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WET STEAM FLOW
A
STUDY OF THE MINIMUM WETTING RATE OF LAMINAR FILM MOTIVATED BY SURFACE SHEAR ONLY

by

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Submitted to

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INTRODUCTION

As part of the continuing research in Multi-Phase Flow at the University of Michigan, the author was assigned the problem of determining the minimum wetting rate (critical flowrate) of liquid (water) that will completely cover the surface of a test turbine blade under the action of shear forces caused by high velocity steam flow. The assignment also included a study of a theoretical model proposed by D.E. Hartley and W. Murgatroyd for establishing the conditions under which a thin liquid film will tend to completely wet a solid surface over which it is flowing.

This paper presents the results of minimum wetting rate obtained under controlled experimental conditions and a discussion of the theoretical model developed by Hartley and Murgatroyd.

NOMENCLATURE

M	rate of mass flow
p	static pressure
Δp	static pressure difference
W	liquid velocity in the direction of flow
x, y, z	retangular co-ordinates
X	width of a liquid stream

Greek symbols

δ	liquid film thickness
θ	angle of contact between liquid and solid
μ	liquid viscosity
ρ	liquid density
σ	liquid to air surface tension
τ	shear stress

Suffixes

c	critical - i.e., at point of film break up
G	gas alone
L	liquid
W	connected with velocity or momentum
δ	at the outer edge of the liquid film
σ	connected with surface tension

Experimental Set-up

A thorough description of the experimental set-up and equipment is given in the original paper by Professor H.G. Hammitt. A brief description of the procedure used in collecting data for determining the minimum wetting rate of the water is given below.

Water was introduced onto the test blade through small openings in the leading end of the blade. Steam was introduced into the test chamber through the pipe line running from the boiler room to the chamber. The test chamber had previously been evacuated to create vacuum conditions.

The steam was allowed to flow into the chamber at a fixed flowrate which was determined by a flow measuring orifice. The pressure difference between the inlet and outlet of the orifice was read directly in height of mercury. When the steam rate was constant, water was slowly introduced onto the blade. The water was quickly spread over the blade by the shear action of the flowing steam. The water flowrate was increased by about 1 cc/min until it just completely covered the blade. At that instant, the flowrate of the water was recorded. The flow of water onto the blade was then increased to its fullest then slowly decreased to the point where the first dry patch started to reappear. At this point, the flow was recorded. The whole process was repeated with a different flowrate of steam.

The two flowrates of water were never found to be the same. The first one obtained by increasing the water flow was always higher than the second which was obtained when the flow was decreased.

The rate at which the liquid completely covered the test blade and the rate at which the first dry patch reappeared were both recorded dependent on the coordination of the person observing the flow and the person controlling the liquid flow. It was not possible for one person to handle both due to the location of the test chamber and the water flowrate meter.

The accuracy of the results was further hampered by poor lighting of the test chamber. It was very difficult to achieve direct lighting in the blade itself due to the quality of the material used to construct the test chamber. Plastic was used, and at the time the experiment was carried out the walls had many scratches.

Results

The results of the minimum wetting rate measurements are shown in Figure 1. Superimposed on the same figure is the form predicted by the Hartley-Murgatroyd model obtained by using our data in their theoretical equation. The equation predicts what the minimum wetting rate of water should be for a given steam velocity.

The water rate was reduced by approximately 1 cc/min for each successive dry patch test. Therefore, each minimum wetting rate falls between two limits. At the upper limit the surface is just completely covered with liquid, and at the lower limit the dry patch has just reappeared. No attempt was made to obtain a more precise figure for minimum wetting rate and the results are plotted as bar lines between the two limits. It will be observed that the minimum does decrease with increase in steam velocity, in agreement with the Hartley-Murgatroyd theory.

The smooth curve through the four data points is an attempt to show how the theory model predicts how the liquid film should act when motivated by surface shear only, as was the case in our experiment. The Hartley-Murgatroyd equation for finding the minimum wetting rate is:

