The calibration curves are shown with output frequency as a function of discharge and calibration coefficient K in cycles per gallon as a function of discharge. The curves on the Figures show that in general, the frequency output is reduced when the fluid viscosity is increased and there appears to be a systematic change with viscosity.

Flow linearity is a function of the meter design. The variation in calibration coefficients is due to the hydraulic losses in the flow; which is, in turn, directly related to fluid viscosity. In order to

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* Numbers in brackets refer to references in the bibliography of this report.

determine the effect of viscosity, a dimensional analysis was made of the problem. It was assumed that the variables involved could be expressed in the following functional relationship

$$\phi_1 (f , Q , \nu , \rho , D) = 0 \qquad (1)$$

where

f = Output frequency of the meter

Q = Volumetric discharge

ν = Kinematic viscosity of the fluid

ρ = Mass density of the fluid

D = Characteristic diameter of the meter

By combining the variables into dimensionless parameters,

$$\phi_2 \left(\frac{Q}{fD^3} , \frac{fD^2}{\nu} \right) = 0 \qquad (2)$$

If only one meter size is considered, as it was in the study, the diameter is constant and Eq. 2 reduces to

$$\phi_3 \left(\frac{Q}{f} , \frac{f}{\nu} \right) = 0 \qquad (3)$$

The parameter $\frac{Q}{f}$ has been previously defined as the calibration factor $\frac{1}{k}$, and $\frac{f}{\nu}$ is termed the viscous influence number N. This is the method used by Fischer and Porter (6) and Waugh (7) Companies in obtaining a single calibration curve which is applicable to a wide range of viscosities.

Functional plots of k versus N are shown in Figs. 4 to 6 for the meters tested. Note in all the figures that a wide variation of calibration factors exist for different fluid viscosities. For the larger discharges of the flow range, the differences are not as great as for the smaller discharges. For example, in Fig. 4 the calibration factors for fluids having viscosities of 12, 20 and 27 centistokes

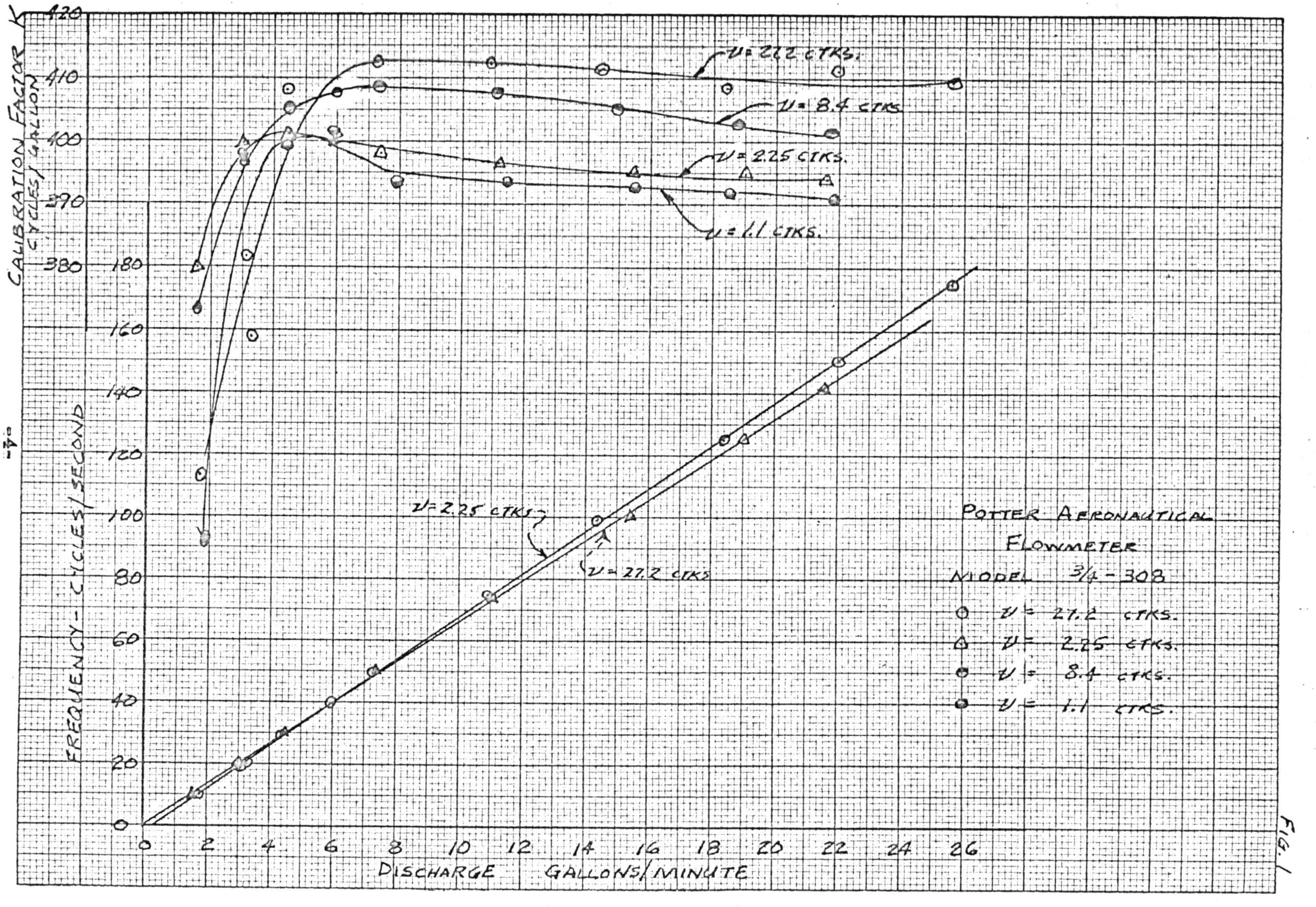

CALIBRATION FACTOR K
CYCLES/GALLON
420
410
400
390
380
FREQUENCY - CYCLES/SECOND
180
160
140
120
100
80
60
40
20
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
DISCHARGE GALLONS/MINUTE
ν = 27.2 CTKS.
ν = 8.4 CTKS.
ν = 2.25 CTKS.
ν = 1.1 CTKS.
ν = 2.25 CTKS
ν = 27.2 CTKS
POTTER AERONAUTICAL
FLOWMETER
MODEL 3/4 - 308
○ ν = 27.2 CTKS.
△ ν = 2.25 CTKS.
● ν = 8.4 CTKS.
● ν = 1.1 CTKS.

