University of Michigan
Department of Mechanical Engineering
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DATA REDUCTION PROCEDURES -STEAM TUNNEL FILM THICKNESS TESTS

by

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(Submitted by A. Mancuso in partial fulfillment of ME 600)

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SUMMARY

A low pressure steam tunnel has been constructed and is currently in operation at the University of Michigan. The steam tunnel is being utilized to study droplet erosion on turbine blades caused by low pressure moisture formation.

The purpose of this report is to describe the procedures involved in reducing the data obtained from the steam tunnel and comparing it to theoretical predictions. Presented in the Appendices are the experimental results and the theoretical predictions.

The theoretical predictions for the liquid film are based on a one-dimensional Couette-flow model. For the steam flow calculations, the velocity profile is assumed to be fully developed.

LIST OF FIGURES

I. INTRODUCTION

Under National Science Foundation grant GK-40130, the University of Michigan is researching droplet erosion on turbine blades caused by low pressure moisture formation. Therefore a low pressure steam tunnel and two blading profiles have been designed and constructed. This equipment has been described previously (1-3 e.g.).

One particular area of concern in this research program is the formation and break-up of the liquid film created on a stationary blading profile within the steam tunnel test section. The thickness of the liquid film under various steam flow conditions is determined experimentally and then compared to theoretical predictions. I have been involved in reducing the data obtained from the steam tunnel and comparing it to theoretical predictions.

This report describes the procedures involved in reducing the data obtained from the steam tunnel and comparing it to theoretical results.

The theoretical predictions of the liquid film thickness under various flow conditions are based on the work of Drs. F.G. Hammitt, J. Mikielewicz and J.B. Hwang.

The experimental data obtained from the steam tunnel includes measurements of the steam line and test section pressures and temperatures; and the temperature and flow rate of the liquid film. The liquid film is formed on the stationary blading profile by injecting a salt water solution on the upstream surface of the blade. This procedure has been described previously (3 e.g.).

The steam velocity is determined by orifice and pitot tube pressure difference measurements. The liquid film thickness under various flow conditions is determined from the resistivity readings of four guages installed in the stationary blading profile. The electrical conductivity guages used in determining the film thickness have been described previously (4 e.g.).

II. PREDICTED SURFACE STRESS OF THE LIQUID FILM AS A FUNCTION OF STEAM VELOCITY

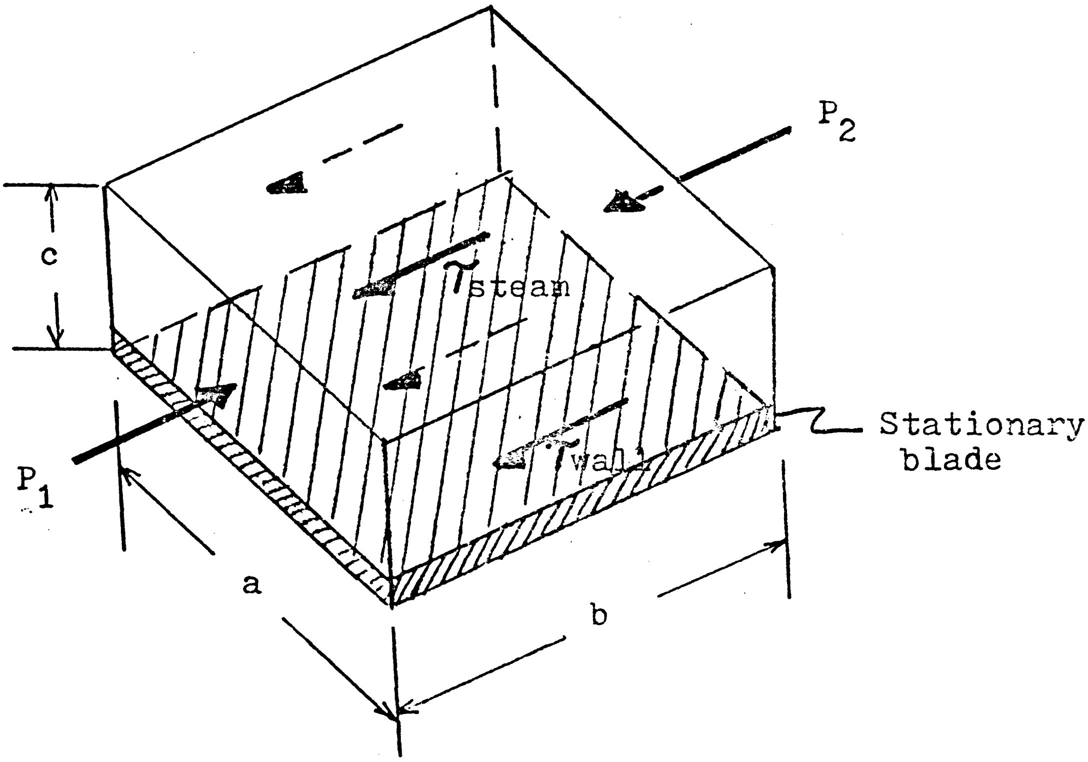


Fig. 1 Forces Acting on Steam Flow

Applying force equilibrium in Fig. 1, we obtain,

$$\Delta P(ac) = \tau_{steam} 2(ab) + \tau_{wall} 2(bc)$$

If we assume that $\tau_{steam} = \tau_{wall} = \tau_{film}$, then

$$\tau_{film} = \frac{(ac)}{2(ab) + 2(bc)} \Delta P$$

where,

τ = surface stress (lb/in^2)

ΔP = pressure difference (lb/in^2)

For our particular steam tunnel configuration,

a = 3.15 in

b = 4.5 in

c = 1.575 in

therefore,

$$\tau_{film} = \frac{(3.15)(1.575)}{2(3.15)(4.5) + 2(4.5)(1.575)} \Delta P$$

$$\tau_{film} = .1167 \Delta P \qquad (1)$$

Equation 1 is a fixed relation between τ and ΔP for our particular steam tunnel configuration.

The pressure drop, ΔP, can be determined from the relation,

$$\Delta P = \frac{f L}{144 D_{HYD}} \cdot \frac{\rho_{stm} V_{stm}^2}{2 g_o}$$

where,

f = friction factor

L = characteristic length (in)

D_{HYD} = hydraulic diameter (in)

ρ_{stm} = density of the steam (lbm/ft^3)

V_{stm} = velocity of the steam (ft/sec)

ΔP = pressure drop (lb/in^2)

for our configuration,

$$L = 4.5 \text{ in}$$

$$D_{HYD} = \frac{4(ac)}{\text{Wetted Perimeter}} = \frac{4(3.15)(1.575)}{2(3.15) + 2(1.575)} = 2.1 \text{ in}$$

therefore,

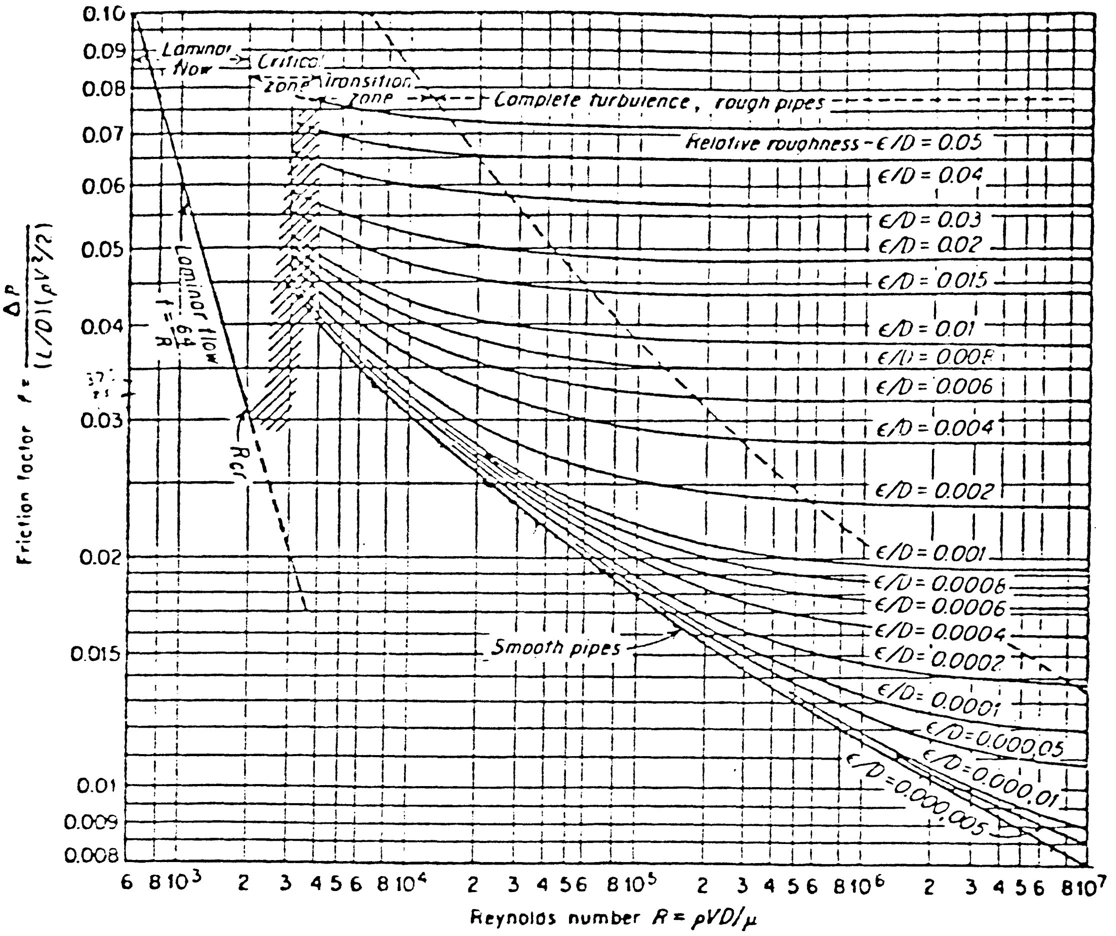
$$\Delta P = 2.3X10^{-4} f \rho_{stm} V_{stm}^2$$

The friction factor, f, can be gotten from the Moody chart, Fig. 2, as a function of Reynolds Number and pipe roughness. For our calculations we assumed a smooth pipe. The Reynolds Number can be calculated using;

$$Re = \frac{\rho_{stm} D_{HYD}}{\mu_{stm}} V_{stm}$$

where,

μ_{stm} = viscosity of the steam (lbm/ft-sec)



*From: ENGINEERING EXPERIMENTATION by G.L. Tuve and L.C. Domholdt. Copyright © 1966 by McGraw-Hill, Inc. Used with permission of McGraw-Hill Book Company. Adapted from: L.F. Moody, *Trans. ASME*, 66:671, 1944

Figure 2. FRICTION FACTOR BASED ON RELATIVE ROUGHNESS FOR VARIOUS KINDS AND SIZES OF PIPE*

III. PREDICTED LIQUID FILM THICKNESS CALCULATIONS

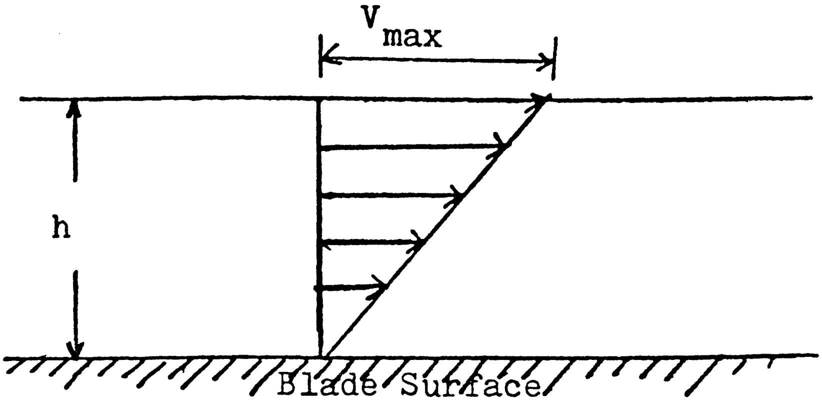


Fig. 3 Liquid Film Velocity Profile

The liquid film thickness, h, can be estimated in the following manner.

$$\tau_{film} = \mu_{liq} \frac{V_{max}}{h g_o} \quad (2)$$

where,

μ_{liq} = viscosity of the liquid film (lbm/ft-sec)

V_{max} = maximum liquid film velocity

$\dot{m}$ = volumetric flow rate of the liquid film

Rearranging equation (2), we obtain.

$$h = \mu_{liq} \frac{V_{max}}{\tau_{film} g_o}$$

and if,

$$\dot{m} = \frac{h \ell V_{max}}{2}$$

and

$$V_{max} = \frac{2 \dot{m}}{h \ell}$$

then

$$h = \mu_{liq} \frac{2\dot{m}/h\ell}{\tau_{FILM}} = \frac{2\mu_{liq}\dot{m}}{h\ell\,\tau_{FILM}}$$

or

$$\frac{h^2}{\dot{m}} = 0.038 \frac{\mu_{liq}}{\ell\,\tau_{FILM}} \left\{ \frac{mils^2}{cc/min} \right\}$$

For our configuration $\ell = .375$ ft in the above equations.

IV. CALCULATION OF STEAM VELOCITY FROM THE ORIFICE READING

The velocity of the steam can be calculated from the pressure difference measured in inches of Hg by an upstream orifice. The derivation of the relation to be used is as follows;

$$V_{steam} = \frac{W_w \nu}{3600\ A}$$

where,

W_w = mass flow rate of the steam (lbm/hr)

ν = specific volume of the steam (ft^3/lbm)

A = area of the test section (ft^2)
(for our configuration A = .069 ft^2)

V_{steam} = steam velocity (ft/sec)

and (Reference No. 8.)

$$W_w = 2781.72 \sqrt{H_{Hg}\left(\frac{P_f}{T_f}\right)}$$

where,

H_{Hg} = inches of mercury manometer head
T_f = steam line temperature (^oR)
P_f = saturation pressure at the steam line temp. (lb/in^2)

V. CALCULATIONS INVOLVED IN DETERMINING THE CRITICAL FILM THICKNESS --(Ref. 5)

The relations used to determine critical film thickness as a function of contact angle are from Fig. 4,

$$f(\theta) = \frac{\rho \tau^2 h_{crit}^3}{6 \mu^2 \sigma}$$

$$h_{crit} = \left(6 f(\theta)\right)^{1/3} \left(\frac{\mu^2 \sigma}{\rho}\right)^{1/3} \tau^{-2/3}$$

if, $C_1 = \left(6 f(\theta)\right)^{1/3}$ and $C_2 = \left(\frac{\mu^2 \sigma}{\rho}\right)^{1/3}$

then,

$$h_{crit} = C_1 \cdot C_2 \cdot \tau^{-2/3}$$

where,

θ_0 = liquid droplet contact angle
μ = viscosity
ρ = density
σ = surface tension

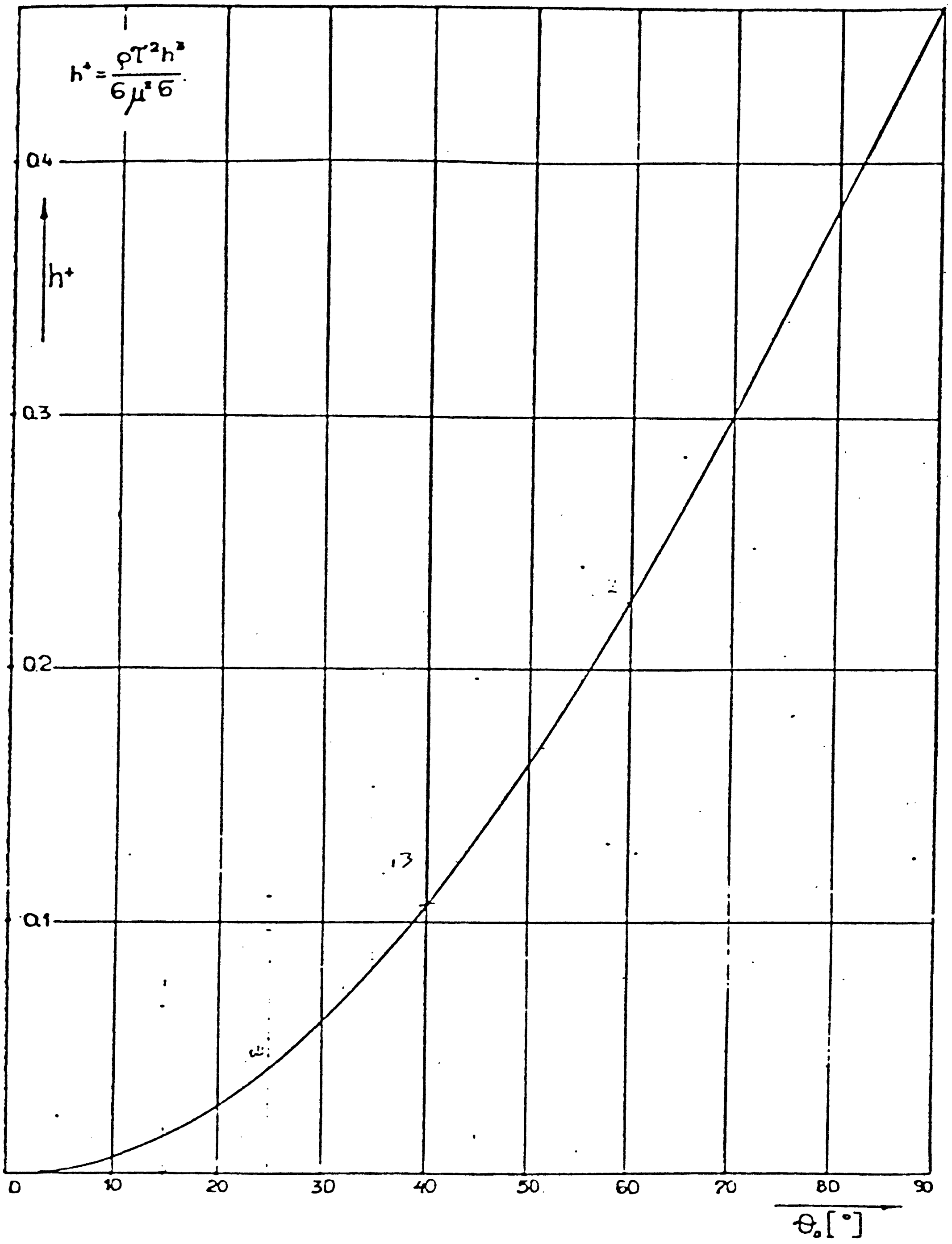


Fig. 4. Dimensionless minimum film thickness as a function of the contact angle

The derivation of these relations are described by Mikielewicz and Moszynski in a report for the Polish Institute of Fluid-Flow Machinery entitled "Shear Driven Liquid Film" (5 e.g.).