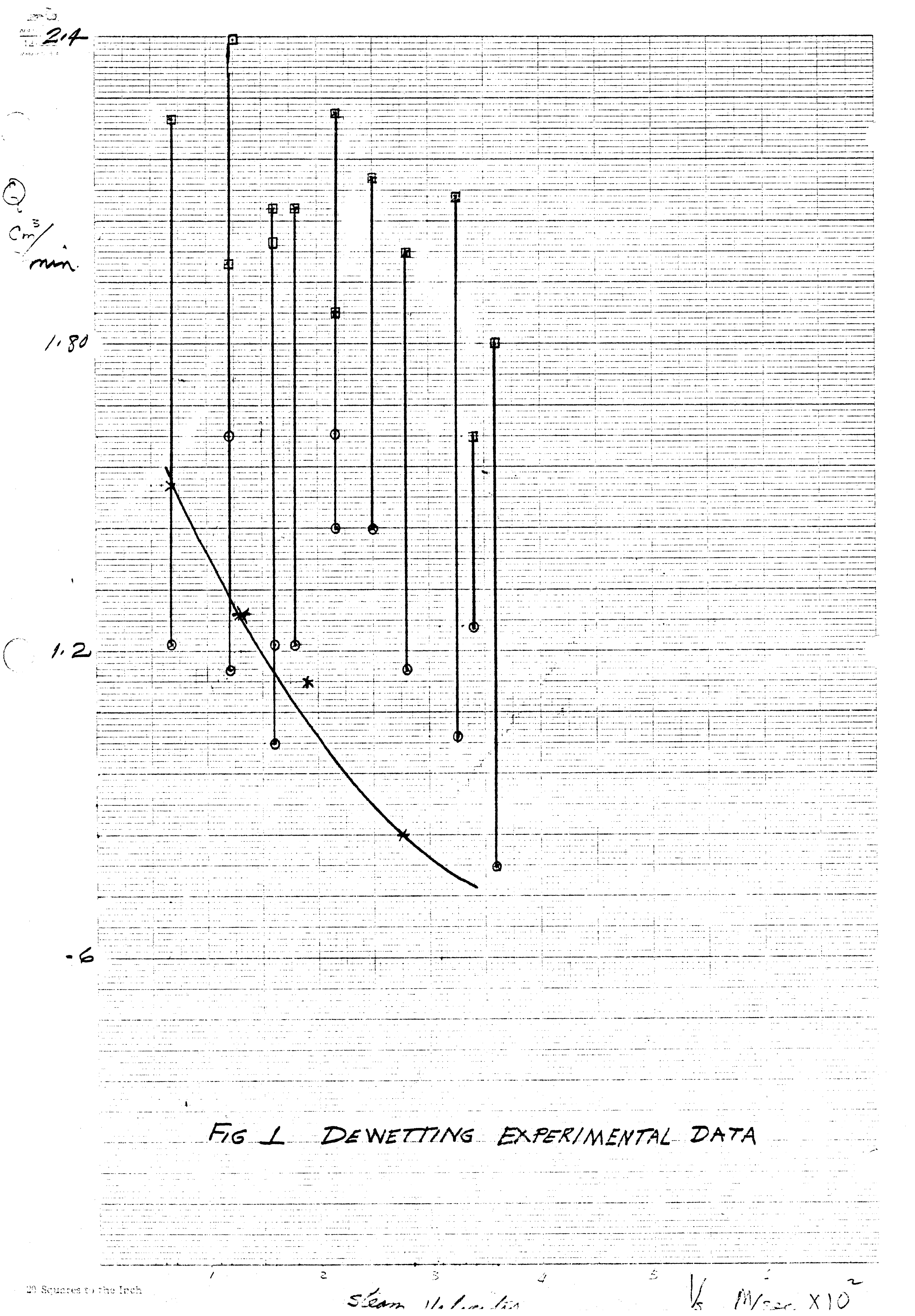


FIG 1 DEWETTING EXPERIMENTAL DATA

$$\left[M/X \right]_c = 2.52 \left(\rho \mu / \tau \right)^{1/3} \sigma^{2/3}$$

This equation was obtained from the power criterion. The same equation from the force criterion is:

$$\left[M/X \right]_c = 3.30 \left(\rho \mu / \tau \right)^{1/3} \left[\sigma (1 - \cos\theta) \right]^{2/3}$$

In the above equation the minimum wetting rate depends on the contact angle θ. We did not measure θ in our experiment, therefore, the equation could not be used with our data in its present form.

Figure 1 shows that our lower data points fall close to the curve generated by the Hartley-Murgatroyd equation.

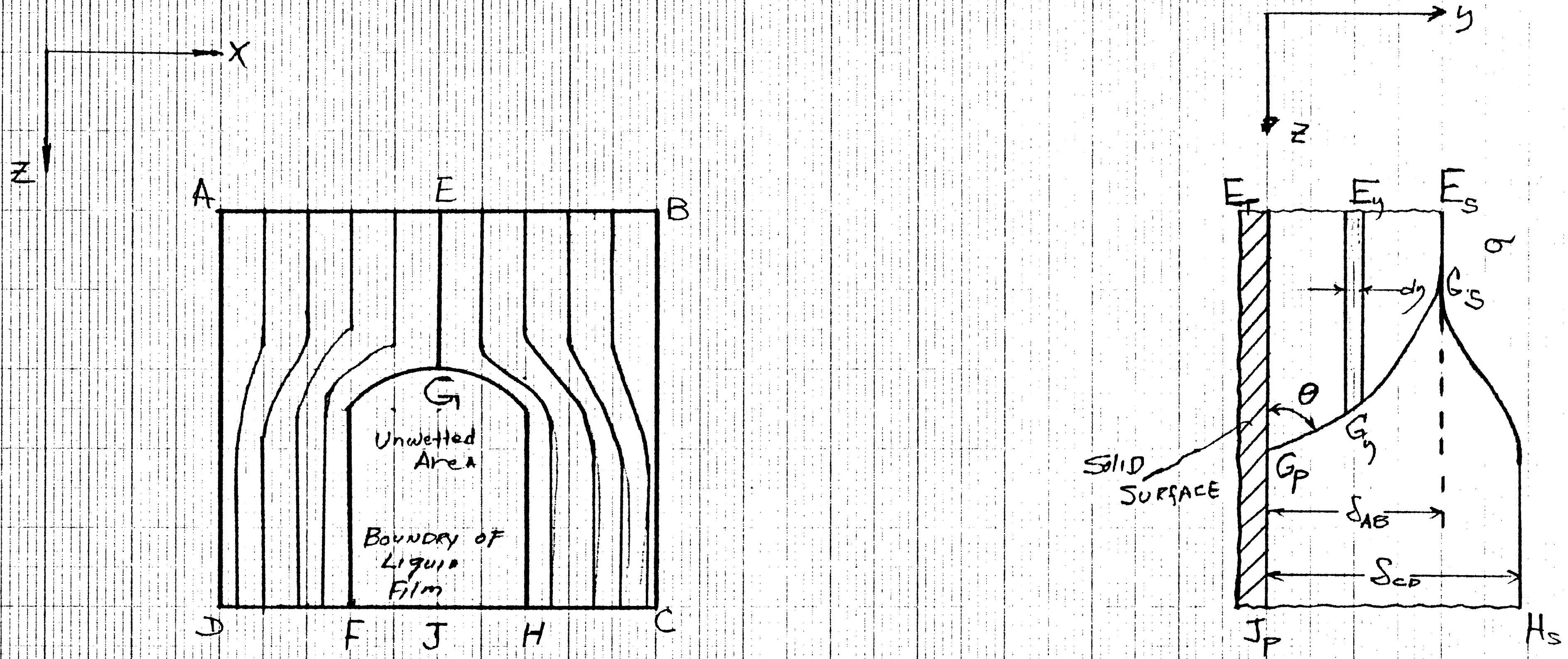
The Hartley-Murgatroyd Theoretical Model