FIG. 1

KEUFFEL & ESSER CO. MADE IN U.S.A.

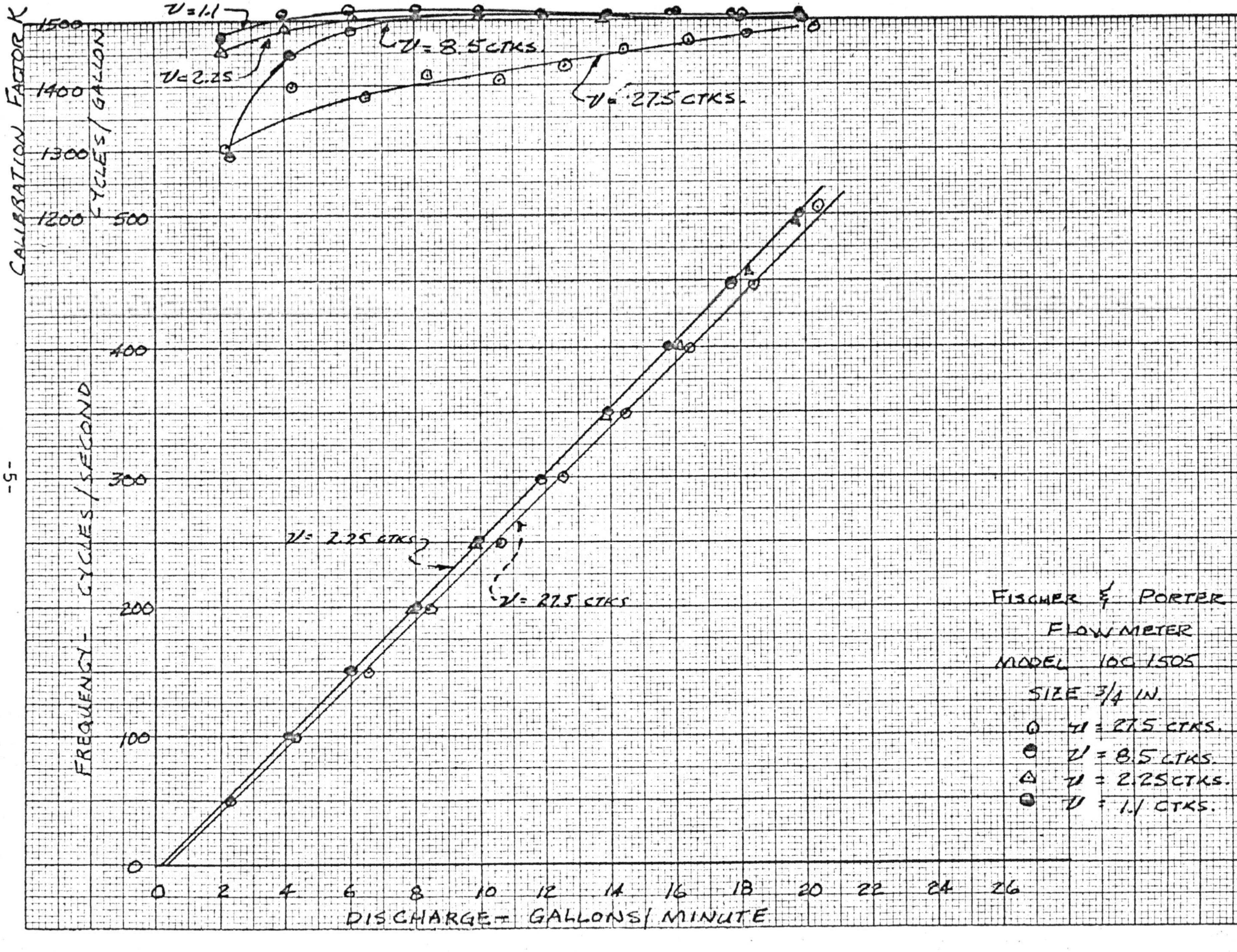


FIG. 2

K&E KEUFFEL & ESSER CO. MADE IN U.S.A.