VI. CALCULATIONS INVOLVED IN DETERMINING THE LIQUID FILM THICKNESS AS A FUNCTION OF RESISTIVITY

The liquid film thickness, h, is measured experimentally in the steam tunnel in terms of resistivity, R, by four electrical conductivity guages. The film thickness is determined from Figs. 12 and 14, which contain plots of film thickness versus resistivity reading for a liquid film temperature of 130°F and 70°F respectively. The procedure required to obtain these curves, together with sample calculations will be outlined in the following discussion. This procedure has been discussed previously (2-4,6 e.g).

In obtaining a curve of liquid film thickness versus resistivi reading, Figs. 5, 6 and 7 are used. Figs. 5 and 6 concern the generalized characteristics of the four electrical conductivity guages and Fig. 7 concerns the calibration of the bridge used in measuring resistivity.

The first step in obtaining curves for the film thickness as a function of resistivity is to obtain an average value for the product of the characteristic factor and specific conductivity, $C_g\sigma$, at the specified temperature. C_g is a guage constant which depends upon the guage geometry and materials used in its construction. σ is specific liquid conductivity.

$C_g\sigma$ as a function of temperature is plotted

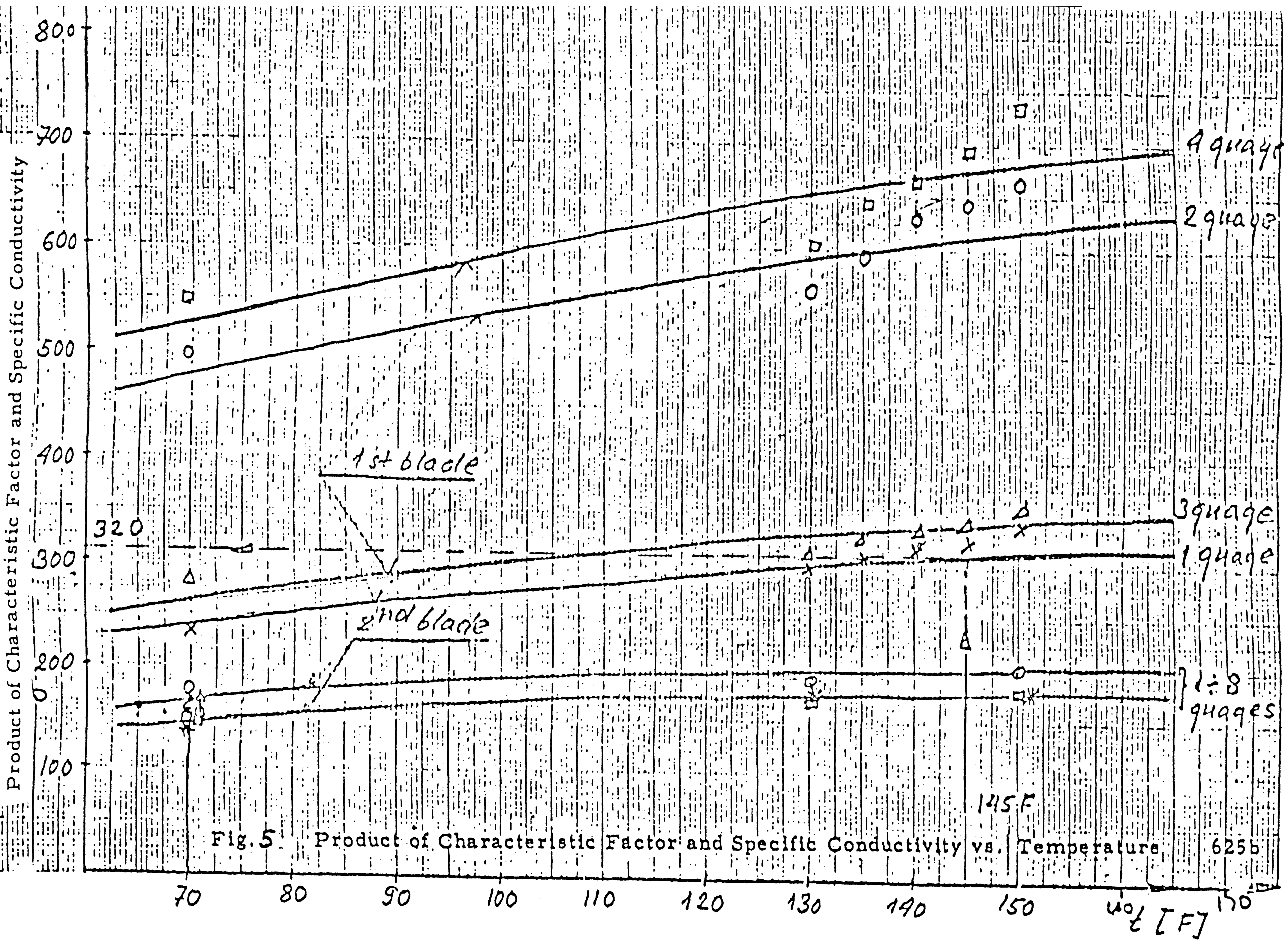


Fig. 5 Product of Characteristic Factor and Specific Conductivity vs. Temperature 625b

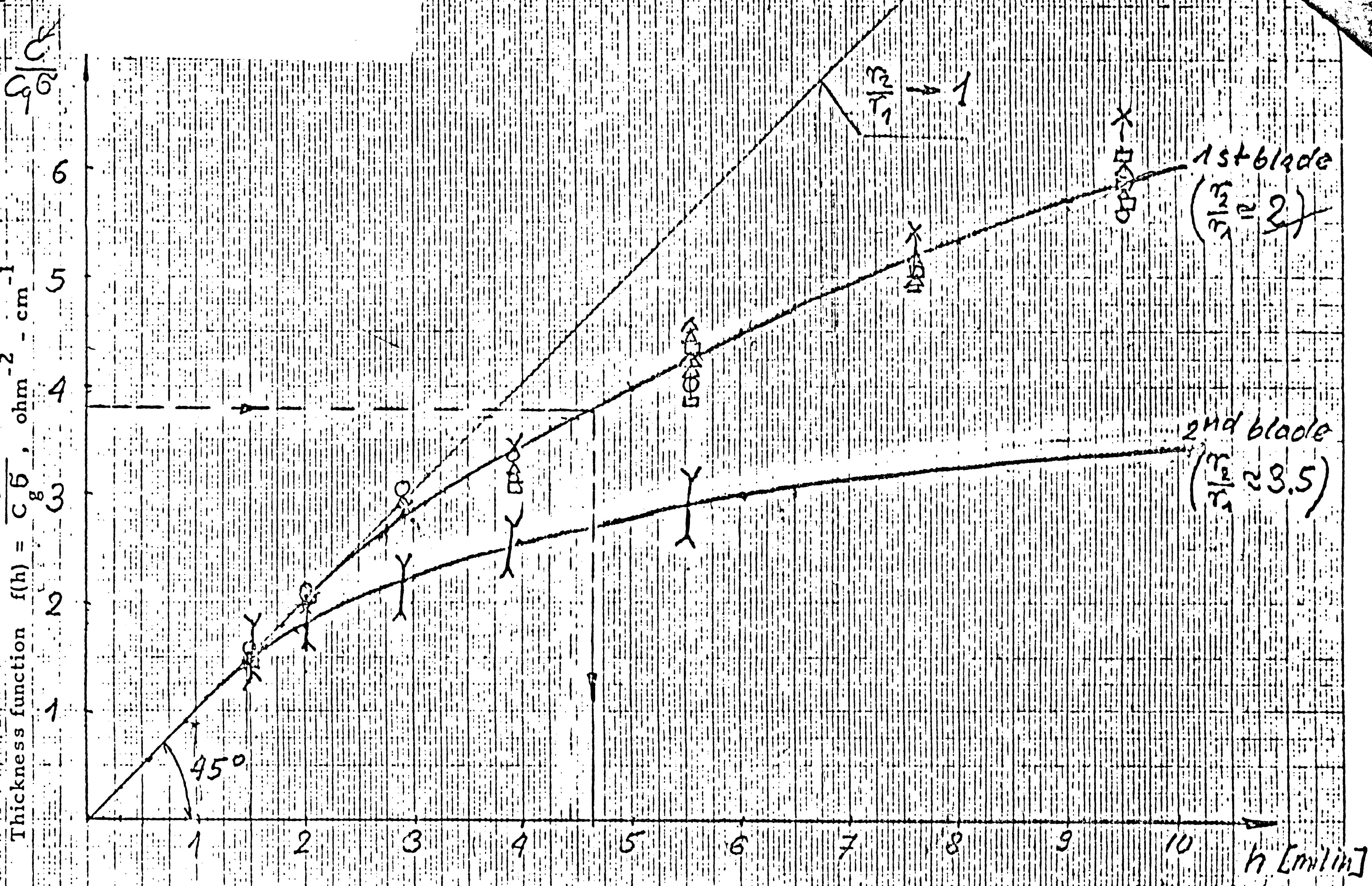


Fig. 6 Generalized Characteristics for Gauges Investigated

625a

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J. Tully.

Bridge Constant CALIBRATION - Data from Blade No. 2.

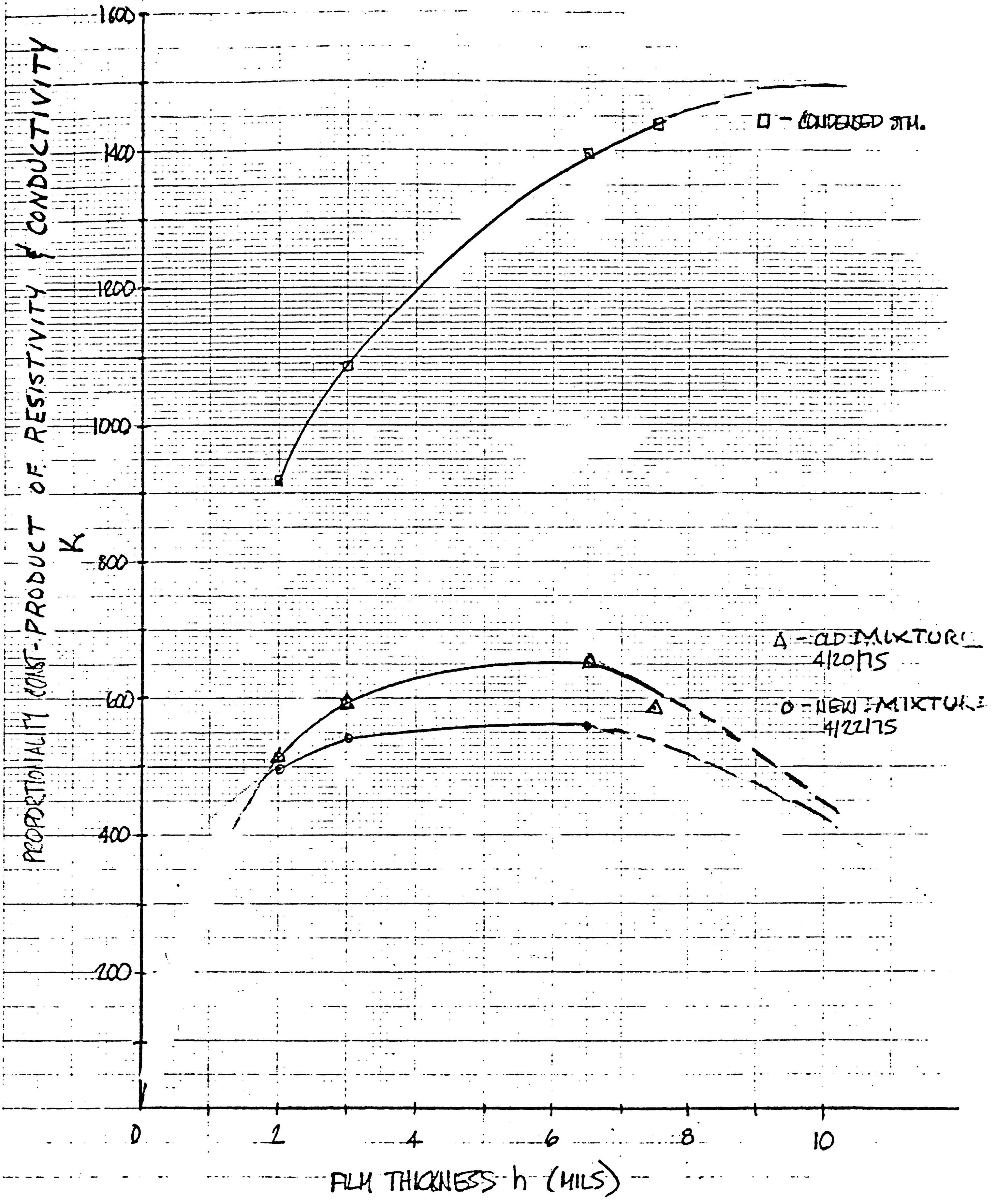

FIG. 7 GAUGE CALIBRATION CURVE

in Fig. 5. The next step is to arbitrarily select a resistivity value and assume a value for the film thickness at that resistivity. Then using Figs. 6 and 7 respectively, the values for the thickness function, f(h), and the proportionality constant, K, are obtained at the assumed film thickness. The next step is to determine the conductivity, C, utilizing the relation $C = K/R$. The thickness function can now be calculated using the relation $f(h) = C/C_g\sigma$.

The calculated value for f(h) is compared to the value of f(h) obtained earlier from Fig. 6 for our assumed film thickness. If the two values of f(h) agree, then the assumed film thickness is the correct value corresponding to the selected resistivity. If the two values of f(h) do <u>not</u> agree , then the assumed film thickness at the selected resistivity is incorrect. Therefore a different value of film thickness is assumed. The procedure continues until the calculated value of the thickness function agrees with the value obtained from Fig. 6 at the assumed film thickness.

To further clarify the procedure involved in determining the film thickness from the resistivity reading a sample calculation is provided below.

If the temperature of the liquid film is 126.07 °F the average value of $C_g\sigma$ is 322(ohm-cm)$^{-1}$ from Fig. 5.

We then select a resistivity of 1.0 and want to determine the film thickness to which this resistivity corresponds. We assume that at R = 1.0 the film thickness is 0.984 mils. Referrin to Fig. 6, we find that at h = .984 mils the thickness function, f(h), is .984 ohm^{-2} cm^{-1}. Referring to Fig. 7 , we find that

$K = 316.8$ at $h = .984$ mils. Therefore $C = K/R = 316.8/1.0 = 316.8$.

We can now calculate the thickness function.

$$f(h) = C/C_g\sigma = 316.8/322 = .984 \text{ ohm}^{-2} \text{ cm}^{-1}$$

The calculated thickness function value is equal to the value obtained earlier from Fig. 6 at the assumed film thickness of .984 mils. Therefore a film thickness of .984 mils corresponds to a resistivity of 1.0.