The theoretical model used to analyze the experimental data was developed by D.E. Hartley and W. Murgatroyd in their paper "Criteria for the Break-up of Thin Liquid Layers Flowing Isothermally Over Solid Surfaces." The model predicts "the conditions under which a thin liquid film will tend to completely wet a solid surface over which it is flowing." The model suggests two criteria; "One is based on a force balance at the upstream stagnation point of a dry patch, and the other on the minimum total energy rate in a transversely unrestrained stream."

The Force Balance Criterion

The force balance criterion was developed in two stages. The first stage was developed in the above mentioned paper. The second stage was developed in a paper by W. Murgatroyd titled "The Role of Shear and Form Forces in the Stability of A Dry Patch in Two-Phase Film Flow." This new development was necessary after the model had been applied to experimental data by F.G. Hewitt and M.C. Lacey. Their results were published in a paper titled; "The Breakdown of the Liquid Film in Annular Two-Phase Flow." The paper disclosed a large discrepancy between the contact angle required to solidify the Hartley-Murgatroyd theoretical model and that measured by Hewitt and Lacey.

Hewitt and Lacey suggested that an important additional force, possibly aerodynamics should be included in the force



(a)

PLAIN VIEW

(b)

Cross section along E G J

FIG 2. DRY Patch formation in Liquid Layer Flowing OVER SOLID SURFACE balance criterion. This force was later found by Murgatroyd to be two forces, shear and form. The effect of these forces on the force balance equation was shown by Murgatroyd in his paper cited above.

First Model

The original model of the Force Balance Criterion only considered two forces; Surface Tension along G_sG_p as shown in Figure 2 and Fluid Pressure Over G_sG_p. Under the assumption implied in Figure 2, the fluid pressure in the inner surface of G_sG_p exceeds that on the outer surface owing to the conversion of fluid kinetic energy into static pressure. The static pressure at G is:

$$\Delta P(y) = \rho/2 \left[W(y)\right]^2$$

The force T_W along G_pG_s due to this resolved in the Z-direction will be:

$$T_W = dx \int_0^{S_{AB}} \rho \left[W(y)\right]^2 / 2 \, dy$$

The restraining force due to surface tension is:

$$\tau_\sigma = dX\,\sigma(1-\cos\theta)$$

where σ is the surface tension and θ the contact angle. Thus, the point G will be in neutral equilibrium if:

$$\sigma(1-\cos\theta) = \int_0^\delta \frac{\rho}{2}\left[W(y)\right]^2 dy$$

Second Model

Figure 3 shows the upstream part of a dry patch which has already formed, together with a few appropriate stream surfaces. The particular surface EG which passes through the stagnation point G is shown in section 3B. The point E (distant l from G) is assumed to be sufficiently far enough upstream for the flow at E to be unperturbed by the dry patch. The thickness of the film at E is δ, and downstream of E, it is assumed to remain of order of magnitude δ.