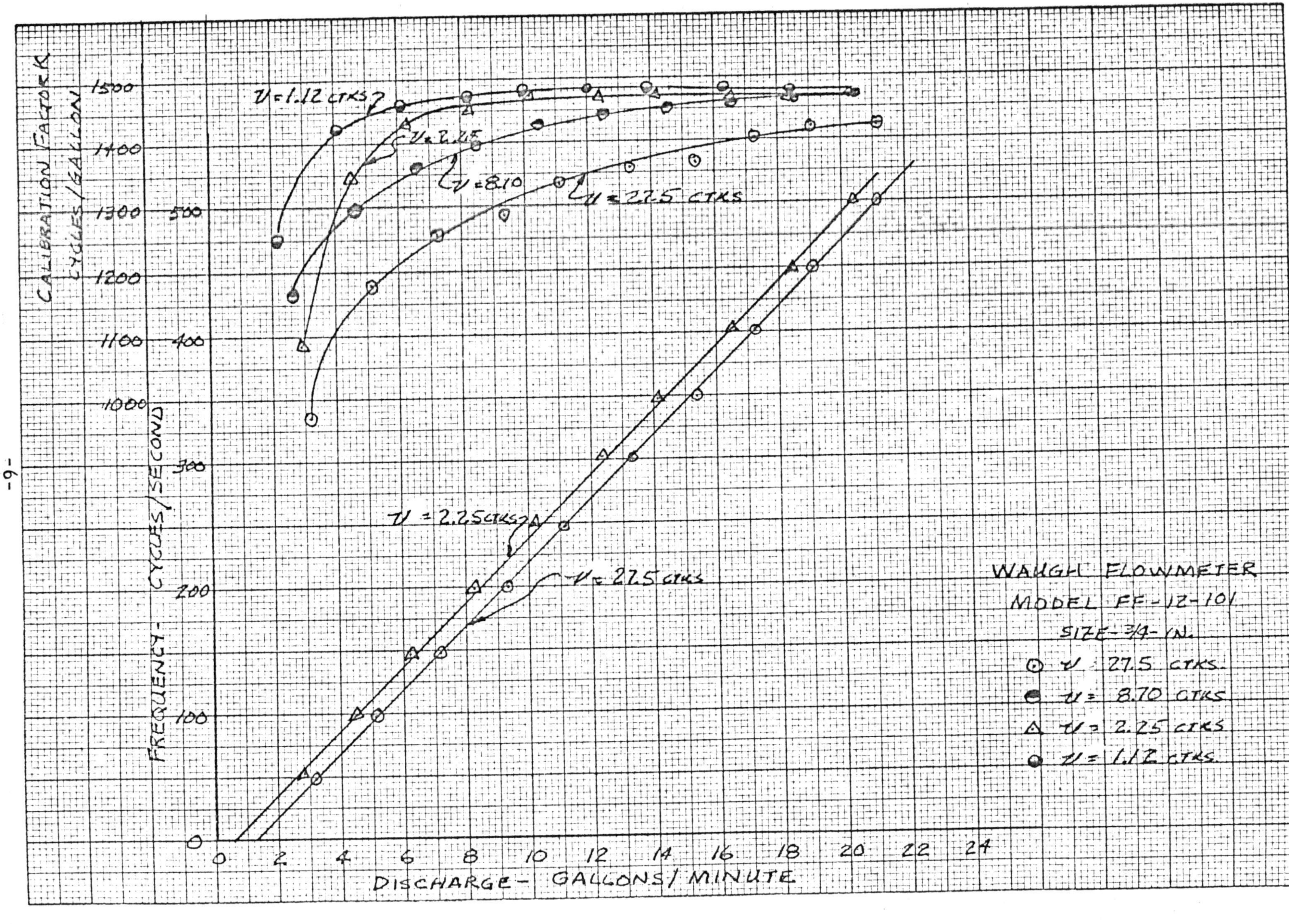
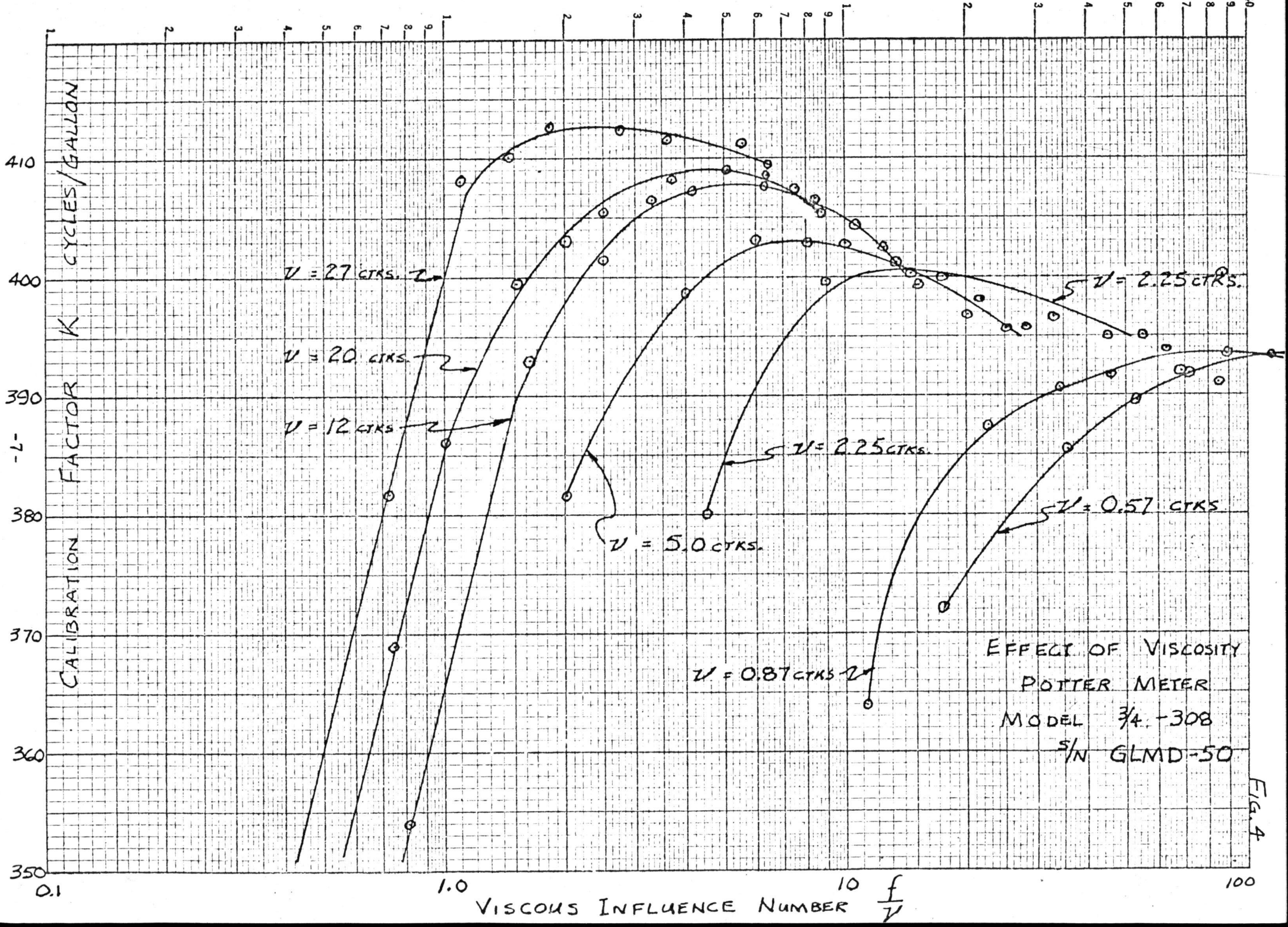