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Appendix A - List of Tables

TABLE 1

TABLE OF CRITICAL FILM THICKNESS VS. STEAM VELOCITY; VARIOUS WETTING ANGLES

$T_{LIQ} = 130°F$ & $T_{LIQ} = 70°F$

$T_{LIQ} = 130°F$

τ_{FILM} (PSI)	$\theta_0 = 15°$ h_{crit} (mils)	$\theta_0 = 45°$ h_{crit} (mils)	$\theta_0 = 70°$ h_{crit} (mils)	$\theta_0 = 80°$ h_{crit} (mils)
$.041 \times 10^{-3}$	10.69	21.87	29.03	31.38
$.3 \times 10^{-3}$	2.84	5.8	7.7	8.33
$.721 \times 10^{-3}$	1.58	3.23	4.29	4.64
1.34×10^{-3}	1.05	2.14	2.84	3.07
2.09×10^{-3}	.78	1.6	2.11	2.28
2.99×10^{-3}	.61	1.25	1.66	1.8
4.05×10^{-3}	.50	1.02	1.36	1.47
5.12×10^{-3}	.43	.88	1.16	1.26

$T_{LIQ} = 70°F$

τ_{FILM} (PSI)	$\theta_0 = 15°$ h_{crit} (mils)	$\theta_0 = 45°$ h_{crit} (mils)	$\theta_0 = 70°$ h_{crit} (mils)	$\theta_0 = 80°$ h_{crit} (mils)
$.041 \times 10^{-3}$	16.83	35.34	45.43	49.64
$.3 \times 10^{-3}$	4.46	9.37	12.03	13.17
$.721 \times 10^{-3}$	2.49	5.23	6.72	7.34
1.34×10^{-3}	1.65	3.46	4.44	4.86
2.09×10^{-3}	1.22	2.57	3.30	3.61
2.99×10^{-3}	.96	2.02	2.60	2.84
4.05×10^{-3}	.79	1.65	2.13	2.32
5.12×10^{-3}	.67	1.41	1.82	1.99

Table 2 - Film Thickness (h) for Different Resistivities at T_{liq} = 126.07°F

Gauges 1 and 3, Blade 1, Mixture 4/22/75 $cg\sigma$ = 322

R	h	$c/cg\sigma$	k	c	CALCULATED $(c/cg\sigma)^*$	h^*
.3	7	4.9	553	1843.3	5.73	
	7.5	5.12	540	1800	5.59	
	8.0	5.35	520	1733.3	5.38	8.0
.4	5.7	4.32	560	1400.	4.35	
	5.8	4.35	560	1400.	4.35	5.8
.6	2.75	2.68	525	875.	2.72	
	2.85	2.75	532	886.7	2.75	2.85
.8	1.8	1.8	480	600	1.86	
	1.85	1.85	482	602.5	1.87	1.85
.9	1.2	1.2	370	411.1	1.28	
	1.27	1.27	385	427.8	1.33	
	1.35	1.35	391	434.4	1.35	1.35
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	
1	.984	.984	316.8	316.8	.984	.984
1.5	.25	.25	100	66.7	.21	
	.3	.3	125	83.3	.26	
	.28	.28	118	78.7	.24	
	.18	.18	80	53.3	.17	.18
	[illegible]	[illegible]	[illegible]	[illegible]		

Table 3 - Film Thickness (h) for Different Resistivities at T_{liq} = 126.07°F

Gauges 2 and 4, Blade 1, Mixture 4/22/75

$cg\sigma$ = 625

h	$c/c_g\sigma$	k	c	CALCULATED $(c/c_g\sigma)$	h^*
6	4.48	560	2800	4.48	6
3.1	2.85	535	1783.3	2.85	3.1
1.25	1.25	390	780.	1.25	1.25
.25	.25	100	142.86	.23	
.3	.3	125	178.6	.29	.3
.1	.1	50	55.6	.09	.1

T= 70°F, GUAGES 1&3, 1st Blade
Mixture 4122175

TABLE. H

THICKNESS FUNCTION $f(h) = C/C_g\sigma$ Vs RESISTIVITY R

AVERAGE VALUE OF $C_g\sigma$ = 250 (ohm cm)$^{-1}$ for quages 1&3 at T= 70°F

R	h	$C/C_g\sigma$	k	C	$(C/C_g\sigma)^*$	h^*
.5	6.2	4.55	560	1120	4.48	
	6.0	4.46	560	1120	4.48	
	6.05	4.48	560	1120	4.48	6.05
1.0	1.1	1.1	350	350	1.4	
	1.8	1.8	480	480	1.92	
	1.9	1.9	488	488	1.95	
	1.99	1.99	497	497	1.99	1.99
1.5	.9	.9	309	206	.824	
	.7	.7	250	166.67	.67	
	.59	.59	220	146.67	.59	.59
2.0	.5	.5	190	95	.38	
	.3	.3	120	60	.24	
	.2	.2	80	40	.16	
	.15	.15	60	30	.12	
	.04	.04	20	10	.04	.04
.6	4.25	3.67	550	916.67	3.67	4.25

TABLE 5

$T_{LIQ} = 70^\circ F$ GAUGES 2&4, 1st Blade, Mixture 4122175

Average value of $Cg\sigma$ = 500 $(\text{ohm cm})^{-1}$

h	$C/Cg\sigma$	k	C	$(C/Cg\sigma)^*$	h^*
2	2	497	994	1.99	2
.7	.7	250	250	.5	
.5	.5	190	190	.38	
.3	.3	120	120	.24	
.05	.05	25	25	.05	.05
.5	.5	190	271.43	.54	
1.2	1.2	375	5357	1.07	
1.1	1.1	350	500	1.0	
.87	.87	300	428.57	.86	.87
.85	.85	297	424.29	.85	.85
.5	.5	190	237.5	.475	
.45	.45	175	218.75	.44	.45
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
1	1	330	550	1.1	
.95	.95	320	533.33	1.06	
.9	.9	305	508.33	1.02	
1.2	1.2	375	625	1.25	
1.25	1.25	385	641.67	1.28	
1.3	1.3	400	666.67	1.33	1.3
10	6	427	4270	8.54	

TABLE 6

TABLE OF PREDICTED ADIABATIC FILM THICKN
VS. STEAM VELOCITY; VARIOUS LIQUID FILM FLOW RATES $T_{LIQUID} = 126\,^{\circ}F$

V_{STEAM} (FT/SEC)	T_{FILM} ($PSI \times 10^{-3}$)	$h/\dot{m}^{\frac{1}{2}}$ $mils/(\frac{cc}{min})^{\frac{1}{2}}$	$\dot{m} = 5^{*}$ h(mils)	$\dot{m} = 10^{*}$ h(mils)	$\dot{m} = 20^{*}$ h(mils)	$\dot{m} = 30^{*}$ h(mils)	$\dot{m} = 40^{*}$ h(mils)	$\dot{m} =$ h(mi
100	.041	.936	2.10	2.96	4.18	5.13	5.92	6.62
300	.300	.346	0.78	1.09	1.55	1.90	2.19	2.45
500	.721	.223	0.50	0.70	1.00	1.22	1.41	1.58
700	1.34	.164	0.37	0.52	0.73	0.90	1.04	1.16
900	2.09	.131	0.29	0.41	0.59	0.72	0.83	0.93
1100	2.99	.110	0.25	0.35	0.49	0.60	0.70	0.78
1300	4.05	.094	0.21	0.30	0.42	0.52	0.59	0.66
1500	5.12	.084	0.19	0.27	0.38	0.46	0.53	0.5

* UNITS OF $\dot{m}$ ARE IN $^{cc}/_{min}$.

TABLE 7 T = 126°F

TABLE OF EXPERIMENTAL ADIABATIC FILM THICKNESS VS. STEAM VELOCITY; VARIOUS LIQUID FILM FLOW RATES

FILM RATE in)	V_{STEAM} (ft/sec)	GAUGE 1 △ h (mils)	GAUGE 2 ○ h (mils)	GAUGE 3 □ h (mils)	GAUGE 4 ▽ h (mils)	DATE 1975
	1288	1.7	.18	1.0	.65 - .30	5/2
	1042	-	.3	1.7 - .68	1.25 - .65	"
	840	-	.65	1.0	.65 - .30	"
	505	1.0	-	4.0 - 1.0	3.0 - 1.25	4/2
	252	5.65 - 1.0	-	—	3.0 - 1.9	"
	200	11.5 - 4.1	-	8.15	6.1	"
	1288	2.2	.3	1.32 - .80	1.25	5/2
	1042	-	.65	1.7 - 1.0	1.9 - 1.25	"
	840	-	1.25 - .65	1.7 - 1.0	1.9 - 1.25	"
	505	1.32	-	5.65 - 2.82	6.1 - 3.0	4/2
	252	5.65	-	8.15	6.1	"
	200	5.65	-	8.15	6.1	"
	1288	2.85 - 4.1	.65	2.2	1.9	5/2
	1042	-	1.25	2.2	1.9	"
	840	-	1.25	2.2	1.9	"
	505	1.7	-	5.65	3.0	4/2
	252	8.15 - 5.65	-	11.5 - 8.15	6.1	"
	200	5.65	-	8.15	6.1	"
	1288	-	1.25	2.82 - 2.2	1.9	5/2
	1042	-	1.25	2.2	1.9	"
	840	-	1.25	2.2	1.9	"

Table 7 (cont)

1

LIQUID FILM FLOW RATE (cc/min)	VSTEAM (ft/sec)	GAUGE 1 △ h (mils)	GAUGE 2 ○ h (mils)	GAUGE 3 □ h (mils)	GAUGE 4 ▽ h (mils)
40	505	2.2	–	8.15	6.1
40	252	8.15	–	11.5 - 8.15	6.1
40	1288	–	1.9	2.82	3.0 - 1.9
40	1042	–	1.9	2.2	1.9
40	840	–	1.9	2.82 - 2.2	1.9
50	505	2.85	–	8.15	6.1
50	252	8.15	–	11.5 - 8.15	6.1
50	1288	–	1.9	2.82	1.9
50	1042	–	1.9	2.82	3.0
50	840	–	1.9	5.65	1.9

TABLE 8

TABLE OF PREDICTED DIABATIC FILM THICKNESS VS. STEAM VELOCITY; VARIOUS LIQUID FILM FLOW RATES $T_{LIQUID} = 70°F$

$h/\dot{m}^{-\frac{1}{2}}$ mils/(cc/min)$^{\frac{1}{2}}$	$\dot{m} = 5$* h(mils)	$\dot{m} = 10$* h(mils)	$\dot{m} = 20$* h(mils)	$\dot{m} = 30$* h(mils)	$\dot{m} = 40$* h(mils)	$\dot{m} = 50$* h(mils)	$\dot{m} = 60$* h(mils)
1.279	2.86	4.04	5.72	7.01	8.08	9.04	9.91
0.473	1.06	1.49	2.11	2.59	2.99	3.34	3.67
0.305	0.68	0.96	1.36	1.67	1.93	2.16	2.36
0.224	0.50	0.71	1.00	1.23	1.42	1.58	1.74
0.179	0.40	0.57	0.80	0.98	1.13	1.27	1.39
0.142	0.32	0.45	0.63	0.78	0.90	1.00	1.10
0.129	0.29	0.41	0.58	0.71	0.82	0.91	1.00
0.115	0.26	0.36	0.51	0.63	0.73	0.81	0.89

* UNITS OF $\dot{m}$ ARE IN cc/min

TABLE 9

FILM THICKNESS VS AXIAL POSITION

V STEAM (FT/SEC)	AXIAL POSITION (INCHES)	h (mils)	ṁ (cc/min)
1.252	.75	8.15	50
	3.75	11.5 - 8.15	
	5.25	6.1	
1.252	.75	8.15	40
	3.75	11.5 - 8.15	
	5.25	6.1	
1.252	.75	8.15 - 5.65	30
	3.75	11.15 - 8.15	
	5.25	6.1	
1.252	.75	5.65	20
	3.75	8.15	
	5.25	6.1	
1.252	.75	5.65 - 1.0	10
	3.75	5.65 - 1.72	
	5.25	3.0 - 1.9	
200	.75	11.5 - 4.1	10
	3.75	8.15	
	5.25	6.1	
200	.75	5.65	20
	3.75	8.15	
	5.25	6.1	
200	.75	5.65	30
	3.75	8.15	
	5.25	6.1	

cont

FILM THICKNESS VS. AXIAL POSITION

EAM $\left(\frac{ft}{sec}\right)$	AXIAL POSITION (inchs)	h (mils)	$\dot{m}$ $\left(\frac{cc}{min}\right)$
505	.75	2.85	50
	3.75	8.15	
	5.25	6.1	
1505	.75	2.2	40
	3.75	8.15	
	5.25	6.1	
505	.75	1.7	30
	3.75	5.65	
	5.25	3.0	
505	.75	1.32	20
	3.75	5.65-2.82	
	5.25	6.1-3.0	
505	.75	1.0	10
	3.75	4.1 - 1.0	
	5.25	3.0 - 1.25	

cont

FILM THICKNESS VS. AXIAL POSITIONS

V_{STEAM} (FT/SEC)	AXIAL POSITION (INCHES)	FILM THICKNESS (mils)	$\dot{m}$ (cc/mi
840	2.25	1.9	50
	3.75	2.82	
	5.25	3.0	
840	2.25	1.9	40
	3.75	2.2	
	5.25	1.9	
840	2.25	1.25	30
	3.75	2.2	
	5.25	1.9	
840	2.25	1.25	20
	3.75	2.2	
	5.25	1.9	
840	2.25	.65	10
	3.75	1.7-1.0	
	5.25	1.9-1.25	
840	2.25	.3	5
	3.75	1.7-.68	
	5.25	1.25-.65	

cont

FILM THICKNESS VS AXIAL POSITION

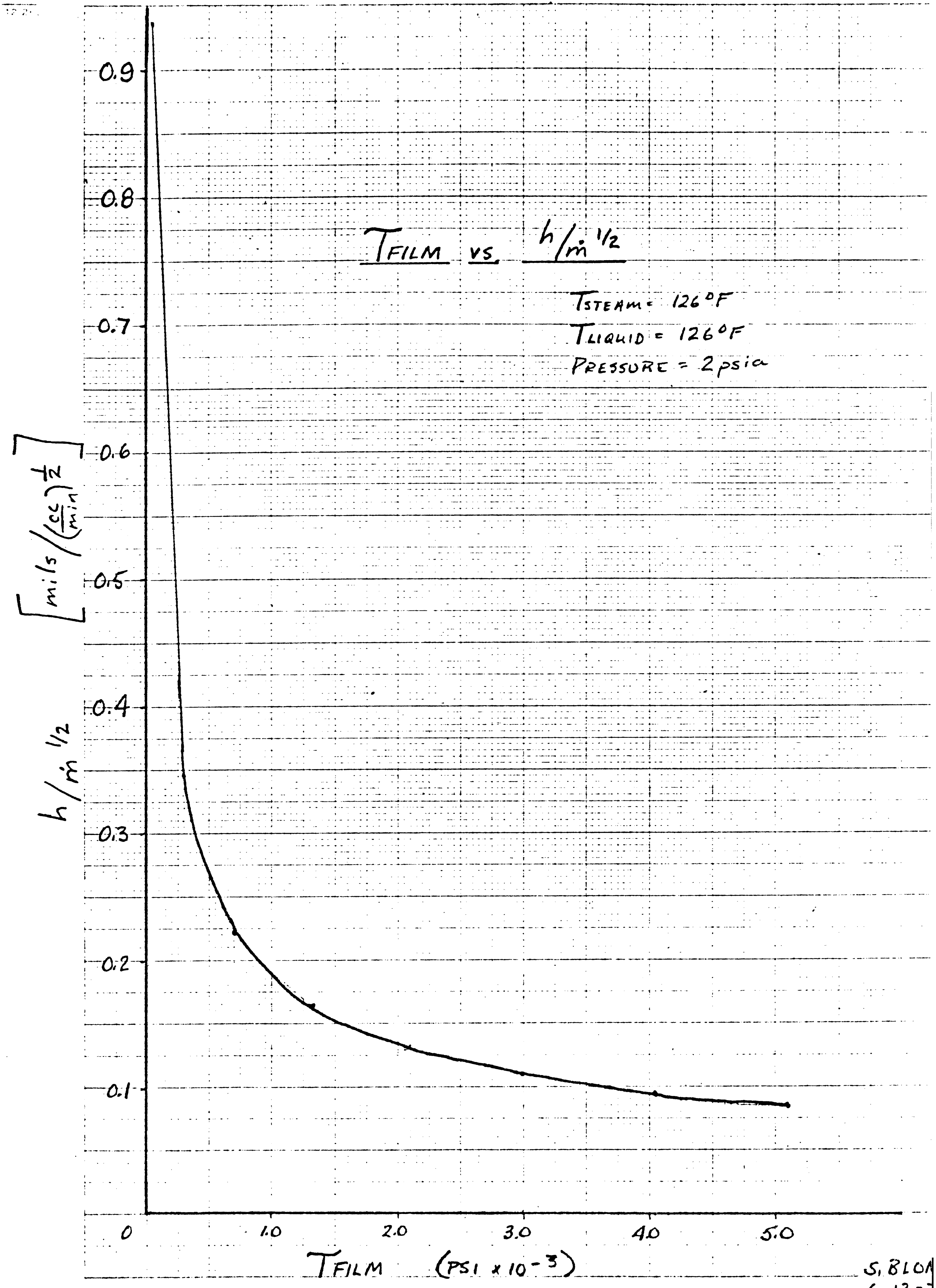
EAM (sec)	AXIAL POSITION (inches)	FILM THICKNESS (mils)	ṁ (cc/min)
42	2.25	1.9	50
	3.75	5.65	
	5.25	1.9	
42	2.25	1.9	40
	3.75	2.82-2.22	
	5.25	1.9	
42	2.25	1.25	30
	3.75	2.2	
	5.25	1.9	
42	2.25	1.25	20
	3.75	2.2	
	5.25	1.9	
42	2.25	1.25 - .65	10
	3.75	1.7-1.0	
	5.25	1.9-1.25	
42	2.25	.65	≈ 5
	3.75	1.0	
	5.25	.65-.3	