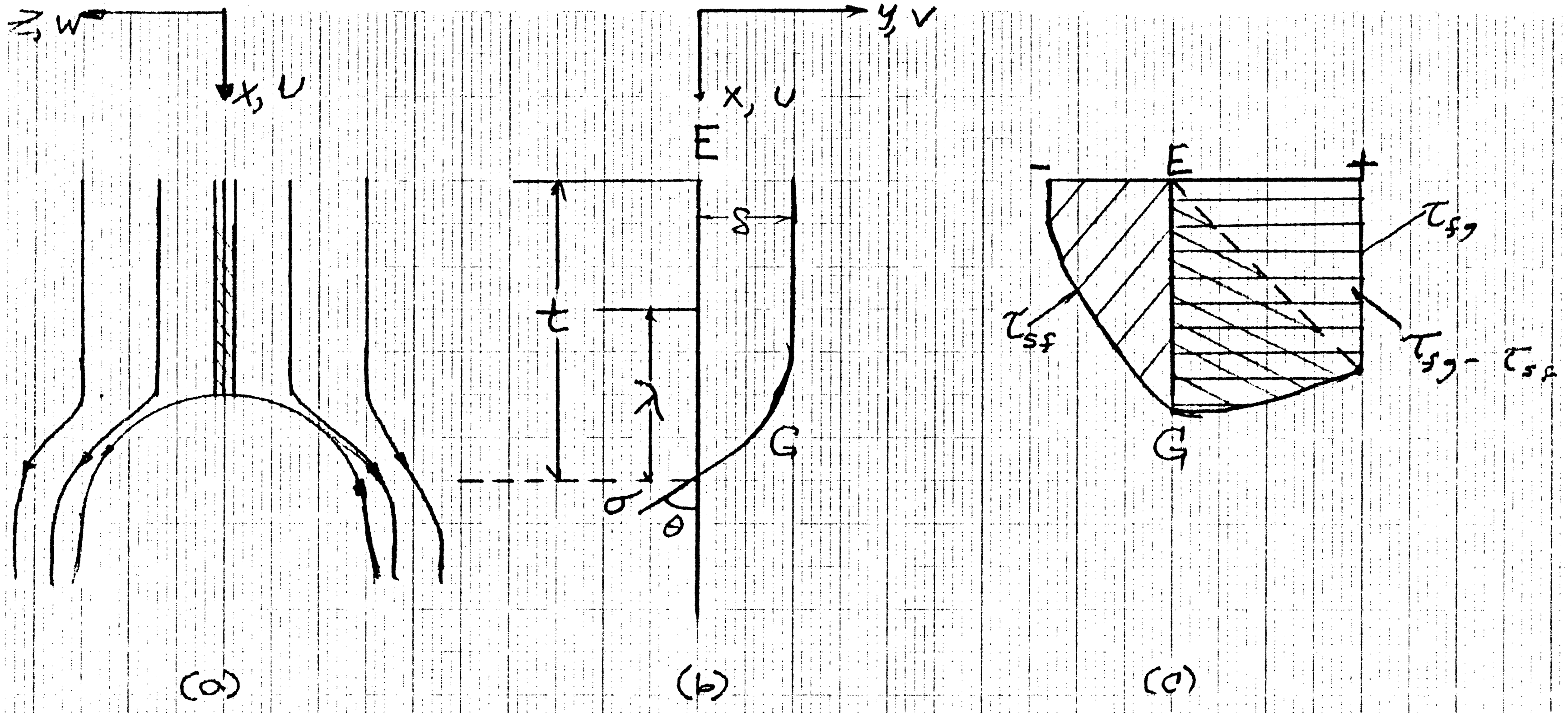

z, w
x, u
y, v
x, u
E
δ
t
λ
G
σ
θ
-
E
+
τ_{fg}
τ_{sf}
$\tau_{fg} - \tau_{sf}$
G
(a)
(b)
(c)

Fig 3

Consider the infinitesimally thin element of liquid centered on EG and shown shaded in Figure 3a, the following forces act on this element.

a. Shear forces

Upstream of E the shear stress τ_{fg} from the gas phase is balanced by the stress τ_{sf} at the solid liquid interface. The film velocity U and therefore, $\tau_{sf} = (\mu_f \partial u/\partial y)_{y=0}$ decrease to zero at G, whereas τ_{fg} at $y=0$ assumed constant except very close to G. Thus, the out-of-balance shear force on the element equals:

$$l\,\tau_{fg} - \int_0^l \tau_{sf}\,dx \equiv \lambda\,\tau_{fg}.$$

Now the state of affairs is such that the dry patch is so large that surface tension forces in the plane of the solid surface are negligible, i.e., $R \gg \delta$.

b. Form forces

$$F = K_2\,\tau_{fg}\,\delta$$

K_2 depends on the distance δ.

c. Surface forces

$$F = \sigma(1 - \cos\theta)$$

an upstream force.

d. Momentum flux

The flux of momentum across unit width of film at E is:

$$\int_0^\delta \rho_f U_0 \, dy$$

where $U_o(g)$ is the velocity in the undisturbed film at E. If EG is assumed to be a straight line and that flow is symmetrical about it, it can be shown, by expanding U and W in Taylor series about their values on the line EG that the ratio of the flow of X-momentum from the element due to the W component to the flow of X-momentum due to U vanishes, in the limit with δX. Thus, in the limit one need only consider the term:

$$\int_0^\delta \rho U_0 \, dy$$

The momentum equation is:

$$\frac{1}{2}\int_0^\delta \rho_f U_0^2 \, dy + K \tau_{fg} \delta = \sigma(1 - \cos\theta)$$

with $K = K_1 + K_2$ in which K_1 and K_2 (and therefore K) can be expected to be in the range of magnitude $10^1 - 10^2$.

The static force has been replaced by the form and shear forces in the final equation. The equation was further refined to read:

$$\sigma(1 - \cos\theta) = K \tau_{fg} \delta$$

For Laminar film motivated by surface shear only, the minimum wetting rate is given by:

$$\left[M/X\right]_c = 3.30 \left(\rho\mu/\tau\right)^{1/3} \left[\sigma(1 - \cos\theta)\right]^{2/3}$$

Power Criterion

The power criterion was developed fully in the first paper published by Hartley and Murgatroyd on the subject.

If a laminar film is flowing under the influence of surface shear so great that the weight of the liquid is not significant, the velocity in the film is given by:

$$W = \tau y/\mu$$

and at the surface of the liquid the velocity is:

$$W(\delta) = \tau\delta/\mu$$

The total specific flowrate is given by:

$$\left[M/X\right] = \int_0^{\delta} \rho W dy = \rho\tau\delta^2/2\mu$$

The minimum wetting rate is given by:

$$\left[M/X\right]_c = 2.52\left(\rho\mu/\tau\right)^{1/2}\sigma^{2/3}$$

Conclusions

The results of the experiment have demonstrated that the minimum wetting rate decreases continuously with increasing steam rate where the water film is motivated by surface shear only.