FIG. 3

K&E KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS



EFFECT OF VISCOSITY
POTTER METER
MODEL 3/4-308
S/N GLMD-50

FIG. 4

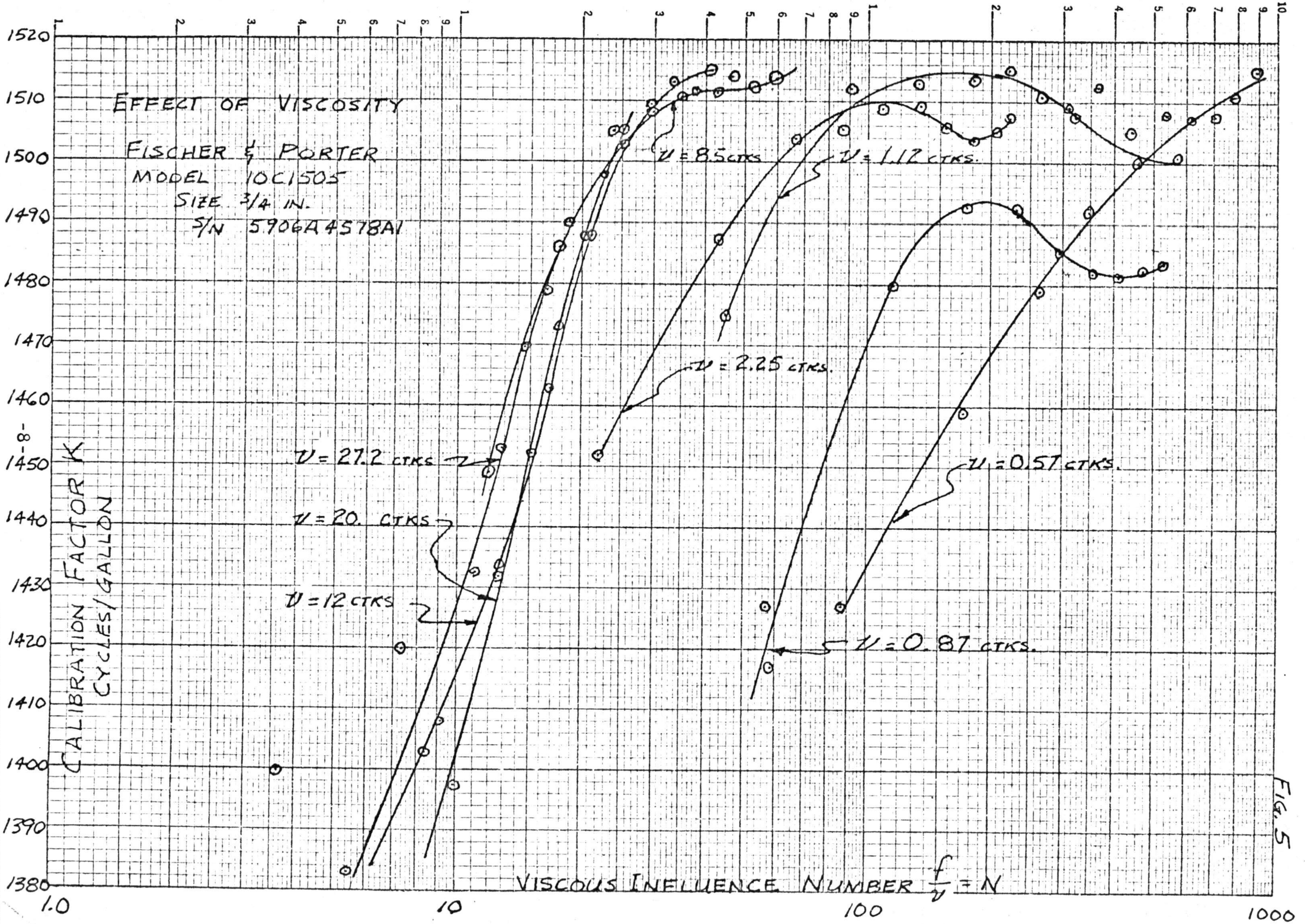
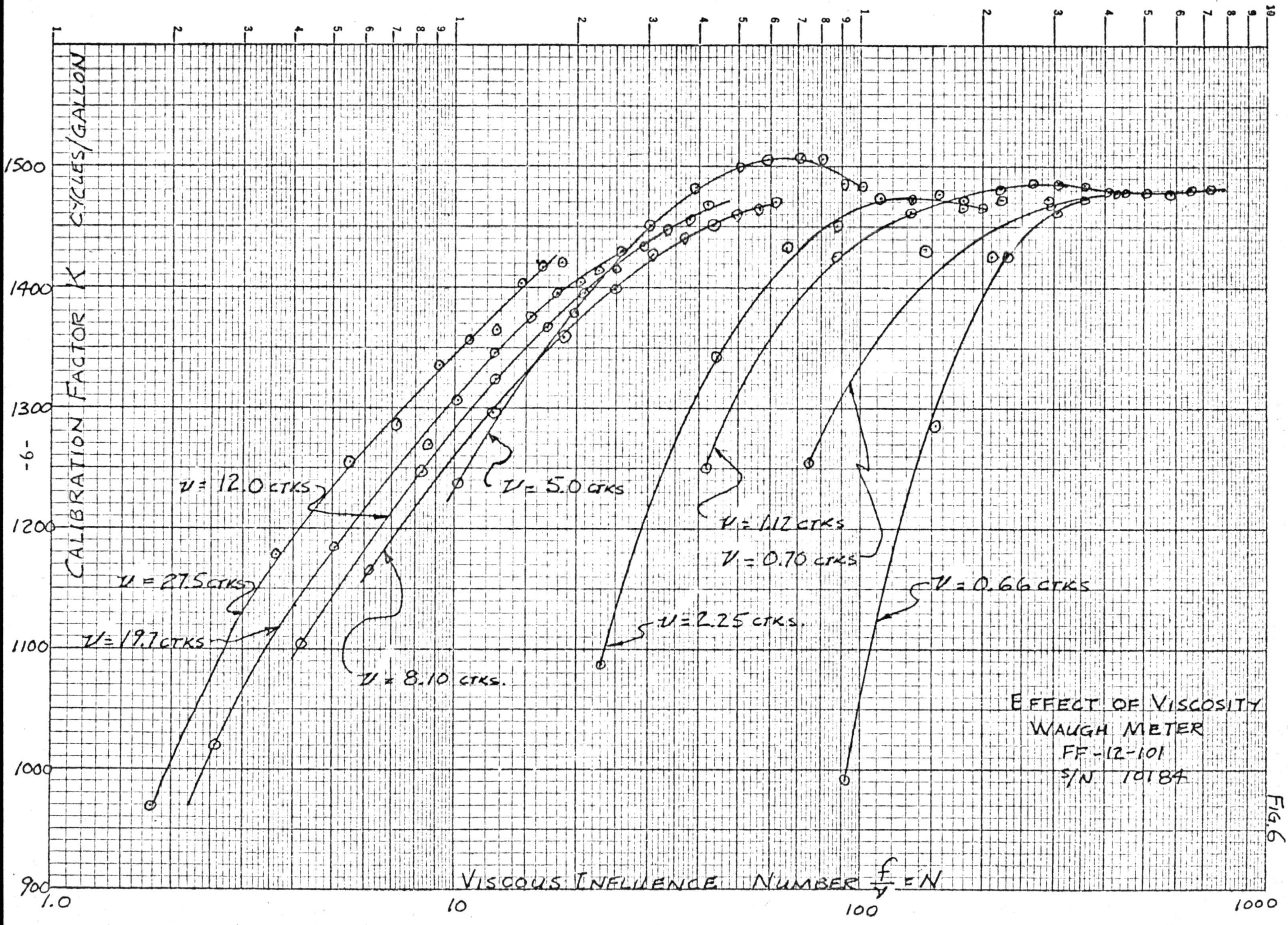