cont

FILM THICKNESS VS AXIAL POSITION

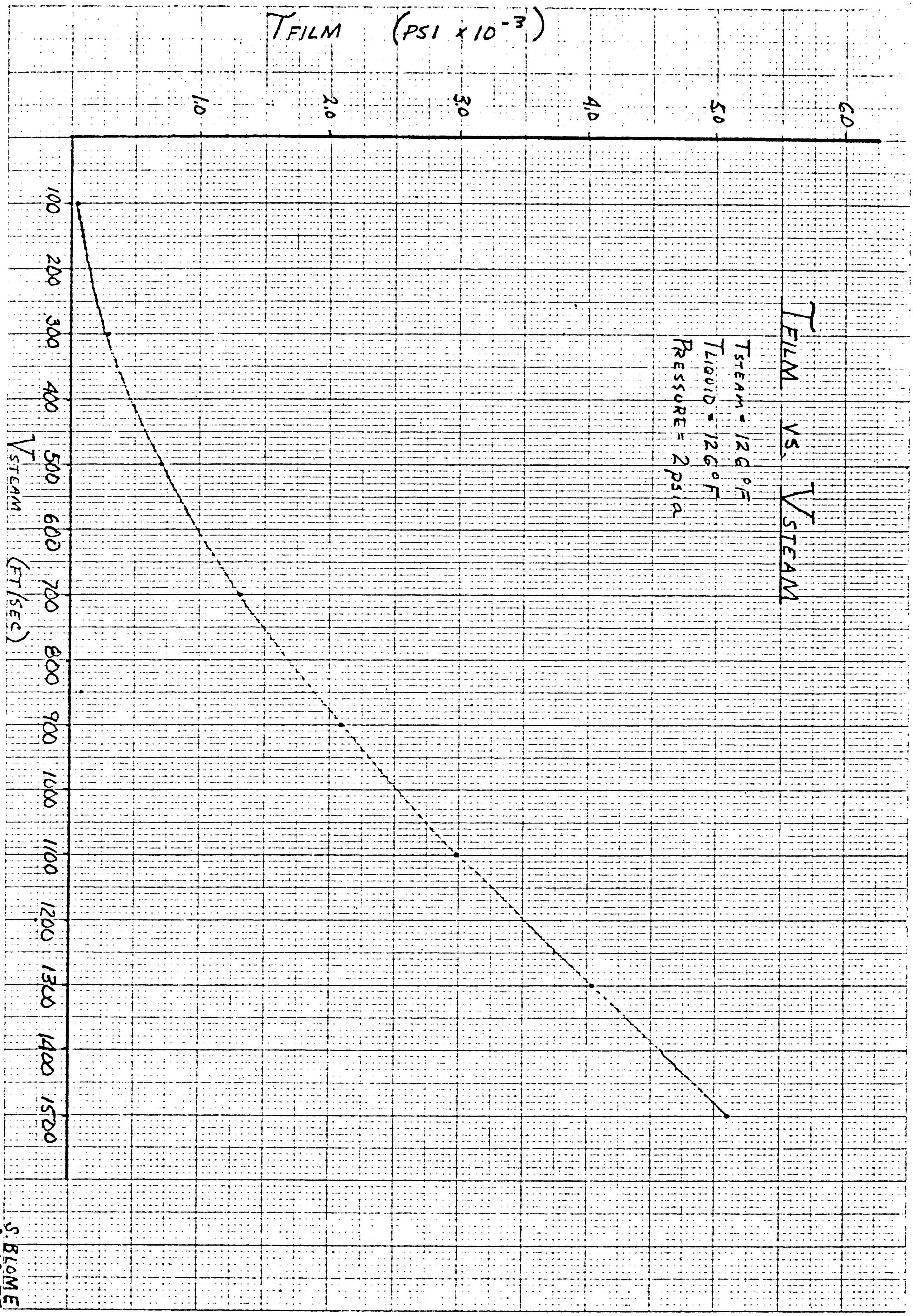
VSTEAM (FT/SEC)	AXIAL POSITION (INCHES)	FILM THICKNESS h (mils)	$\dot{m}$ (cc/mi
1288	.75	—	50
	2.25	1.92	
	3.75	2.82	
	5.25	1.9	
1288	.75	—	40
	2.25	1.9	
	3.75	2.82	
	5.25	3.0 - 1.9	
1288	.75	—	30
	2.25	1.25	
	3.75	2.82 - 2.2	
	5.25	1.9	
1288	.75	4.1 - 2.85	20
	2.25	.65	
	3.75	2.2	
	5.25	1.9	
1288	.75	2.2	10
	2.25	.3	
	3.75	1.32 - .8	
	5.25	1.25	
1288	.75	1.7	≈5
	2.25	.18	
	3.75	1.0	
	5.25	.65 - .3	

Appendix B - List of Figures



S. BLOM
6-12-

FIG. 8 T_{FILM} vs. $h/\dot{m}^{1/2}$


TFILM VS. VSTEAM
TSTEAM = 126°F
TLIQUID = 126°F
PRESSURE = 2 PSIA
TFILM (PSI x 10^-3)
1.0
2.0
3.0
4.0
5.0
6.0
VSTEAM (FT/SEC)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
S. BLOME

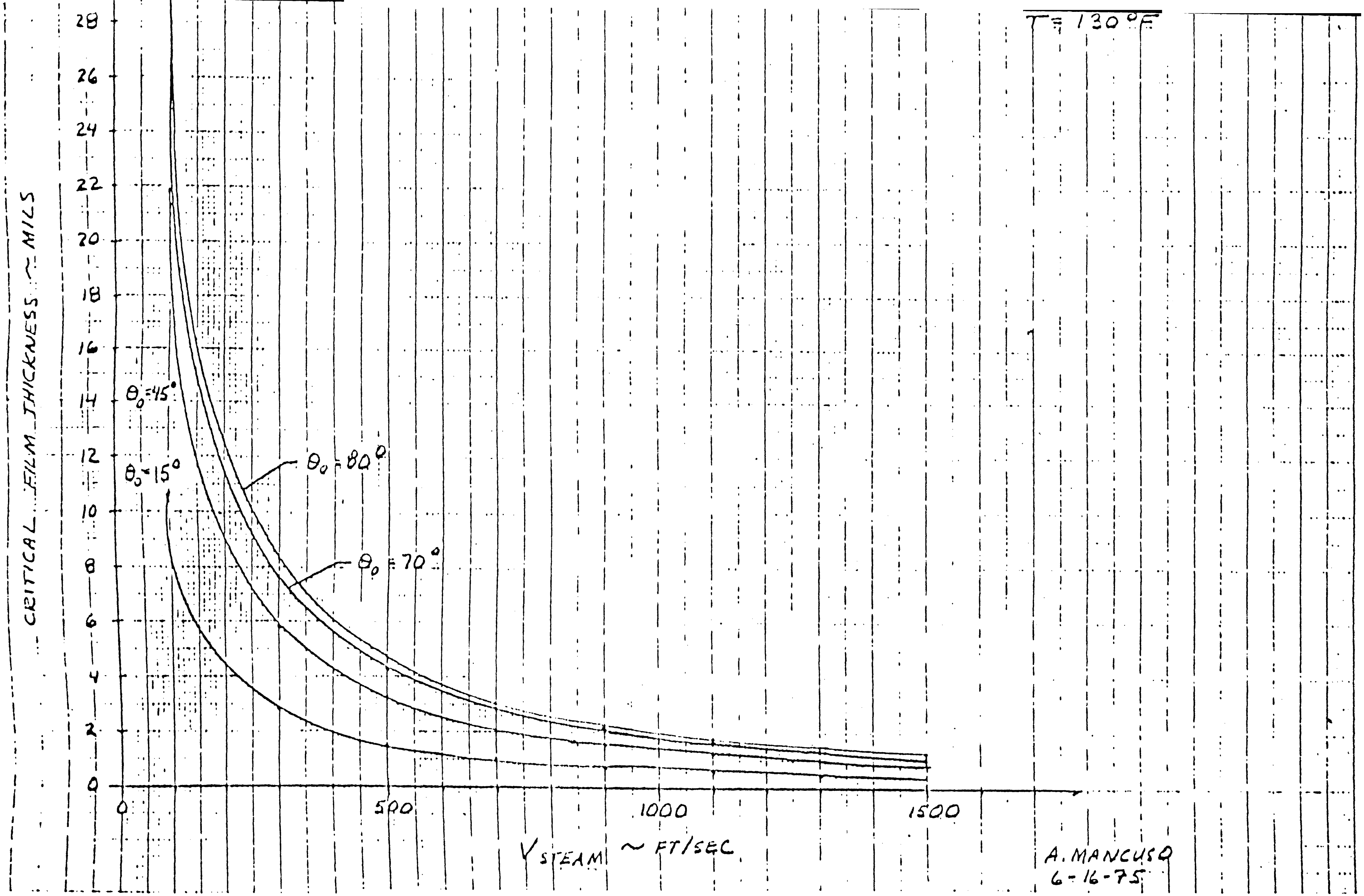


FIG 10 Critical Film Thickness Vs Steam Velocity

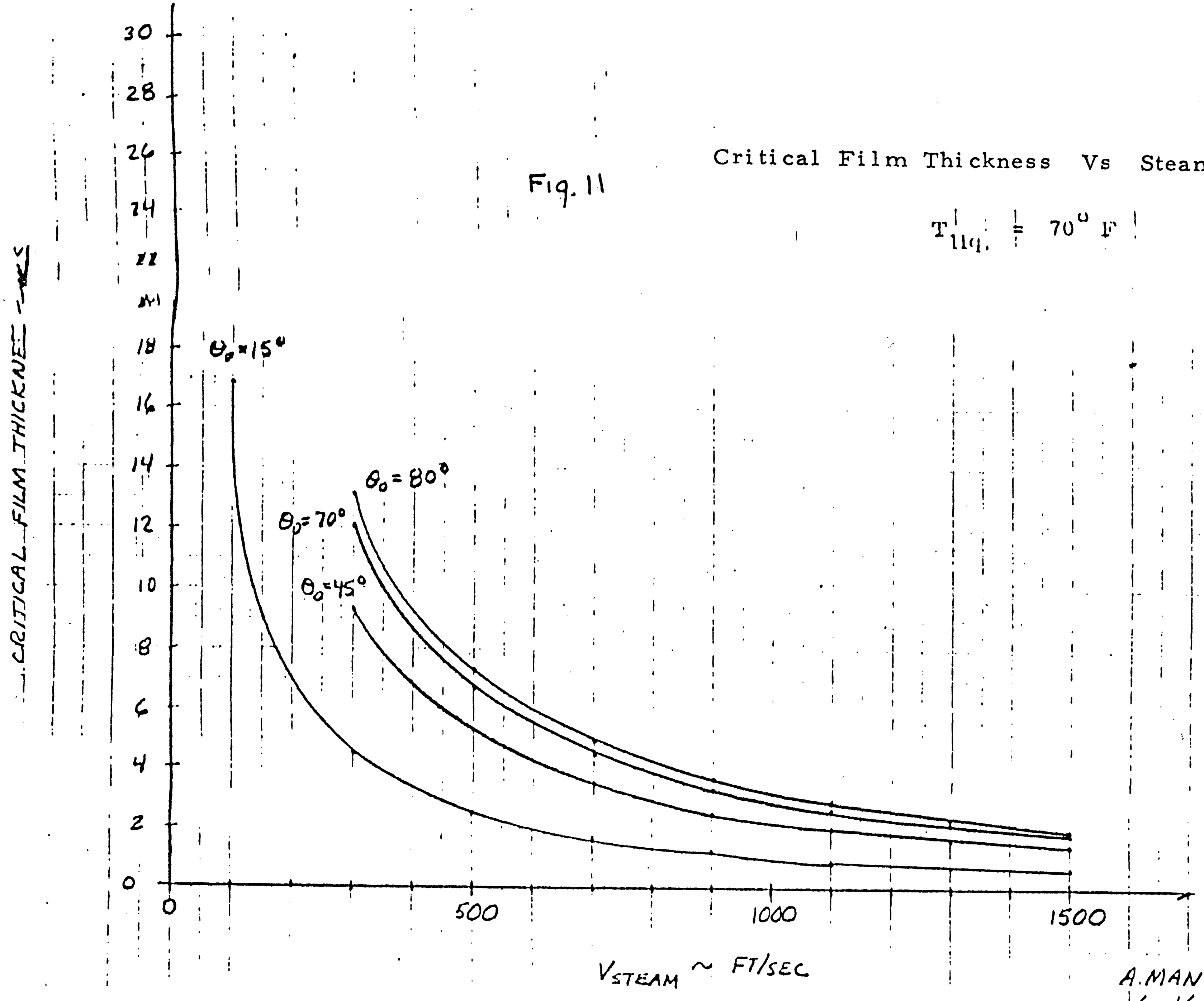


Fig. 11

Critical Film Thickness Vs Steam Velocity

$T_{liq.} = 70° F$

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Film Thickness Function Vs Resistivity