We made no attempt to discover if the new force balance equation clarified the discrepancy between the contact angle required to satisfy the theory and that measured by Hewitt and Lacey.

No special attention was paid to the form the liquid film took at breakdown.

REFERENCES

1. D.E. Hartley and W. Murgatroyd, Criteria for the Break-up of Thin Liquid Layers Flowing Isothermally Over Solid Surfaces, Int. J. Heat Mass Transfer, Volume 7, pp 1003-1015, 1964

2. G.F. Hewitt and M.C. Lacey, The Breakdown of the Liquid Film in Annular Two-Phase Flow, J. Heat and Mass Transfer, Volume 8, pp 784-791, 1965

3. W. Murgatroyd, The Role of Shear and Form Forces in The Stability of a Dry Patch in Two-Phase Film Flow, J. Heat and Mass Transfer, Volume 8, pp 297-301, 1965

APPENDIX

DATA

Nomenclature

$\overline{U}_0$: Max Steam Velocity m/sec

Q : Liquid flow Rate cc/min

h : film thickness cm

$\overline{U}_i$; Interface Velocity cm/sec $\left(\frac{Q \times 2}{60 \times 8 \times h} \right)$

R : Liquid Reynolds No $\left(\frac{\overline{U}_i h}{\nu} \right)$

τ_0 : Mean Interface Shear Stress $\left(\mu \frac{\overline{U}_i}{h} \right)$

W : Weber Number $\left(\frac{\rho_L \overline{U}_i^2 h}{\sigma} \right)$

W_s : 〃 $\left(\frac{\rho_s \overline{U}_0^2 h}{\sigma} \right)$

F ; Froude Number $\left(\frac{\overline{U}_i^2}{g h} \right)$

T ; $\frac{1}{W}$

G : $\frac{1}{F}$

λ : Wave length cm

f : frequency sec^{-1}

c' : Dimensional Wave Vel cm/sec

c : Dimensionless 〃 $(c'/\overline{U}_i)$

k : Wave number $\left(\frac{2\pi}{\lambda} \right)$

α : Dimensionless Wave Number (kh)

R_s : $\left(\frac{\overline{U}_0 H}{\nu_s} \right)$: Steam Reynolds Number based on Tunnel Height

R_α ; $\left(\frac{\overline{U}_0}{k \nu_s} \right)$: 〃 〃 Wave length

T_T = 104°F (41°C)

P_T = 2.5 psia (0.17 atm)

τ_w = 75.50 dyne

$f \cong .043$

U_o = 73 m/sec ($M = 0.175$)

$\rho_f = 1$ g/cm³ $\rho_s = 6.59 \times 10^{-5}$ g/cm³

$\mu_f = 6.47 \times 10^{-3}$ dyne·s/cm $\mu_s = 9.6 \times 10^{-5}$ dyne-s/cm

$\nu_f = 6.47 \times 10^{-3}$ cm²/s $\nu_s = 1.457$ cm²/s

$\sigma = 69.561$ dyne/cm $R_s = 2.67 \times 10^4$

Q cc/min	h cm	U_L cm/sec	R	τ_o dyne/cm	W ×10^3	F	λ cm	f sec⁻¹	C′ cm/sec	C	k cm⁻¹	α	R_α	W_s	h_2^+
2.5	0.0025	4.17	1.61	10.79	0.62	7.10	0.18	25	4.5	1.08	34.9	0.087	143.56	0.13	2.538
5	0.0038	5.48	3.22	9.33	1.64	8.06	0.15	25	3.75	0.68	41.89	0.159	119.60		3.825
7.5	0.0076	4.11	4.83	3.50	1.84	2.27	0.12	20	2.40	0.58	52.36	0.398	95.69		7.382
10	0.0109	3.82	6.44	2.27	2.29	1.37	0.10	15	1.50	0.39	62.83	0.685	79.74		10.505
20	0.0140	5.95	12.87	2.75	7.12	2.58	0.12	40	4.80	0.81	52.36	0.733	95.69		13.53
30	0.0152	8.22	19.31	3.50	14.76	4.54	0.15 (1.5)	55 (42)	8.25 (63.0)	1.00 (7.87)	41.89 (4.19)	0.637 (0.087)	119.60 (1195.78)		17.765
40	0.0208	8.01	25.75	2.49	19.18	2.86	0.1 (1.2)	160 (35)	16.0 (42.0)	2.00 (4.62)	62.83 (5.24)	1.307 (0.120)	79.74 (956.[illegible])		20.075
50	0.0229	9.10	32.21	2.57	27.25	3.69	0.12 (1.0)	120 (50)	14.4 (50.0)	1.58 (5.08)	52.36 (6.28)	1.199 (0.016)	95.69 (79[illegible])		22.113
60	0.0254	9.84	38.63	3.51	35.34	3.89	0.10 (0.7)	120 (42)	12.0 (29.4)	1.22 (2.69)	62.83 (8.98)	1.596 (0.274)	79.74 (657.94)		24.518
80	0.0305	10.93	51.52	2.32	52.36	4.00	0.12 (0.56)	188 (43)	21.6 (24.1)	2.07 (1.76)	52.36 (41.22)	1.597 (0.342)	95.69 (446.55)		29.405
100	0.0305	13.86	64.39	2.70	81.78	6.24	0.12	135	13.5	1.00	62.83	1.916	79.74	1.54	29.51

T_T = 112 °F (44 °C)