EFFECT OF VISCOSITY
FISCHER & PORTER
MODEL 10C1505
SIZE 3/4 IN.
S/N 5906A4578A1
CALIBRATION FACTOR K
CYCLES/GALLON
VISCOUS INFLUENCE NUMBER $\frac{f}{\nu} = N$
ν = 27.2 CTKS
ν = 20. CTKS
ν = 12 CTKS
ν = 8.5 CTKS
ν = 1.12 CTKS.
ν = 2.25 CTKS.
ν = 0.57 CTKS.
ν = 0.87 CTKS.
1520
1510
1500
1490
1480
1470
1460
1450
1440
1430
1420
1410
1400
1390
1380
1.0
10
100
1000

FIG. 5

KEUFFEL & ESSER CO.
3 CYCLES X 70 DIVISIONS



EFFECT OF VISCOSITY
WAUGH METER
FF-12-101
S/N 10184

FIG. 6

varies from 366 to 405 c.p.g. at a viscous influence number of 1.0. This variation represents a difference of about 10 per cent in the calibration factor, which is directly reflected in the measured discharge. At the larger discharges of the flow range, the differences in calibration factors decrease to only a few per cent.

If turbine meter performance is expressed by Equation 1, linearity of operation exists if

$$\frac{df}{dQ} = \text{constant.}$$

For linear flow meters the performance characteristics are described by a linear function as suggested in Report CER60SSK14:

$$f = MG + F_o \tag{4}$$

where

f = Frequency output

M = Slope of the line

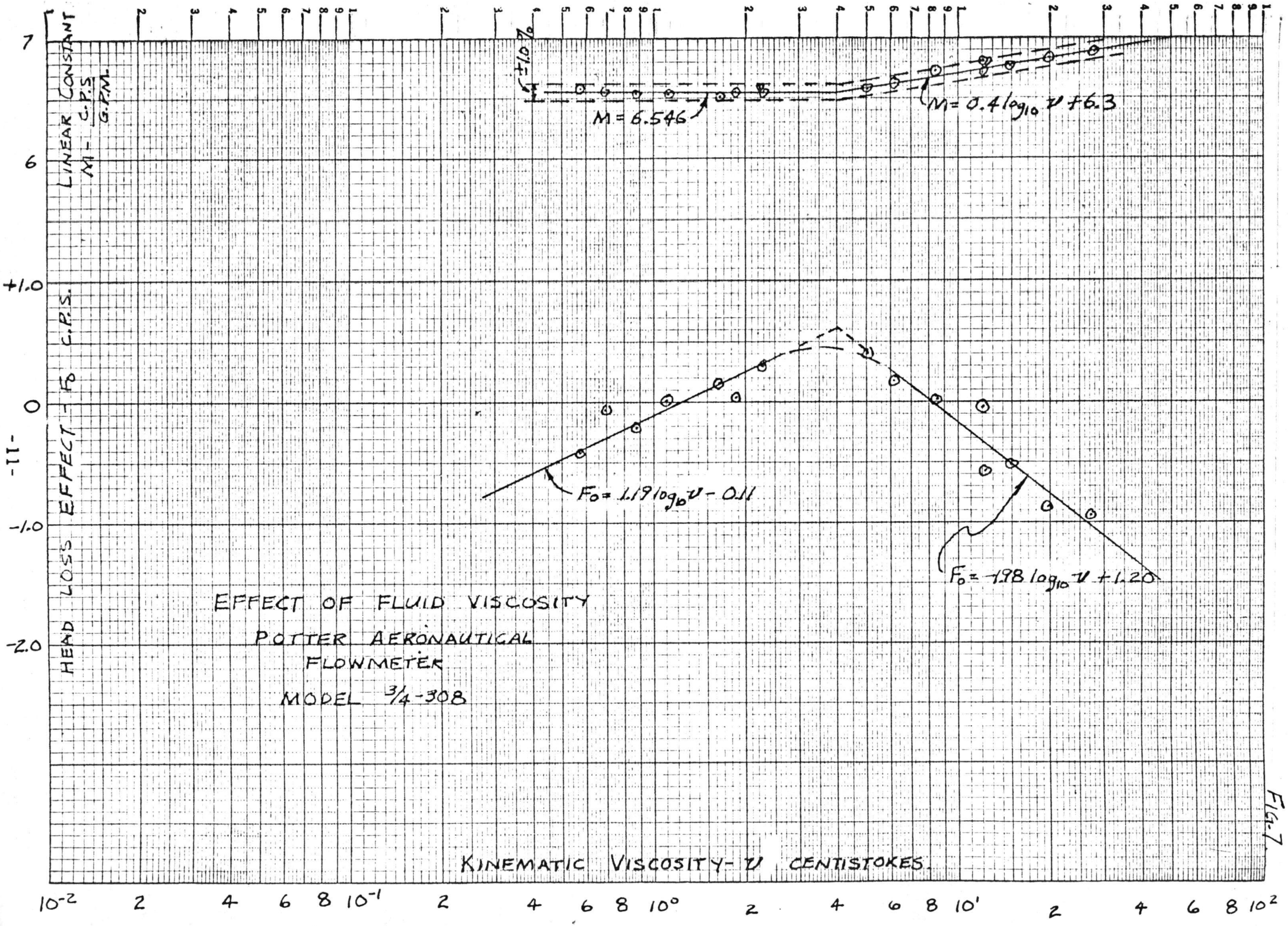
G = Volumetric discharge

F_o = Intercept of the curve with the ordinate.

The values of the constants M and F_o are a measure of the hydraulic losses, and variations of M and F_o for different fluids are measures of the effects of fluid viscosity.

The experimental data was analyzed by linear regression to determine the constants M and F_o for each set of data. The resulting functional variations of M and F_o with fluid viscosity are shown in Figs. 7 to 9 . Fig. 7, shows the results for the Potter Aeronautical flowmeter. Within the range of viscosities tested, there are two separate functions for M and F_o ; the dividing zone appears to be between 3 and 4 centistokes. Fluids of viscosities less than 3 centistokes will be arbitrarily referred herein as "non-lubricating" fluids, while fluids with viscosities greater than about 4 centistokes will be called "lubricating" fluids.