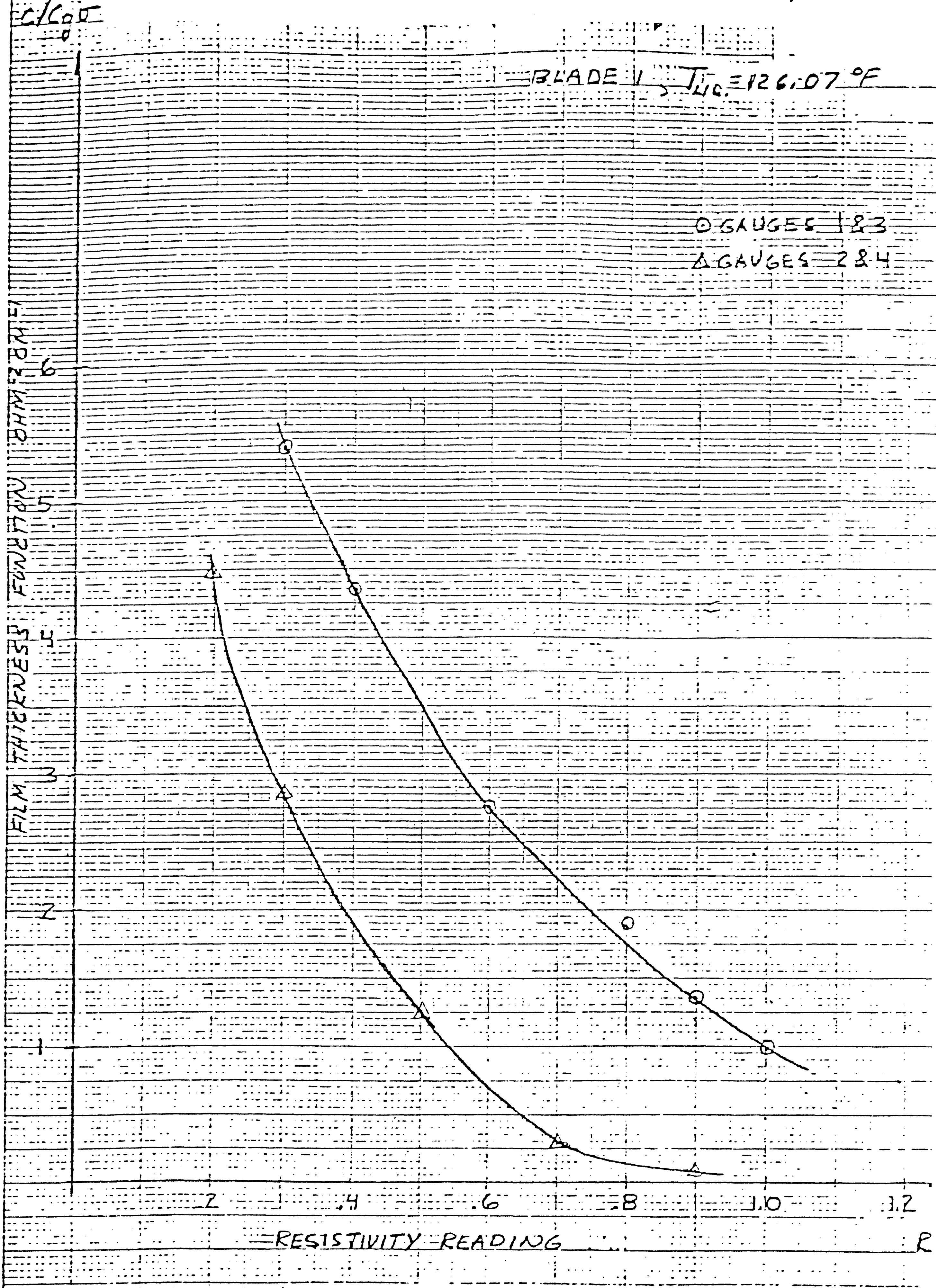
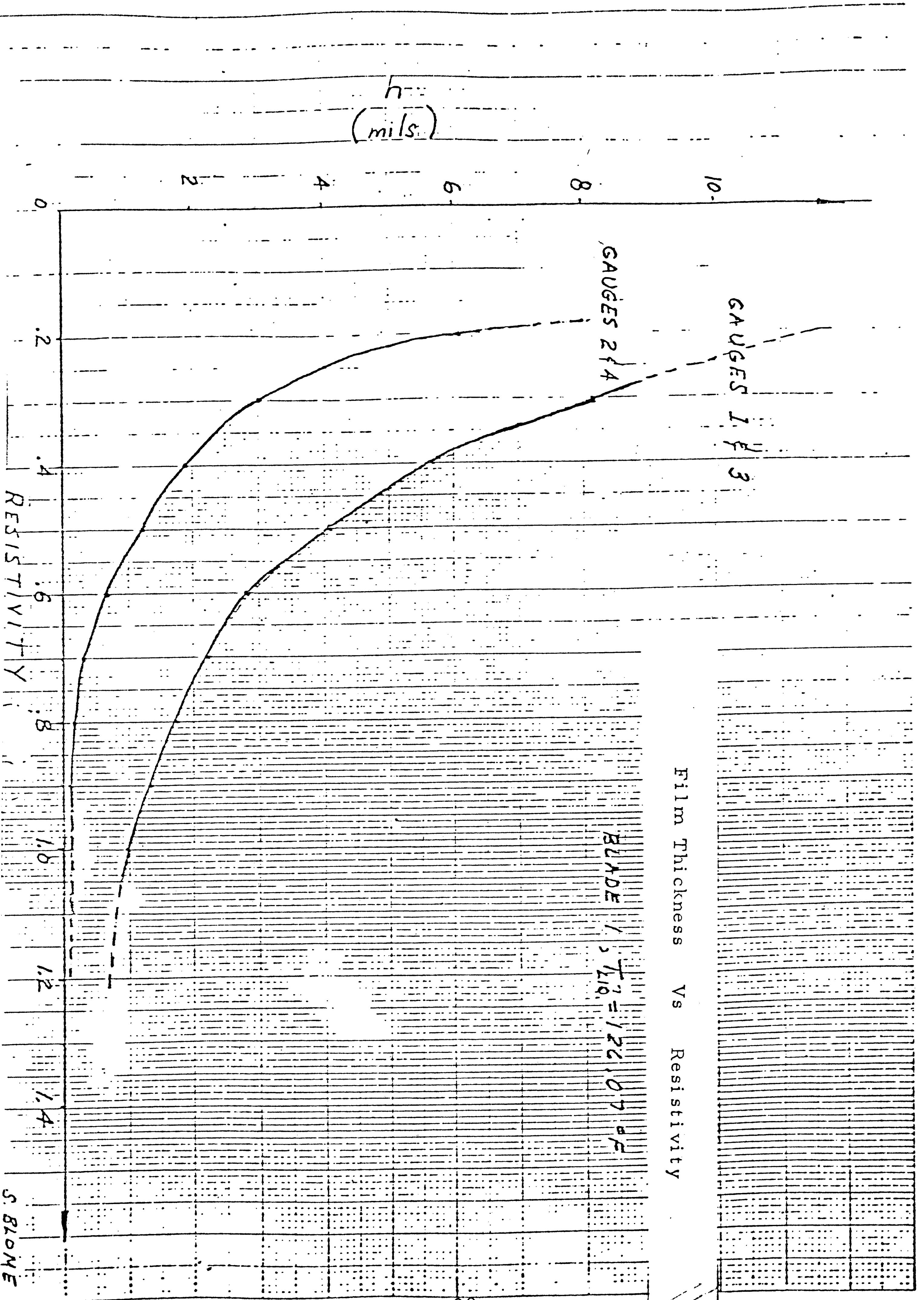


FIG. 12 Film Thickness Function Vs Resistivity



Film Thickness Vs Resistivity

Film Thickness Function Vs Resistivity

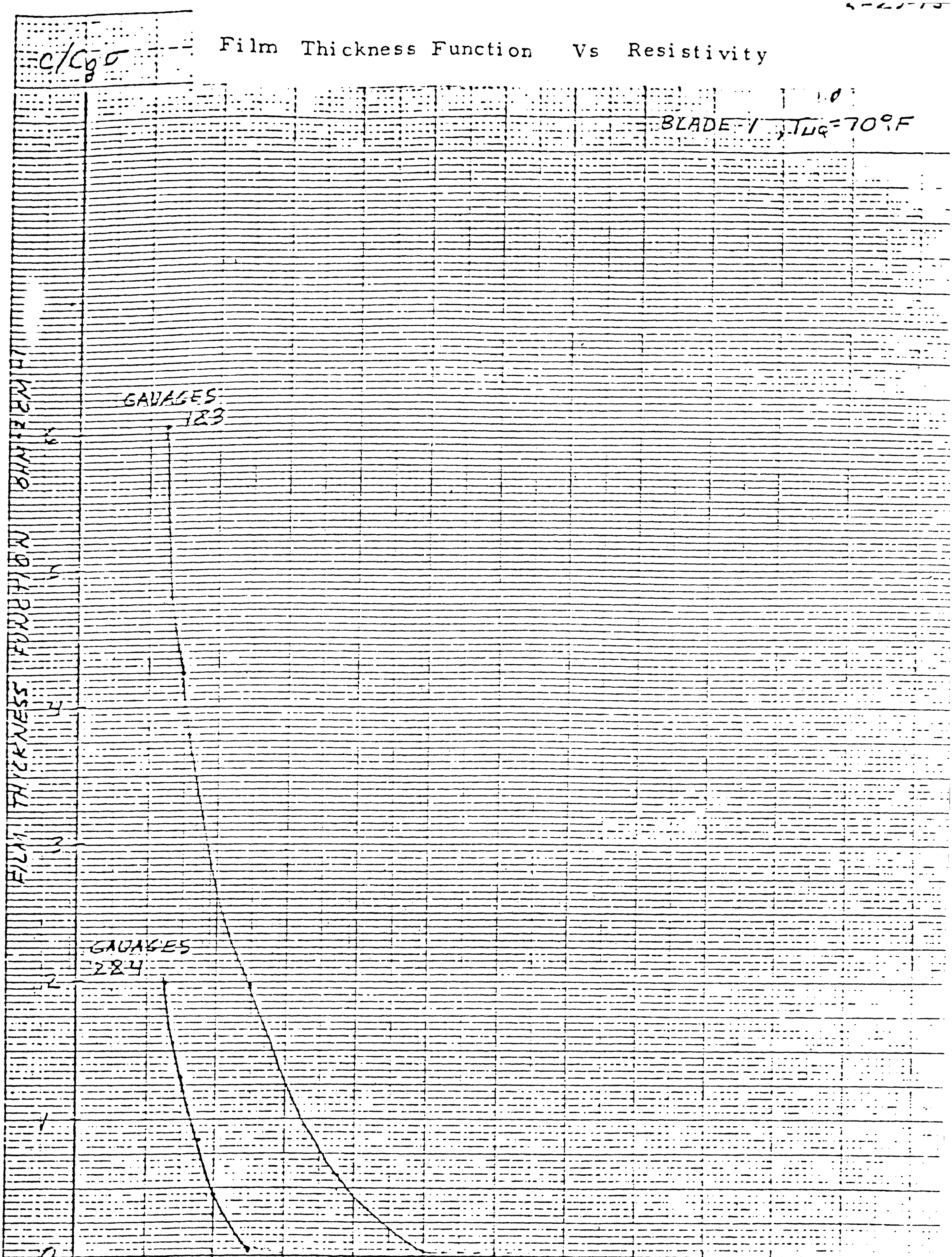
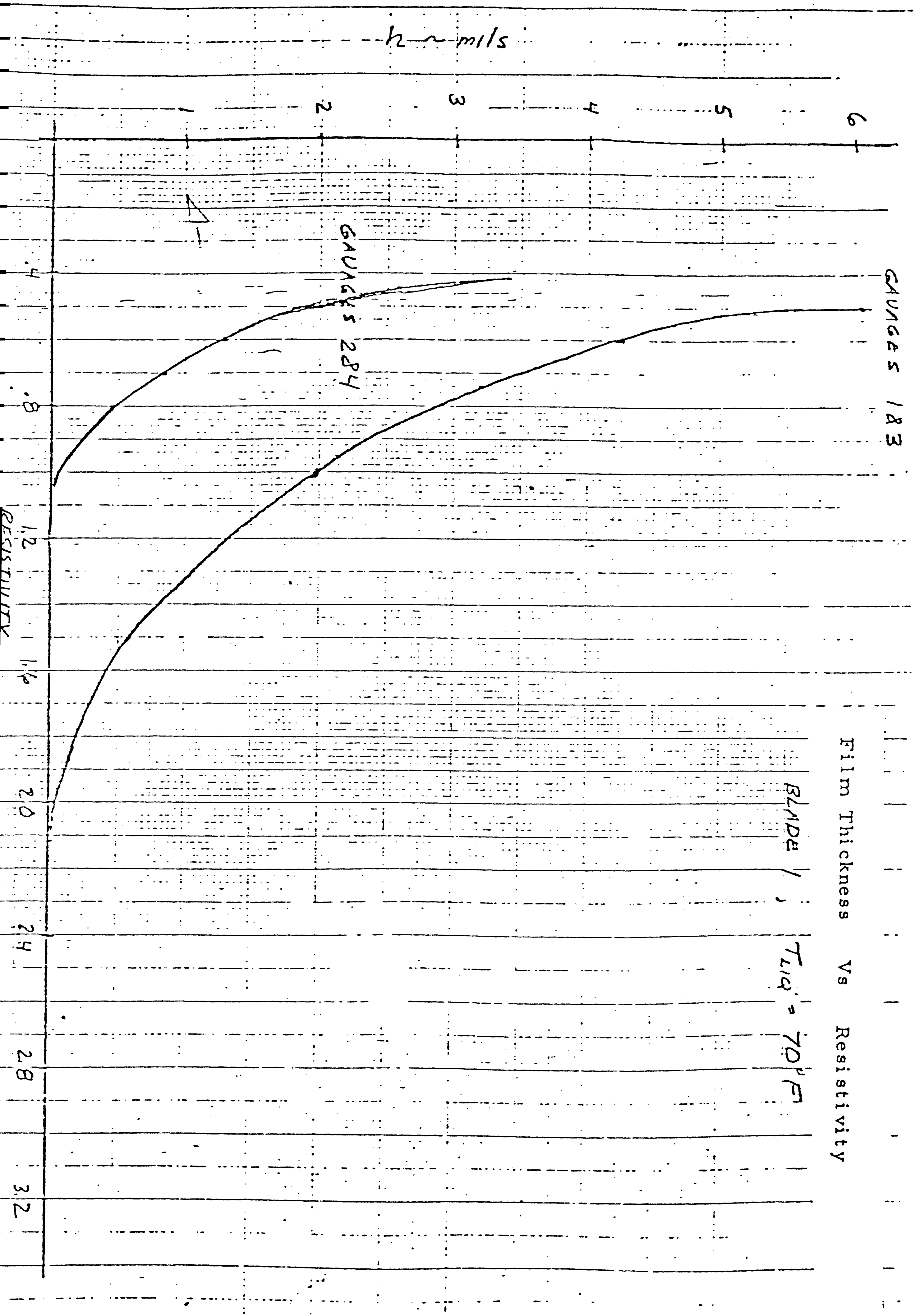