P_T = 2.5 psia (0.17 atm)

$f \cong .0378$

$\tau_w = 2.4$ [illegible]

U_o = 132 m/sec (M = 0.32)

$\rho_f = 1$ $\rho_g = 7.5 \times 10^{-5}$ (g/cm³)

$\mu_f = 6.08 \times 10^{-3}$ $\left(\frac{dyne \cdot s}{cm^2}\right)$ $\mu_s = 9.65 \times 10^{-5}$ $\left(\frac{dyne \cdot s}{cm^2}\right)$

$\nu_f = 6.08 \times 10^{-3}$ $\left(\frac{cm^2}{s}\right)$ $\nu_s = 1.287$ (cm²/s)

$\sigma = 68$ (dyne/cm) $R_S = 5.47 \times 10^4$

h^+	Q cc/min	h cm	U_i cm/sec	R	τ_o dyne/cm	W ×10³	F	λ cm	f sec⁻¹	C' cm/sec	C	k cm⁻¹	α	R_α	u_s	h_2^+
1.85	5	0.0032	6.51	3.43	12.37	1.95	13.51	0.15	40	6.0	0.92	41.89	0.13	245	0.61	5.993
2.67	10	0.0069	6.64	6.86	5.12	3.62	5.40	0.12	50	6.0	0.99	52.36	0.36	196	1.33	12.746
3.70	20	0.0102	8.17	13.71	4.87	9.78	6.68	0.10	50	5.0	0.61	62.83	0.64	163	1.96	26.62
4.53	30	0.0083	15.06	20.56	11.03	27.06	27.88	(1.4) 0.10	(48) 203	(67.2) 20.3	(4.46) 1.38	(4.49) 62.83	(0.037) 0.52	(2250) 163	1.6	15.504
5.14	40	0.0114	14.62	27.41	7.80	35.03	19.13	(1.1) 0.10	(48) 147	(52.8) 14.7	(3.61) 1.01	(5.71) 62.83	(0.065) 0.72	(1796) 163	2.19	21.161
5.85	50	0.0127	16.40	34.26	7.85	49.11	21.61	(1.0) 0.12	(42) 152	(41) 18.24	(2.56) 1.11	(6.28) 52.36	(0.080) 0.66	(1633) 196	2.44	23.578
6.41	60	0.0203	12.32	41.13	3.69	44.30	7.63	(0.8) 0.10	(50) 200	(40) 20.0	(3.25) 1.62	(7.85) 62.83	(0.159) 1.275	(1306) 163	3.9	37.379
7.41	80	0.0305	10.93	54.83	2.18	52.38	4.00	(0.69) 0.12	(93) 230	(60.45) 27.6	(5.53) 2.53	(9.67) 52.36	(0.295) 1.60	(1060) 196	5.81	55.99
8.27	100	0.0305	13.66	68.53	2.72	81.82	6.24	(0.5) 0.10	(67) 260	(33.5) 26.0	(2.45) 1.90	(12.57) 62.83	(0.38) 1.92	(816) 163	5.80	56.05

T_T = 120F (48.9°C)

P_T = 2.5 psia (0.17 atm)

$\frac{U_o}{\nu_s} = 16979.44$

$\tau_w = 281.77$ dynes

U_o = 190 m/sec

$f \simeq .0178$

(M = 0.46)

$\rho_f = 1\ g/cm^3$

$\rho_s = 8.77 \times 10^{-5}\ (g/cm^2)$

$\mu_f = 5.5 \times 10^{-3}\ \left(\frac{dyne \cdot s}{cm^2}\right)$

$\mu_s = 9.81 \times 10^{-5}\ \left(\frac{dyne-s}{cm^2}\right)$

$\nu_f = 5.5 \times 10^{-3}\ (cm^2/s)$

$\nu_s = 1.119\ cm^2/s$

$\sigma = 67.9\ (dyne/cm)$

$R_{os} = 9.056 \times 10^4$

	Q l/min	h cm	U_i cm/sec	R	τ_o dyne/cm	W $\times 10^3$	F	λ cm	f sec^{-1}	C′ cm/sec	C	k cm^{-1}	α	R_α	W_s	h_z^+
.45	5	0.002	10.42	3.79	28.66	3.2	55.40	0.12	60	7.2	0.69	52.36	0.10	324.28	0.93	4.530
.75	10	0.0046	9.06	7.58	10.83	5.56	18.21	0.15 (1.4)	70 (50)	10.5 (70)	1.16 (5.79)	41.89 (4.49)	0.19 (0.03)	405.33 (5781.61)	2.14	10.116
.89	20	0.0069	12.08	15.15	9.63	14.83	21.58	0.08 (1.3)	320 (50)	25.6 (65)	2.12 (2.91)	78.54 (4.83)	0.54 (0.027)	216.20 (3515.41)	3.22	15.140
1.11	30	0.0056	22.32	22.73	21.92	41.09	90.78	0.08 (1.1)	350 (55)	28 (60.5)	1.25 (3.01)	78.54 (5.71)	0.44 (0.047)	216.20 (2973.63)	2.61	12.545
.51	40	0.0083	20.08	30.30	13.31	49.29	50.56	0.10 (0.8)	400 (60)	40 (48)	1.99 (2.05)	12.83 (7.85)	0.52 (0.070)	270.24 (2162.98)	3.87	18.330
.16	50	0.0089	23.41	37.88	14.47	71.83	62.83	0.10 (0.9)	370 (55)	37 (49.5)	1.58 (2.02)	62.83 (6.98)	0.559 (0.071)	270.24 (2432.58)	4.15	19.908
.74	60	0.0102	24.51	45.45	13.22	90.24	60.10	0.12 (0.7)	380 (50)	45.6 (35)	1.86 (1.33)	52.36 (8.98)	0.53 (0.144)	324.28 (1890.8)	4.76	22.522
.79	80	0.0127	26.25	60.61	11.37	128.88	55.36	0.10 (0.7)	420 (60)	42 (42)	1.6 (1.66)	62.83 (8.98)	0.80 (0.148)	270.24 (1890.8)	5.92	27.955
.21	100	0.0165	25.25	75.75	8.42	154.93	39.43	0.10	410	41	1.62	62.83	1.05	270.24	7.69	36.136