K+E SEMI-LOGARITHMIC 359-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



EFFECT OF FLUID VISCOSITY
POTTER AERONAUTICAL
FLOWMETER
MODEL 3/4-308

FIG. 7

K+E SEMI-LOGARITHMIC 359-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS

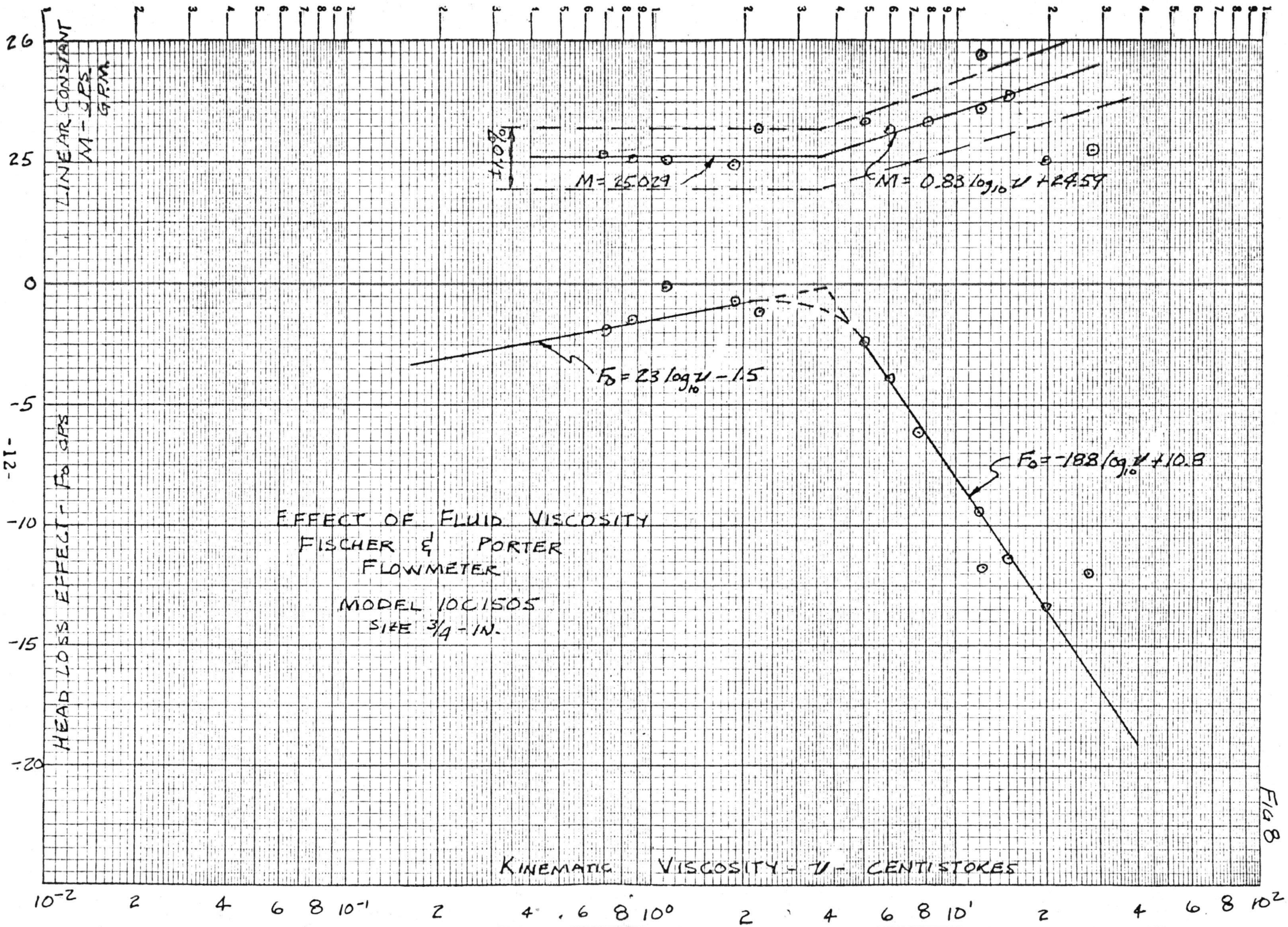
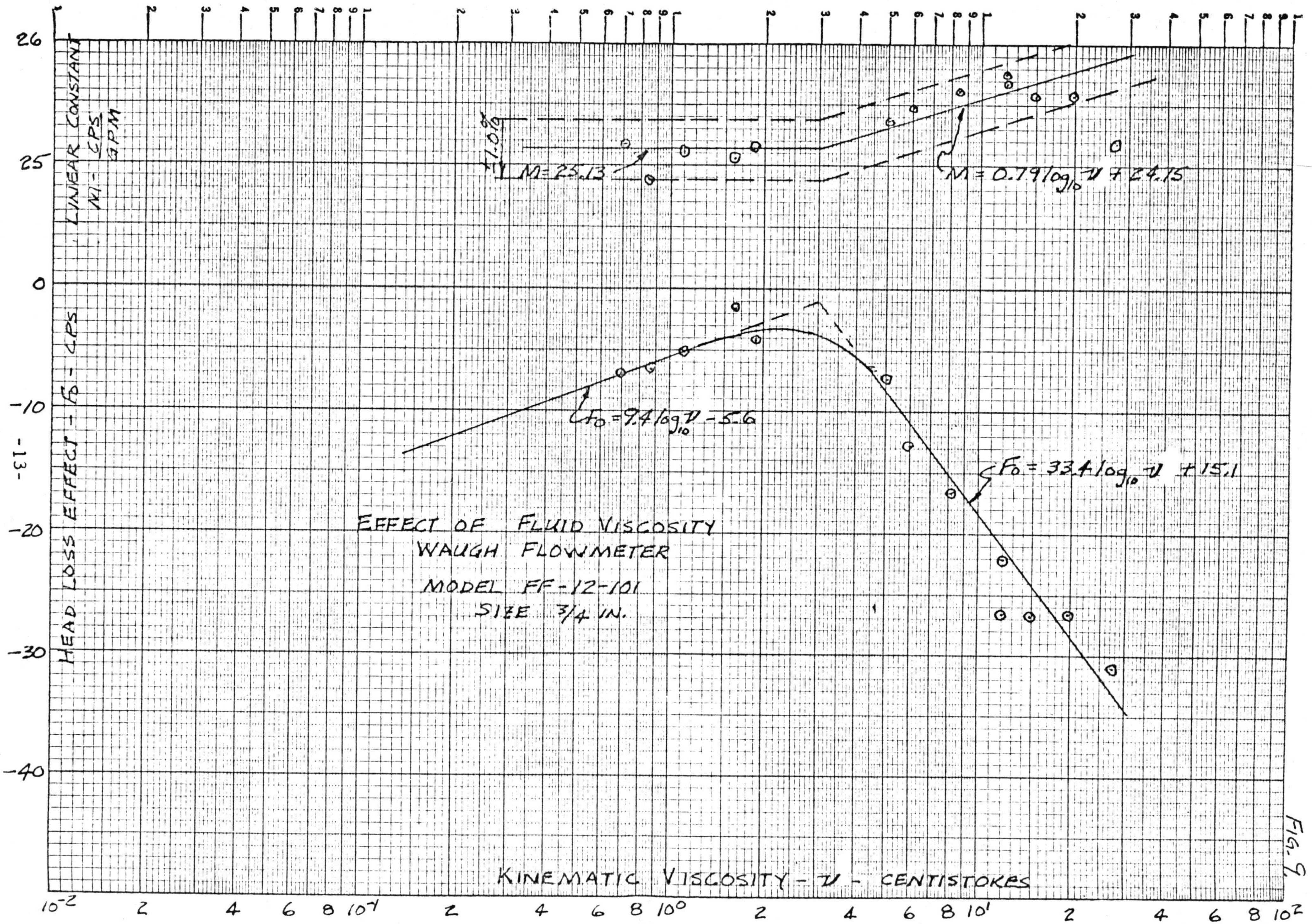


Fig 8

K+E SEMI-LOGARITHMIC 359-81
KEUFFEL & ESSER CO. MADE IN U.S.A.
4 CYCLES X 70 DIVISIONS



EFFECT OF FLUID VISCOSITY
WAUGH FLOWMETER
MODEL FF-12-101
SIZE 3/4 IN.

FIG. 9

With non-lubricating fluids, M appears to be constant with changing viscosity for the Potter flowmeter, while F_o varies slightly in accordance with the relationship:

$$F_o = 1.19 \log \nu - 0.11$$

Thus, for the size of meter and model for which this study was made, if a fluid with a viscosity of 2 centistokes was used to calibrate the meter for use with a fluid of viscosity 0.6 centistokes, the errors in measurement would be less than ± 1 percent if the minimum meter range was limited to 100 c.p.s. In the lubricating fluid range, considerable care should be exercised in using the calibration results from one fluid to another for both M and F_o vary considerably with discharge. For the Potter meter model 3/4-308 used in this study,

$$M = 0.4 \log \nu + 6.3$$

and

$$F_o = -1.98 \log \nu + 1.80$$

for the lubricating fluids.