FIG. 14

Film Thickness Function Vs Resistivity



Film Thickness Vs Resistivity

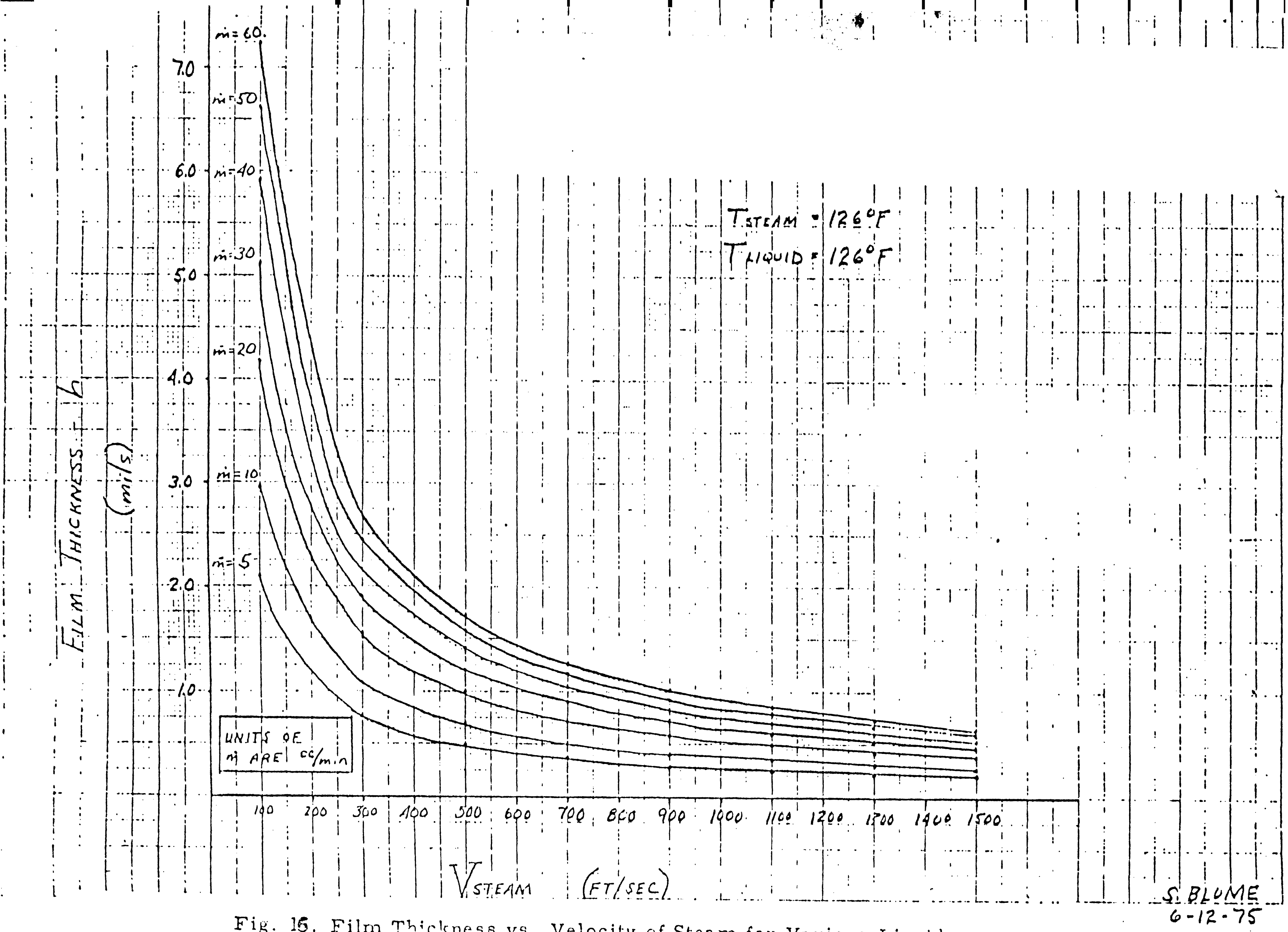


Fig. 15. Film Thickness vs. Velocity of Steam for Various Liquid Film Flow Rates

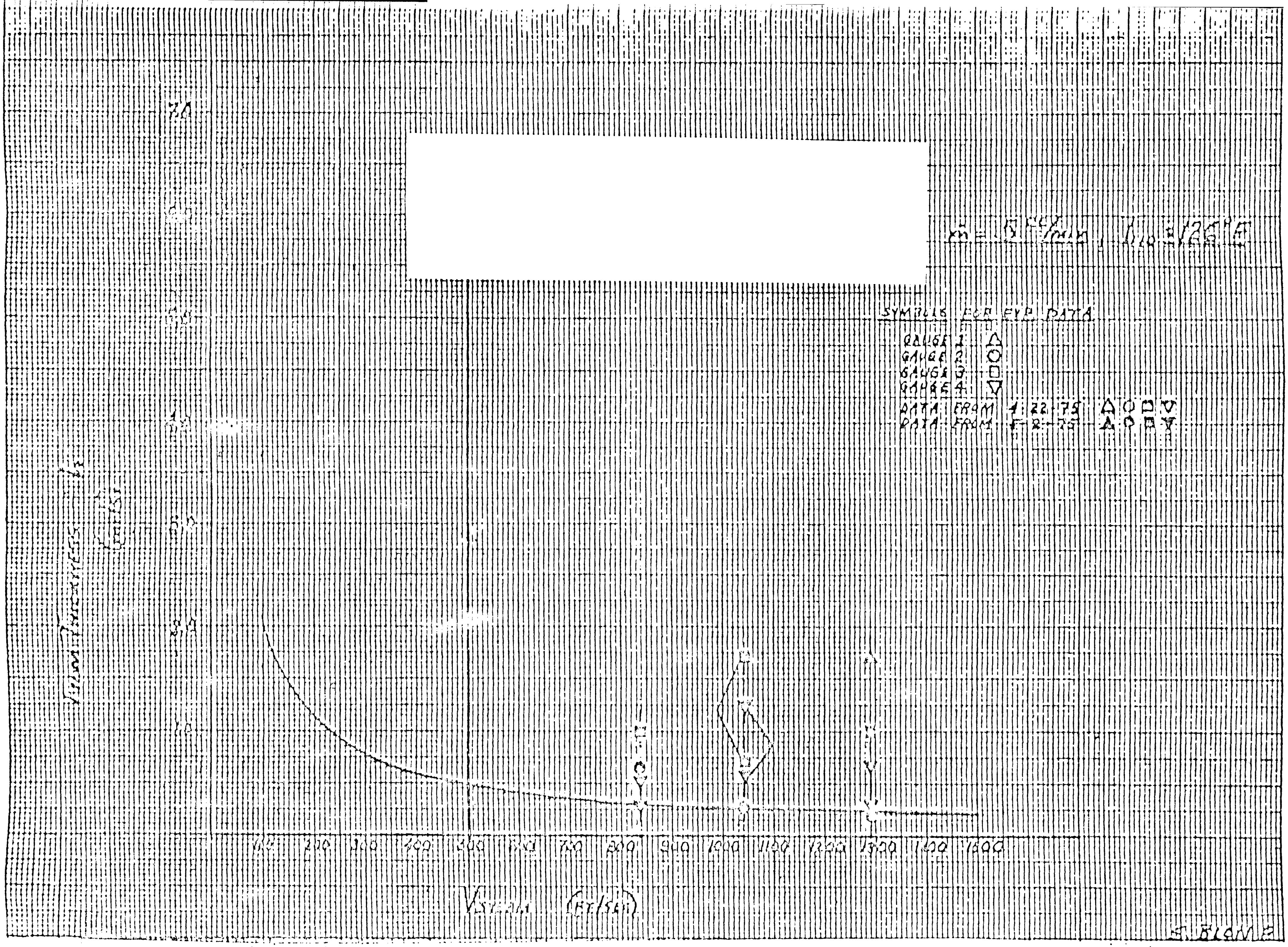


Fig. 17 Film Thickness vs. Velocity of S

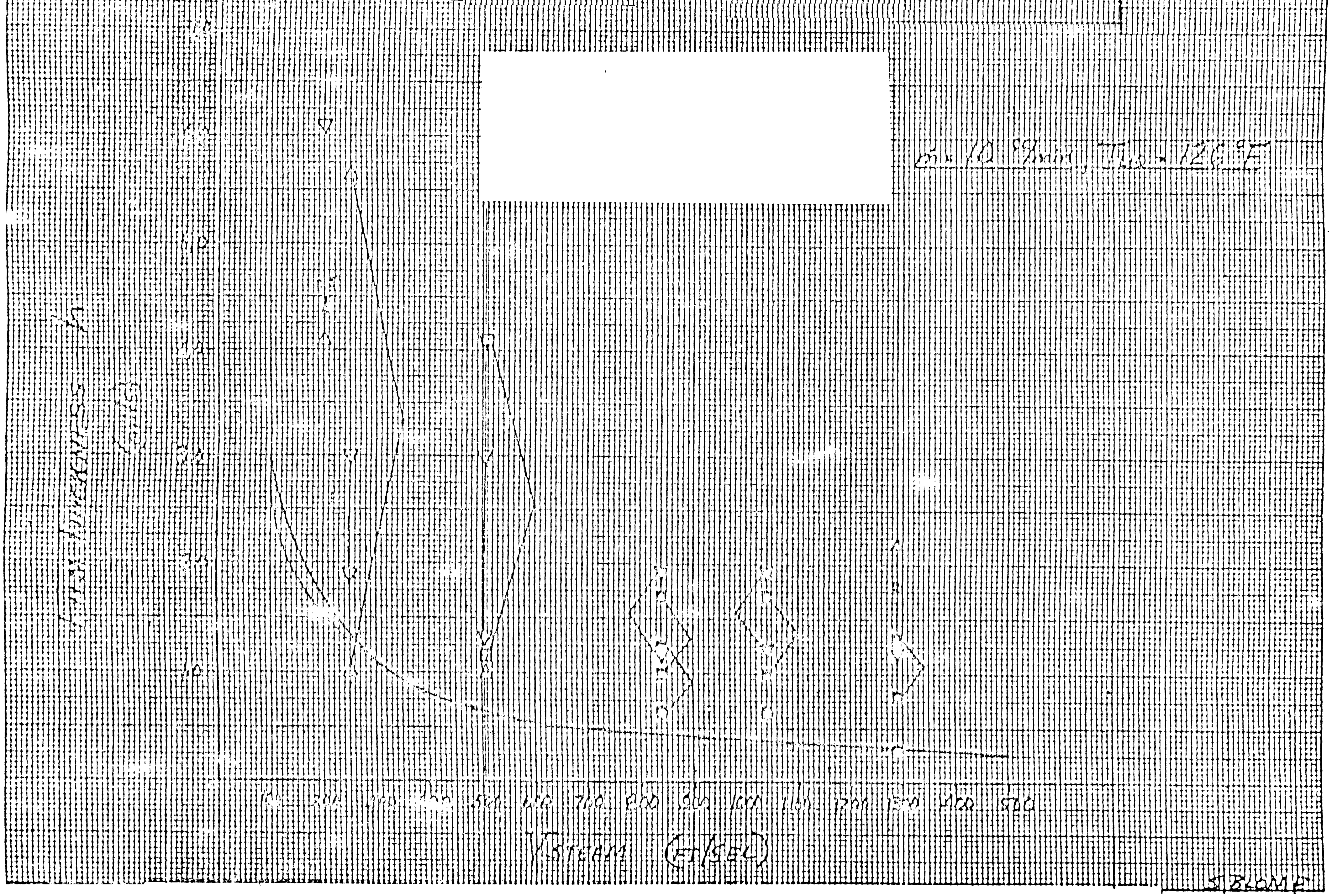
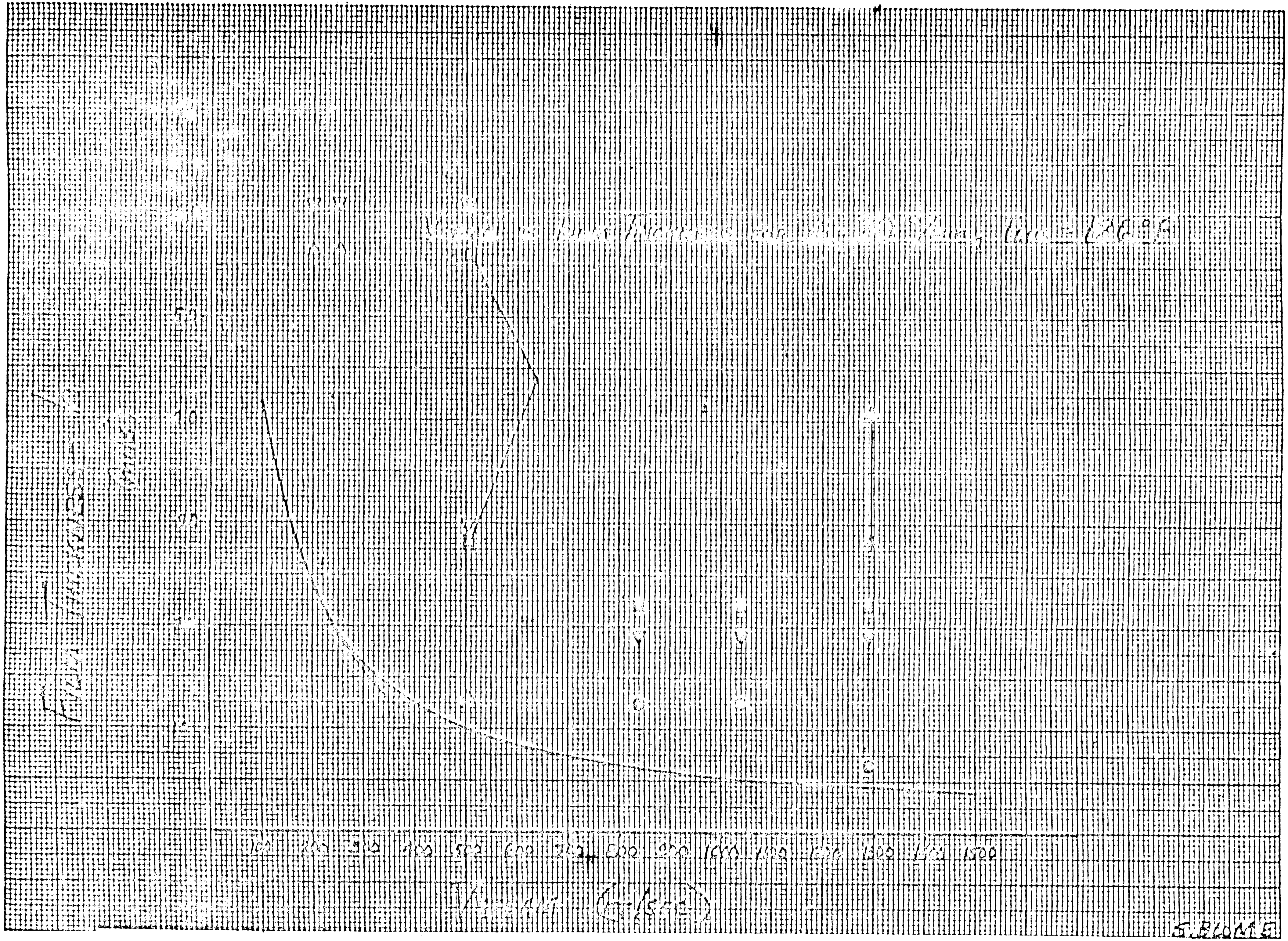


Fig. 18 Film thickness vs. Velocity of Steam; Liquid Film Flow Rate = 10 cc./min.

Film Thickness – A
(mils)
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Vacuum
S. BLOME

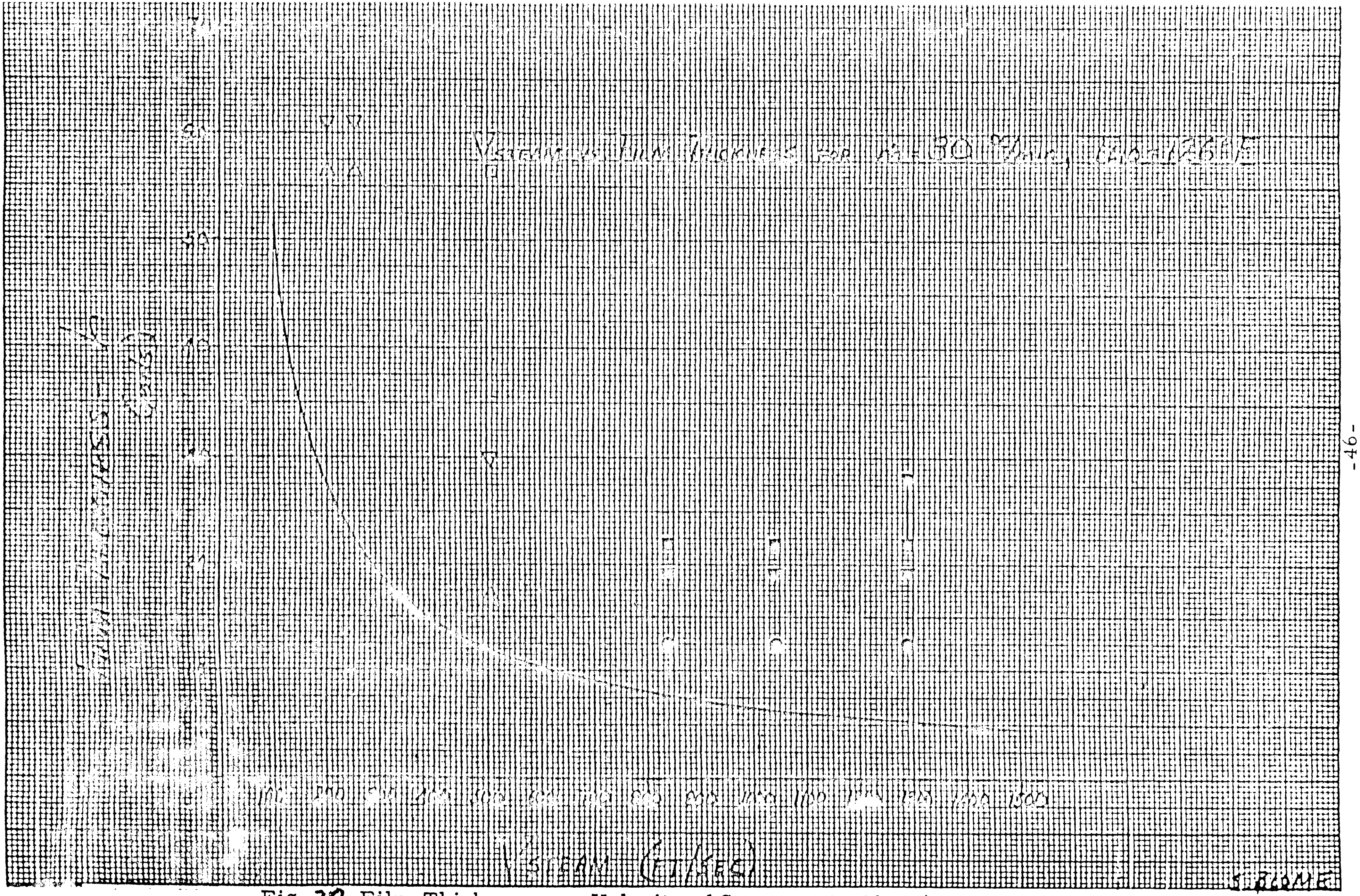


Fig. 20 Film Thickness vs. Velocity of Steam; Liquid Film Flow Rate = 30 cc./min.