T_T = 125°F (52°c)

P_T = 2.5 psia (0.17 atm)

$\frac{U_0}{\nu_s}$ = 28773.584

τ_w = 721.4 dynes f = .0165

U_0 = 1305 m/sec   (M = 0.75)

ρ_f = 1 (g/cm³) ρ_s = 9.4 ×10⁻⁵ (g/cm³)

μ_f = 5.28 ×10⁻³ $\left(\frac{dyne \cdot s}{cm^2}\right)$ μ_s = 9.97 ×10⁻⁵ $\left(\frac{dyne \cdot s}{cm}\right)$

ν_f = 5.28 ×10⁻³ (cm²/s) ν_s = 1.06 (cm²/s)

σ = 67.5 (dyne/cm) R_s = 1.534 ×10⁵

h'	Q cc/min	h cm	$\bar{U}_c$ cm/sec	R	τ_0 dyne/cm	W ×10³	F	λ cm	f sec⁻¹	C' cm/sec	C	k cm⁻¹	α	R_α	W_s	h_2^+
1.99	5	0.0013	16.03	3.95	65.11	4.95	201.70	0.08 (1.0)	200 (130)	16.0 (130)	0.998 (9.98)	78.54 (6.28)	0.10 (0.02)	366.36 (4581.78)	1.68	4.88
2.81	10	0.0032	13.02	7.89	21.48	8.04	54.06	0.08 (0.8)	480 (150)	38.4 (120)	2.95 (6.62)	78.54 (7.85)	0.25 (0.04)	366.26 (3665.42)	4.15	11.680
3.97	20	0.0046	18.12	15.79	20.80	22.38	72.83	0.05 (0.6)	600 (150)	30.0 (90)	1.66 (3.31)	125.66 (10.47)	0.59 (0.048)	228.98 (2748.19)	5.96	16.783
4.87	30	0.0046	27.17	21.06	31.19	50.31	163.76	0.05 (0.4)	800 (180)	40.0 (72)	1.47 (2.64)	125.66 (15.7)	0.58 (0.096)	228.98 (1832.71)	5.96	16.900
5.62	40	0.0061	27.32	31.56	23.65	67.45	124.89	0.05 (0.4)	850 (140)	42.5 (56)	1.56 (1.91)	125.66 (15.71)	0.77 (0.11)	228.98 (1896..6)	7.9	22.294
6.28	50	0.0071	29.34	39.45	21.82	90.55	123.72	0.05 (0.3)	780 (200)	39.0 (60)	1.33 (2.45)	125.61 (20.94)	0.89 (0.214)	228.98 (1374.09)	9.2	25.921
6.88	60	0.0102	24.51	47.35	12.69	90.78	60.10	0.05 (0.35)	900 (200)	45.0 (70)	1.84 (2.67)	125.66 (17.95)	1.28 (0.23)	228.98 (1602[illegible])	13.2	37.010
7.94	80	0.0127	26.25	63.14	10.91	129.60	55.36	0.05 (0.4)	1000 (200)	50.0 (80)	1.90 (2.68)	125.66 (15.71)	1.60 (0.22)	228.98 (1832[illegible])	16.45	46.025
8.90	100	0.0139	29.83	78.93	11.27	184.56	64.86	0.05	950	47.5	1.59	125.66	1.76	228.98	18.1	50.640

F_T : T_T = Date: 6-3/77

Name: [illegible]

F_T :

T_S

F_{T_2} = $V_s = \overline{W}\bar{w}$

F_S =

H	V_s	Q↑	Q↓	T_S	T_T	P_S	P_T
12 × 2		14 14	10 12	266 265	116 115	-15 -0.9	-13 -11.5
10 × 2		13 16	12 17	[illegible] 254	114 111	-2.9 -3	[illegible] -12
9 × 2		[illegible]	14 12	253 246	105 103	-3.5 -4	-12.0 -12.2
8 × 2		[illegible] 16	14 12	[illegible] 239	[illegible] 104	-4.7 -5.1	[illegible] -12.2
7 × 2		13 13	15 12	236 227	[illegible] 104	-5.[illegible] -6.3	-12.5 -12.5
6 × 2		14	14 12	[illegible] [illegible]	99 100	-7.0 -7.5	-13.5 -12.5
[illegible] × 2		13 15	12 10.5	210 205	101 97	-8.5 -8.9	-12.5 -12.6
5 × 2		16 12	13.5 11	201 194	103 100	-10 -9.8	-12.5 -12.4
3 × 2		[illegible] 17	12 11	190 186	[illegible]	-10.5 -11	[illegible] -12.2
2 × 2		15	14 11	[illegible]	[illegible] 105	[illegible]	[illegible]