The Fischer and Porter Model 10C1505 3/4-inch flowmeter of Fig. 8 and the Waugh Meter of Fig. 9 both show functional variation of M and F_o with fluid viscosity. The relationships are shown on the graphical plots.

CONCLUSIONS

The effect of an increase in fluid viscosity on turbine-type flowmeters is to reduce the speed of the rotor; so that, if a meter was calibrated with, say water, and was used to meter flow of oil, the indicated discharge would be less than the actual discharge. The flowmeters tested apparently perform differently depending upon whether the fluid is "lubricating" ($\nu \gtrsim 4$ centistokes) or "non-lubricating" ($\nu \lesssim 3$ centistokes). For the flowmeters tested, empirical relationships were derived for use in computing the calibration coefficients, which depend upon the fluid viscosity. Care should be exercised in extrapolating the functions beyond the limits of the experimental data.

A functional plot of calibration factor k , versus the viscous influence number N does not appear to be adequate to describe meter performance and because of the variations of each flowmeter, it is advisable to calibrate each meter with the specific fluid for which it is to be used, particularly if the fluids have viscoities greater than 4 centistokes. The effect of changing viscosity for "non-lubricating" fluids is to limit the lower discharge of the flow range to which a constant calibration factor could be applied.

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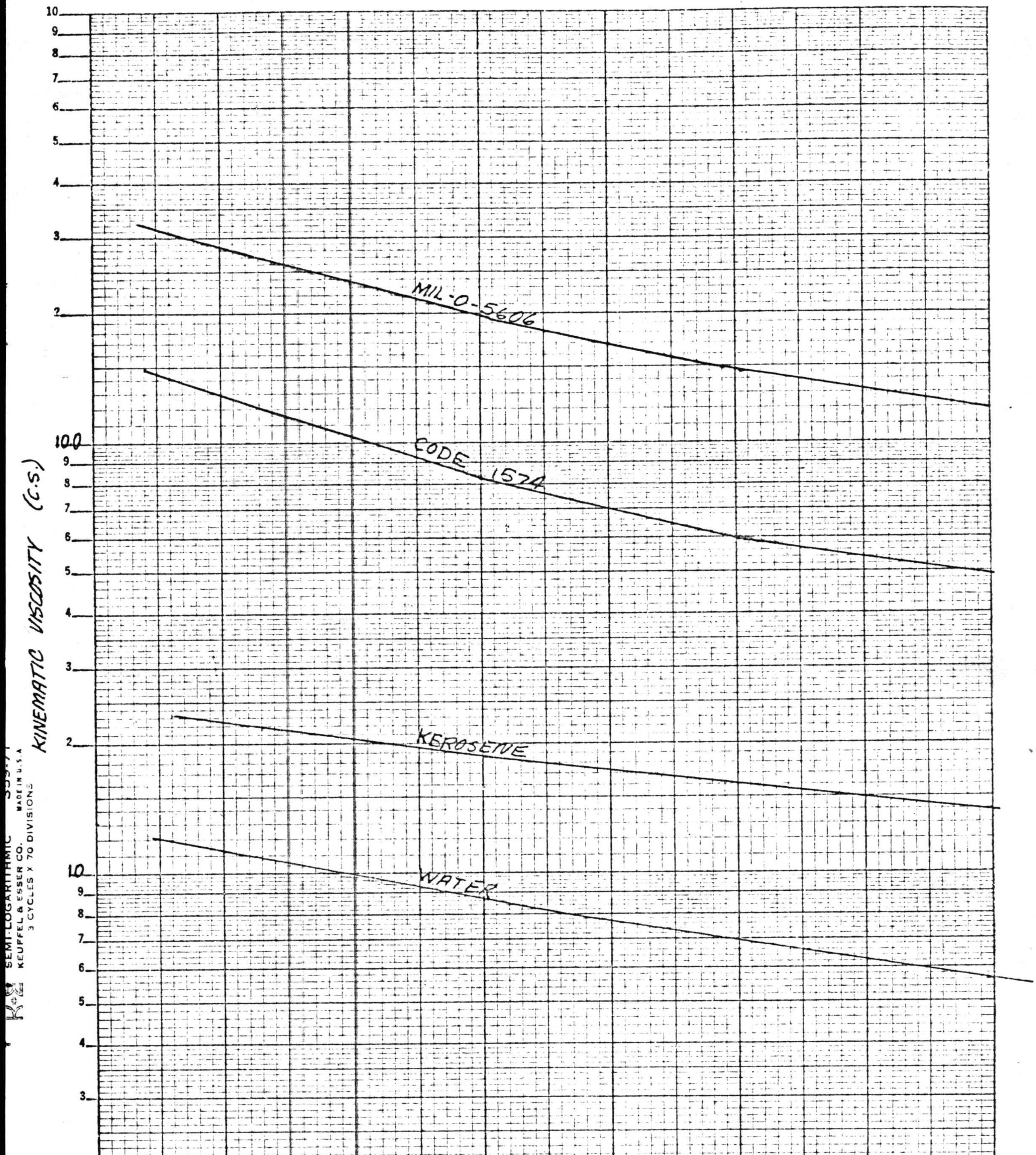
APPENDIX


10
9
8
7
6
5
4
3
2
10.0
9
8
7
6
5
4
3
2
1.0
9
8
7
6
5
4
3
2
0.1
50
60
70
80
90
100
110
120
TEMP. (°F)
KINEMATIC VISCOSITY (C.S.)
MIL-0-5606
CODE 1574
KEROSENE
WATER
SEMI-LOGARITHMIC 359-71
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 CYCLES X 70 DIVISIONS