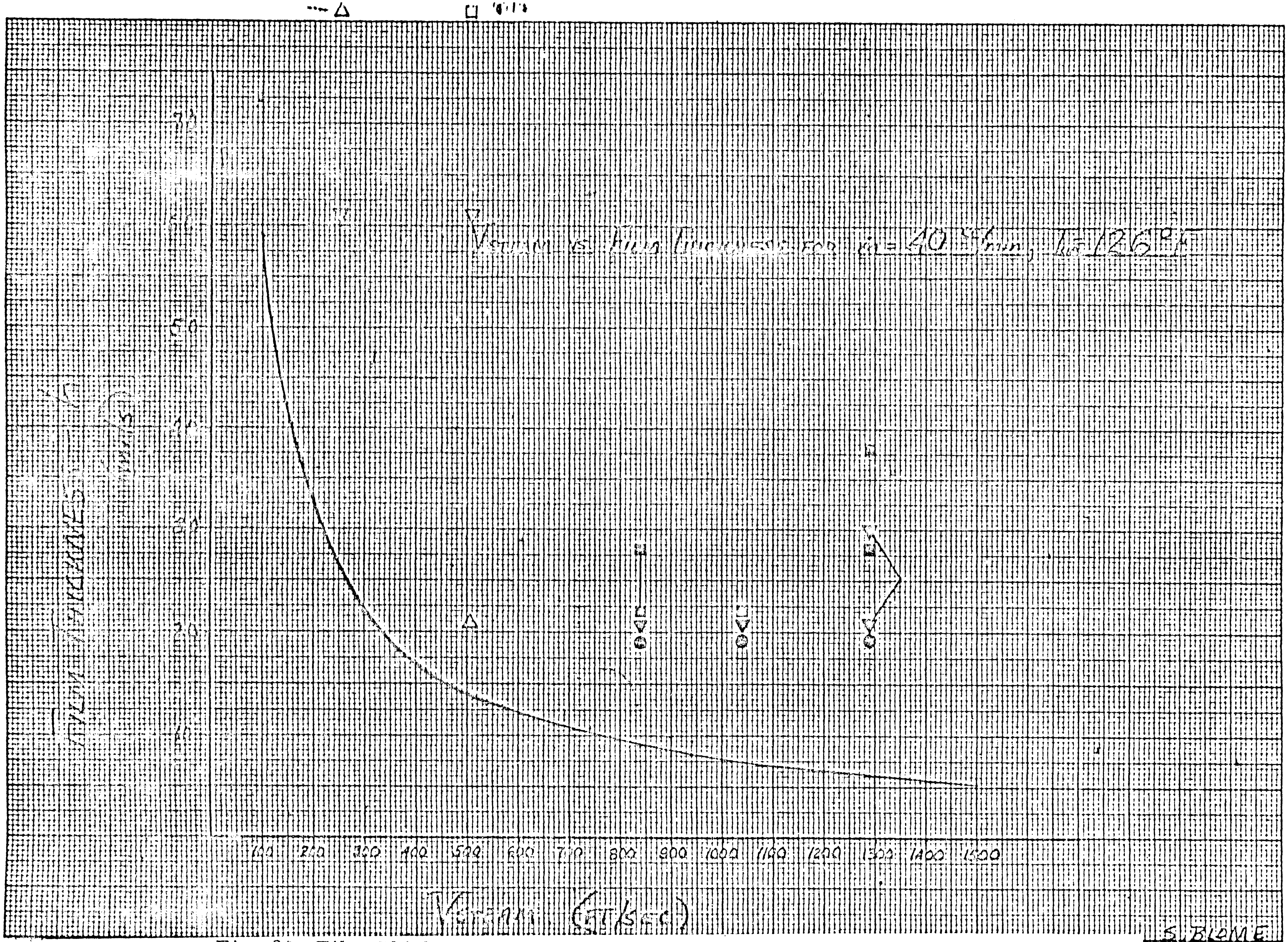


Fig. 29. Film Thickness vs. Velocity of Steam; Liquid Film Flow

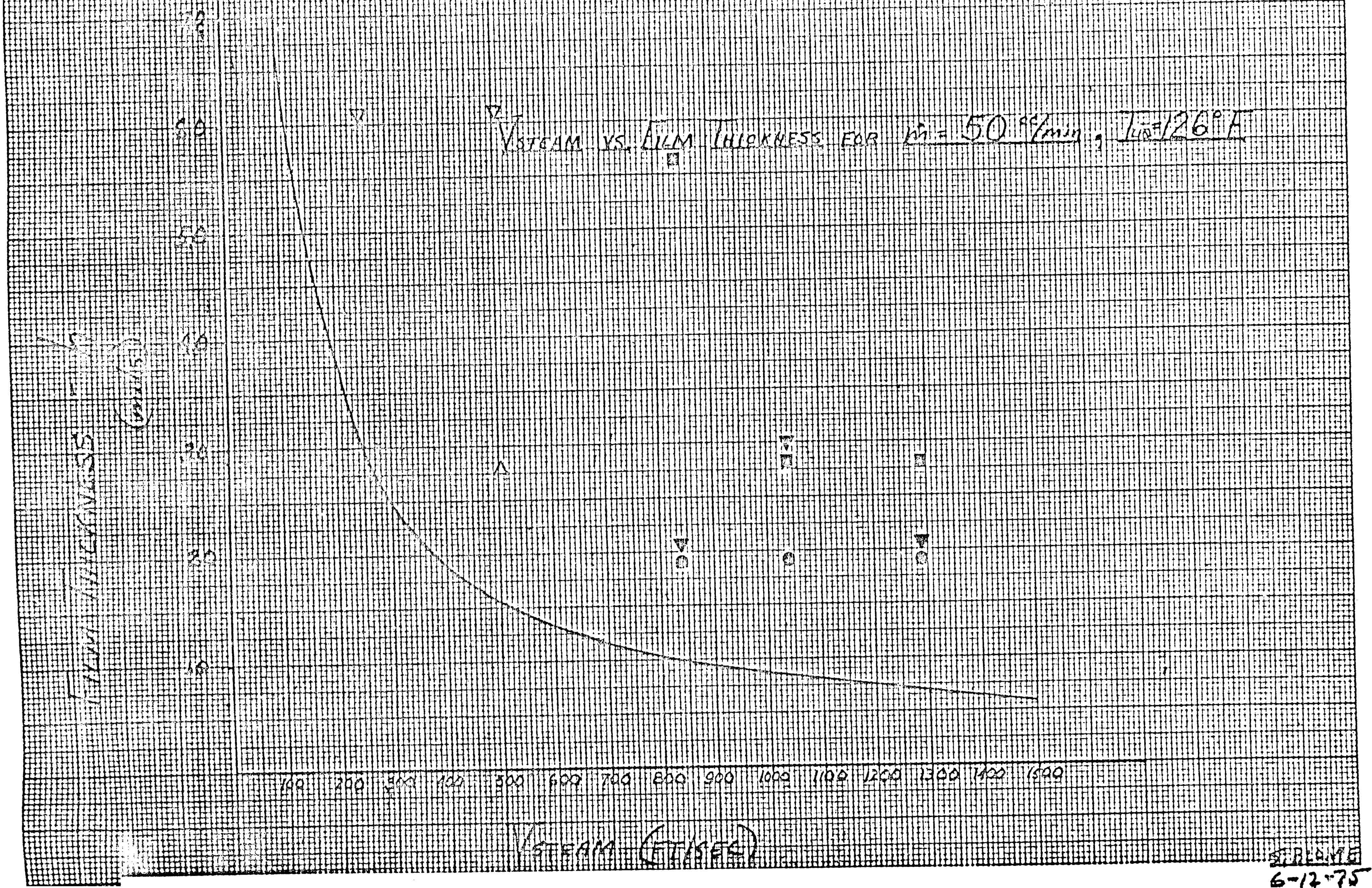


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Fig. 21. Film Thickness vs. Velocity of Steam; Liquid Film Flow Rate = 50 cc./min.

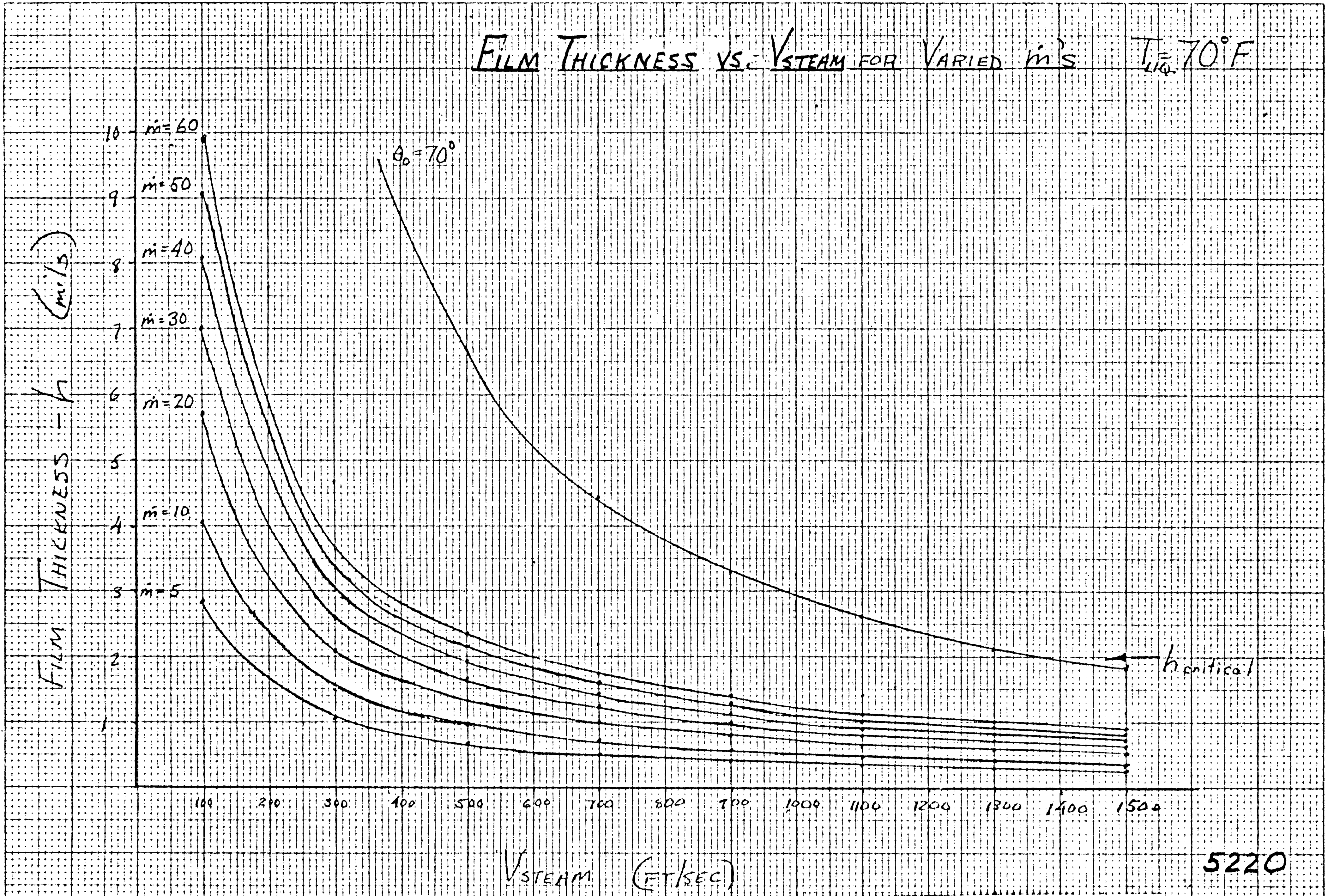


FIG. 23 Predicted Diabatic (Cold Water) Film Thickness vs Steam Velocity; Various

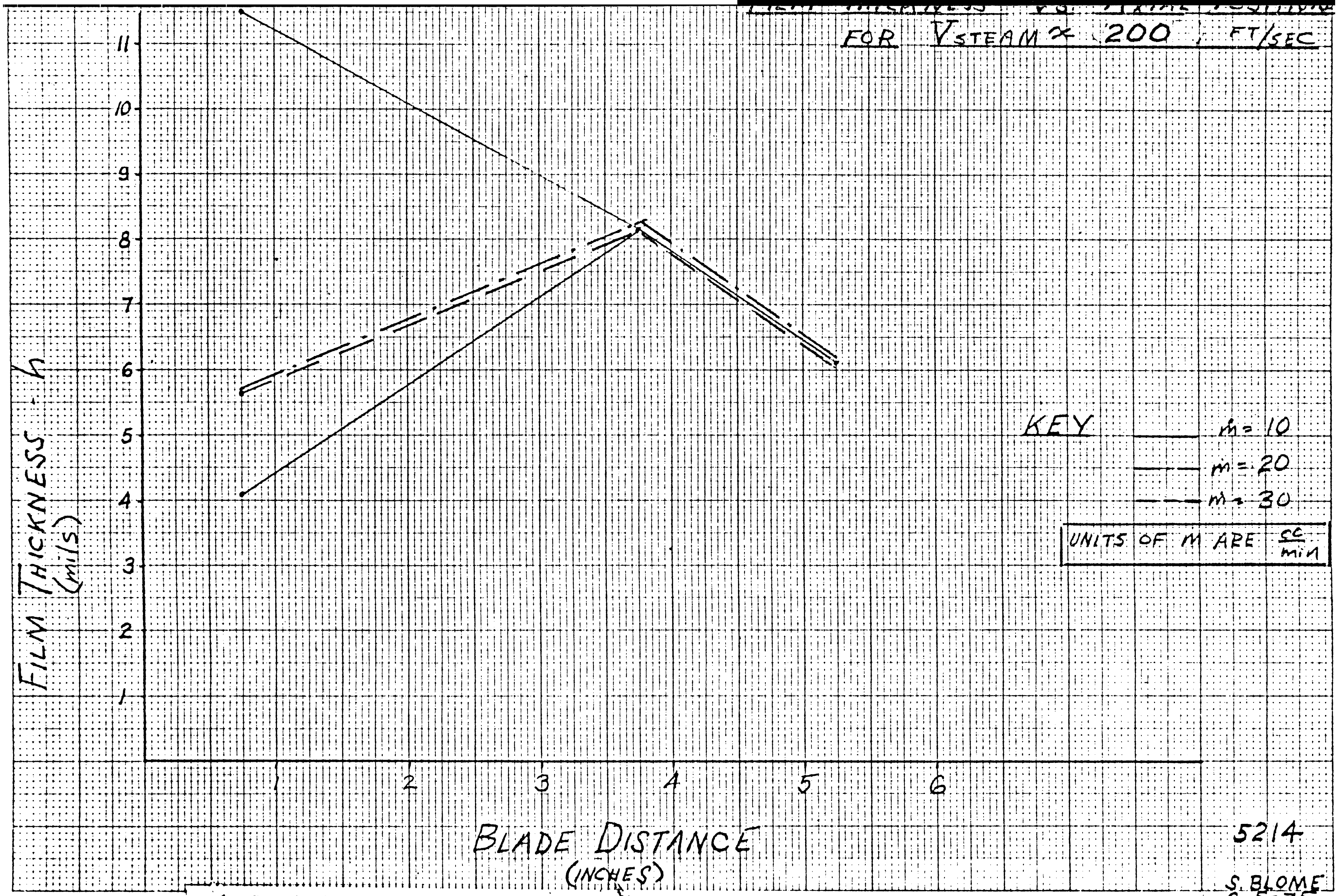
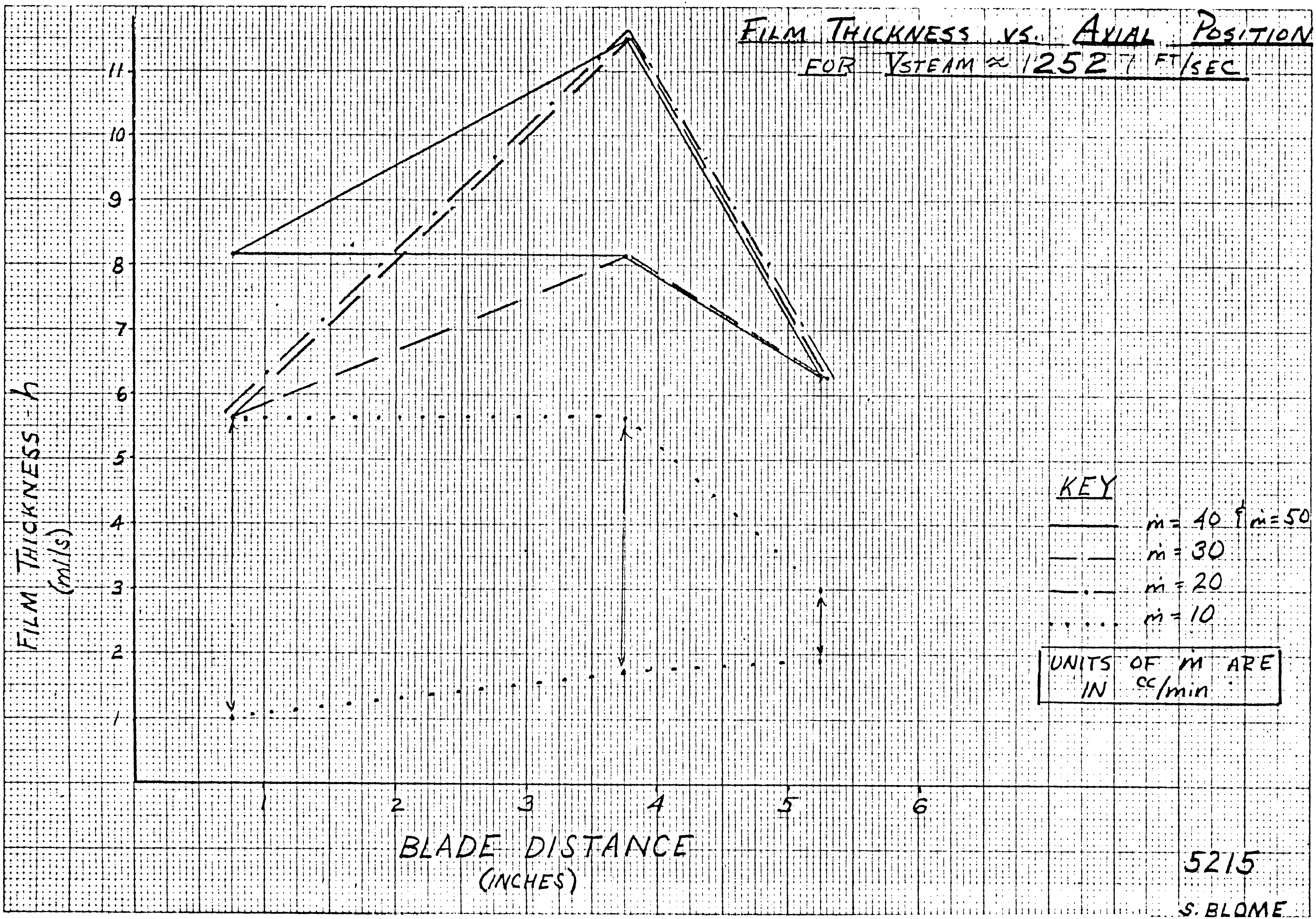