P_T :

T_T =

DATE: 6/13/77

Name:

F :

T_s

F_L =

$V_s = 7\sqrt{w}$

F_s =

H	V_s	Q↑	Q↓	T_s	T_T	P_s	P_T
12 × 2		14 14	10 12	266 265	116 115	-15 [illegible]	-13 -15
[illegible] × 2		13 16	12 [illegible]	[illegible]	[illegible]	-2.9 -2	[illegible] -1[illegible]
[illegible] × 2		16 15	[illegible] 12	[illegible]	[illegible]	-3.[illegible] [illegible]	[illegible] [illegible]
[illegible] × 2		16	14 12	[illegible]	[illegible]	[illegible]	[illegible]
7 × 2		13[illegible] [illegible]	[illegible] 12	[illegible]	98.5 104	[illegible]	[illegible]
[illegible] × 2		[illegible]	1[illegible] 12	226.5 220	99 100	[illegible]	[illegible]
[illegible] × 2		13[illegible] 13	12 [illegible]	210 [illegible]	101 97	-8.5 -8.9	-12.5 [illegible]
[illegible] × 2		[illegible]	13 11	[illegible] 194	103 100	-10 [illegible]	-12.5 [illegible]
3 × 2		[illegible]	12	[illegible]	[illegible]	[illegible]	[illegible]
[illegible] × 2		15	11	[illegible]	101	[illegible]	[illegible]

$\bar{T}$:   T =   Date: [illegible]

Name

$\bar{T}_2$ =

T_s

P_{T_2} =

P_s =

not consistent

Remark : Steam Supply   steamline   root line steamline

H	V_s	Q↑	Q↓	T_s	T_T	P	P
x 2							
x 2							
y 2		14 12	6 8	250 244	110 113	1.5 2.4	11.5 11.7
x 2		13 17	10 13	242 252	112 107	2.7 4.2	12 12
y 2		15 12	9 12	235 249	110 106	40 4.4	12 12
x 2		16 14	10 14	226 245	105 105	5 5.2	125 12.4
x 2		17 15	11 12	220 222	104 104	6 5.4	125 12.3
x 2		14 18	8 12	210 202	100 100	7 8	125 12.4
x 2		13 16	10 12	200 192	101 98	8 9	125 12.5
x 2		16 16	11 12	188 181	100 100	9 10	12.5 12.5
x 2		14 13	12 12	200 170	103 100	10.5 11	12 12.5

F_{T_1} =

I_T =

DATE 6/24/77

NAME [illegible]

F_{T_2} =

T_E

F_{T_3} =

F_S =

H_{hr}	V_s	Q↑	Q↓	T_s	T_T	P_s	P_T		
12 x 2									
11 x 2		11	7.5	255	106	-.2	-.7		
10 X 2		17	16	247	[illegible]	-2.4	-1.7		
9 X 2		13	14	[illegible]	105	-3.5	-9		
8 X 2		12	[illegible]	232	105	-4.5	-12		
7 X 2		13	16	223	101	-5.8	-12.2		
6 X 2		13	12	212	98	-7.0	-12.2		
5 X 2		13	10	204	98	-7.2	-12.2		
4 X 2		10	7.5	190	98	-9.4	-12.3		
3 X 2		10	7.5	77	98	-10.4	-12.3		
2 X 2		9	7	186	100	-11.5	-12.3		

P_T =

F_T =

F_{T_2} =

T_s

F_{L_2} =

m / sec

F_s =

ft / sec ~~cfm~~ ft³ / min x density / 60 min / hr

Name

x.002083

Hz	V_s	Q↑	Q↓	T_s	T_T	P_s	P_T
21 2 × 10.5	(358.99) 1177.8	(4.5) 14 (.1030) 15	(6.5) 6 (.10135) 7	250 249	107 104	1 1.5	11.5 11.5
20 2 × 10	(339.18) 1112.78	(13) 13 (.0271) 13	(10) 9 (.0208) 11	247 244	107 112	1.3 2	11.5 11.5
18 2 × 9	(324.67) 1065.178	(16.5) 16 (.0344) 17	(8) 8 (.0166) 8	240 237	110 110	2.7 3.0	11.7 11.7
16 2 × 8	(286.00) 938.301	(16) 16 (.0333) 16	(9) 10 (.0187) 8	232 228	108 109	4 4	11.8 11.5
14 2 × 7	(257.70) 825.763	(17) 17 (.0354) 17	(11.5) 9 (.0240) 14	225 221	105 110	5 5.5	12 11.5
12 2 × 6	(217.90) 714.892	(18) 18 (.0375) 18	(11.5) 11 (.0240) 12	215 210	119 110	6.3 6.5	12.1 11.5
10 2 × 5	(181.23) 594.589	(16.5) 15 (.0344) 18	(11) 10 (.0208) 10	205 202	100 110	7.3 7.5	12.1 11.5
8 2 × 4	(159.23) 522.40	(16.5) 16 (.0344) 17	(8) 8 (.0166) 8	195 195	100 100	8.5 8.8	12 12
6 2 × 3	(119.86) 393.26	(15.5) 15 (.0323) 16	(9) 8 (.0187) 10	180 182	102 109	9.6 10	12 12
4 2 × 2	(68.35) 224.25	(17.5) 17 (.03646) 18	(10) 10 (.0208) 10	163 161	101 103	10.8 11	11 12

Hz
sec

X PIPE Area x density / ~~3600 sec~~ / hr