FIG. 24. Variation of Liquid Film Thickness with Axial Position, Steam Velocity = 200 f/s



FILM THICKNESS VS. AXIAL POSITION
FOR $V_{STEAM} \approx 1252$ FT/SEC

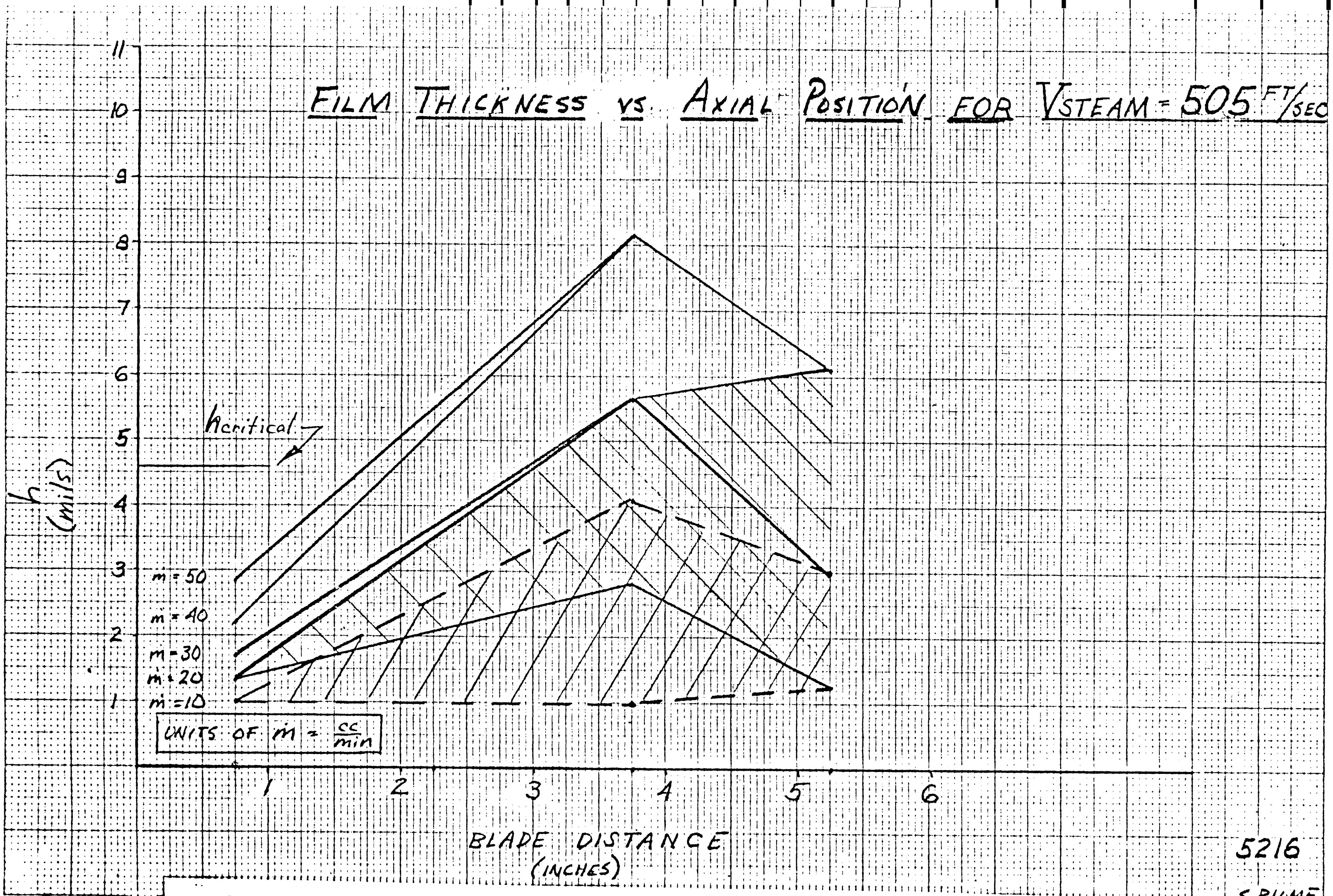
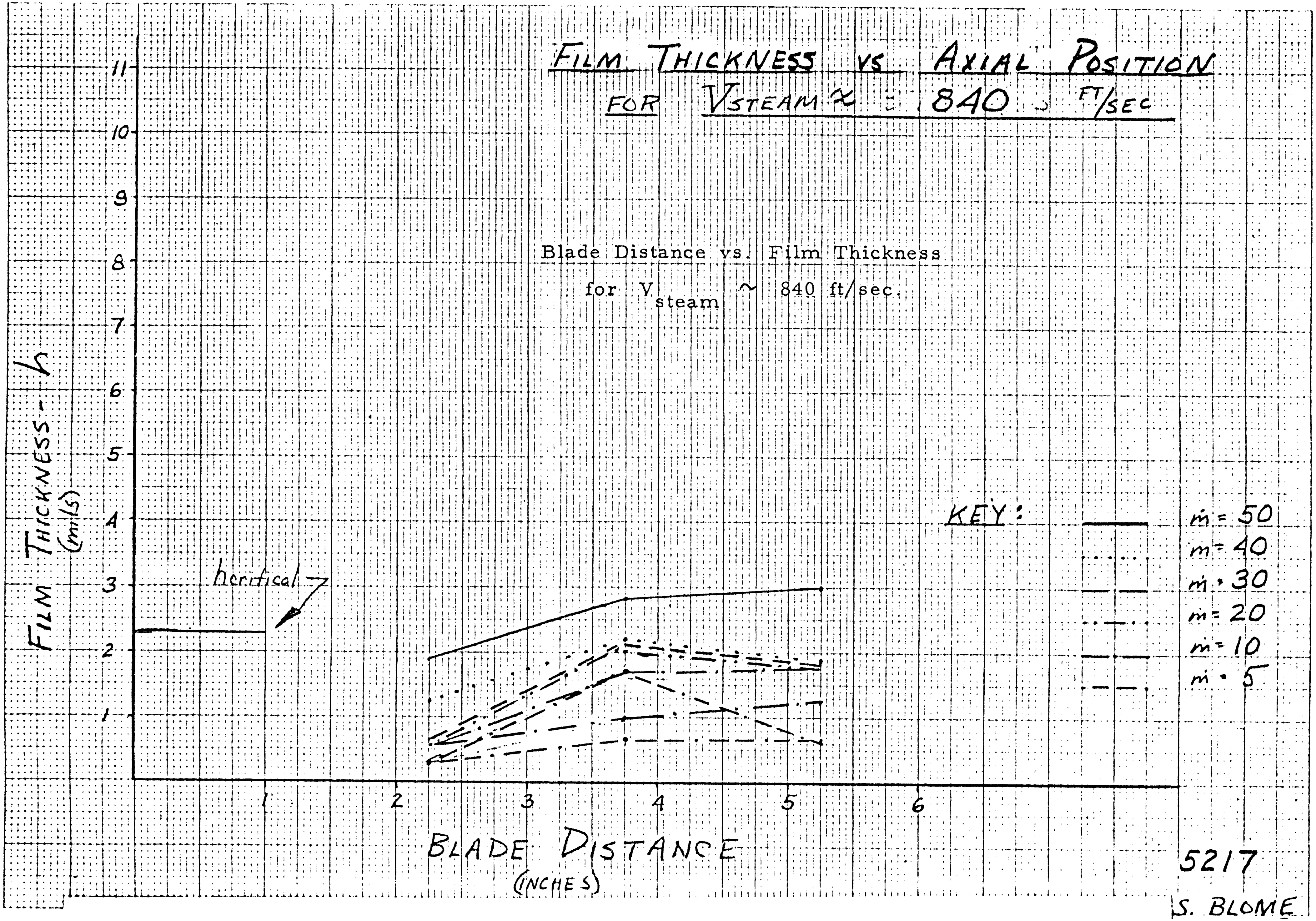


FIG. 26. Variation of Liquid Film Thickness with Axial Position, Steam Velocity = 505 f/s



FILM THICKNESS VS AXIAL POSITION FOR $V_{STEAM} \approx$ 840 FT/SEC

Blade Distance vs. Film Thickness for $V_{steam} \sim$ 840 ft/sec.

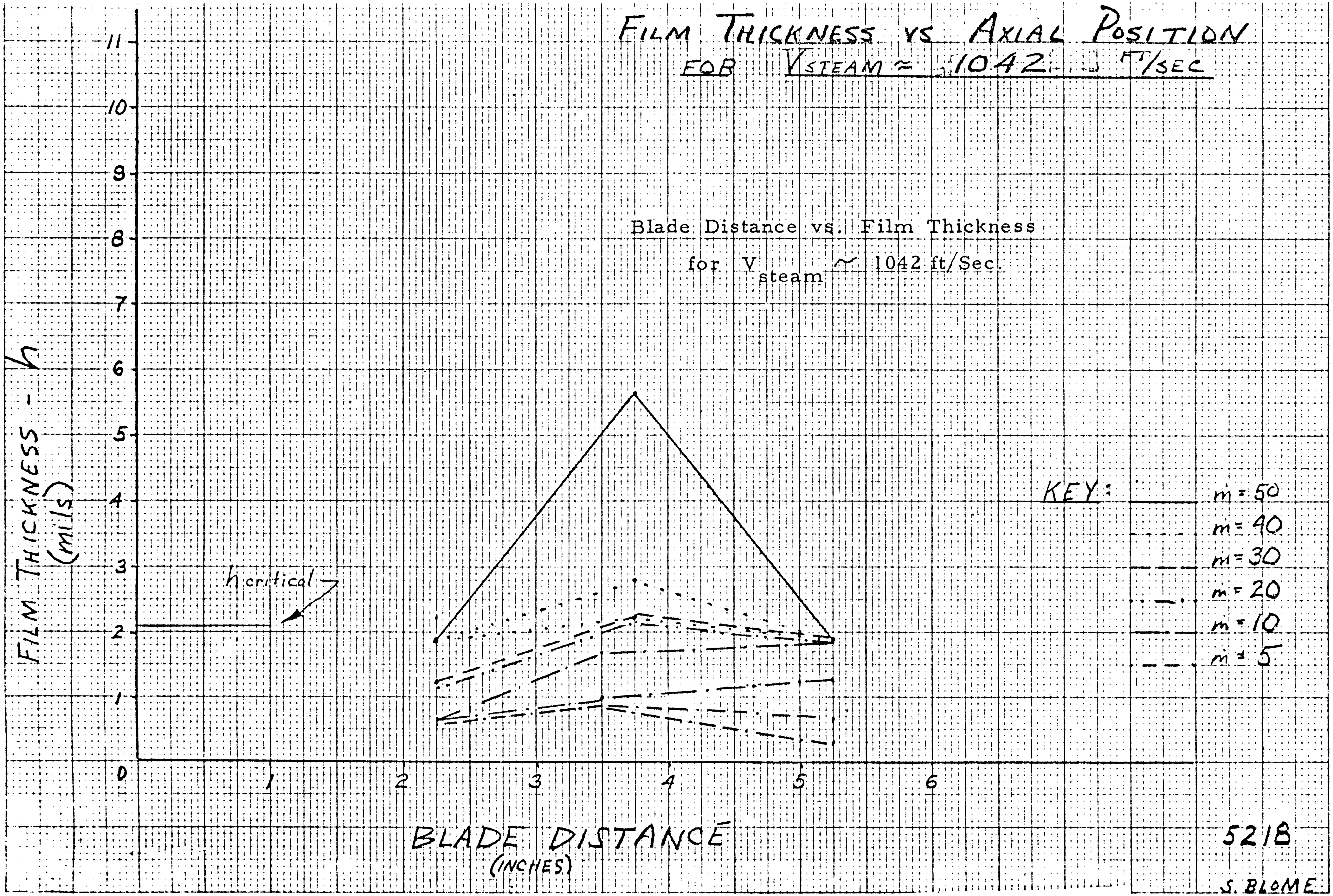
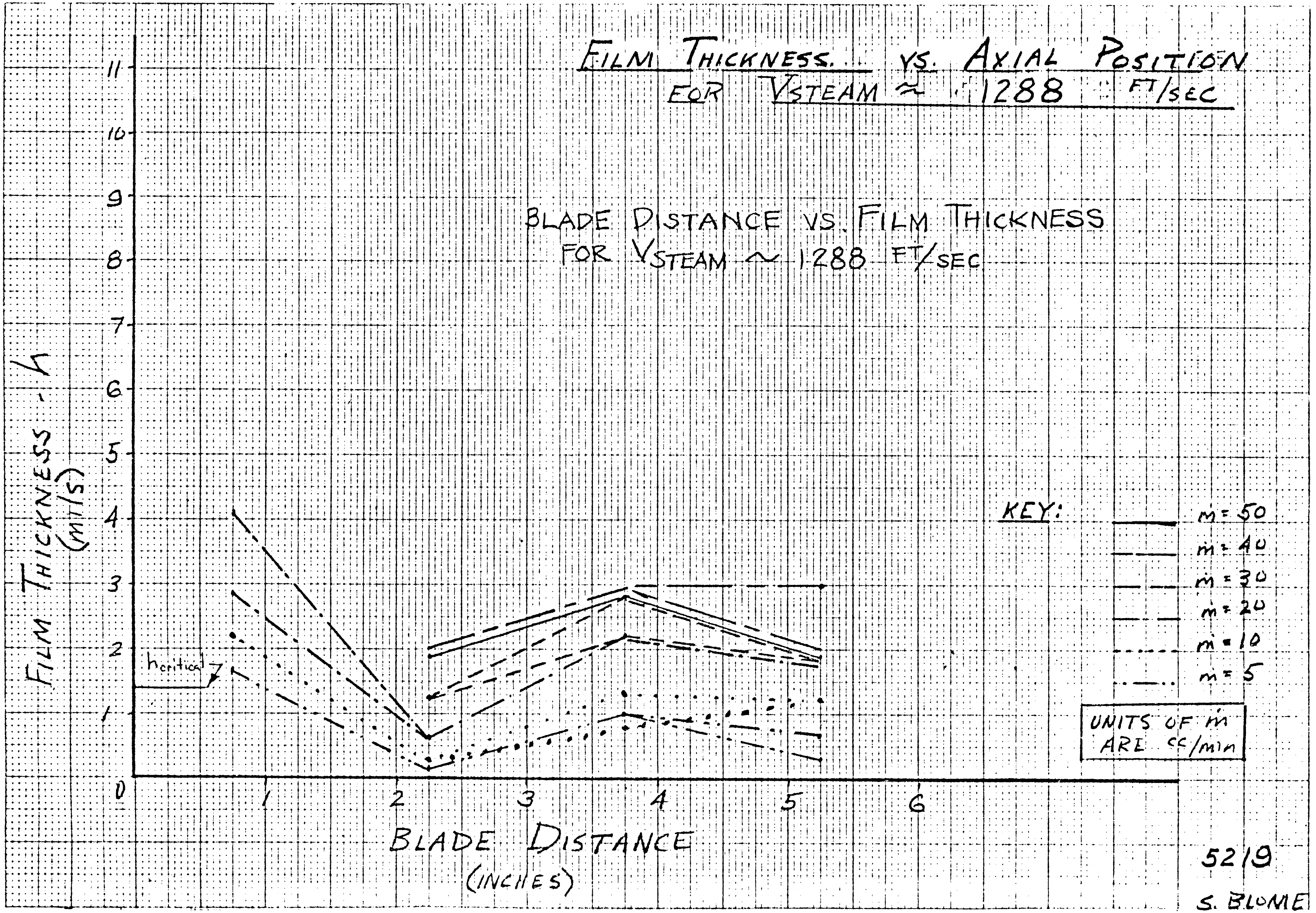


FIG 28 Variation of Liquid Film Thickness with Axial Position, Steam Velocity = 1042 f/s



FILM THICKNESS VS. AXIAL POSITION FOR VSTEAM ≈ 1288 FT/SEC

BLADE DISTANCE VS. FILM THICKNESS FOR VSTEAM ~ 1288 FT/SEC

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