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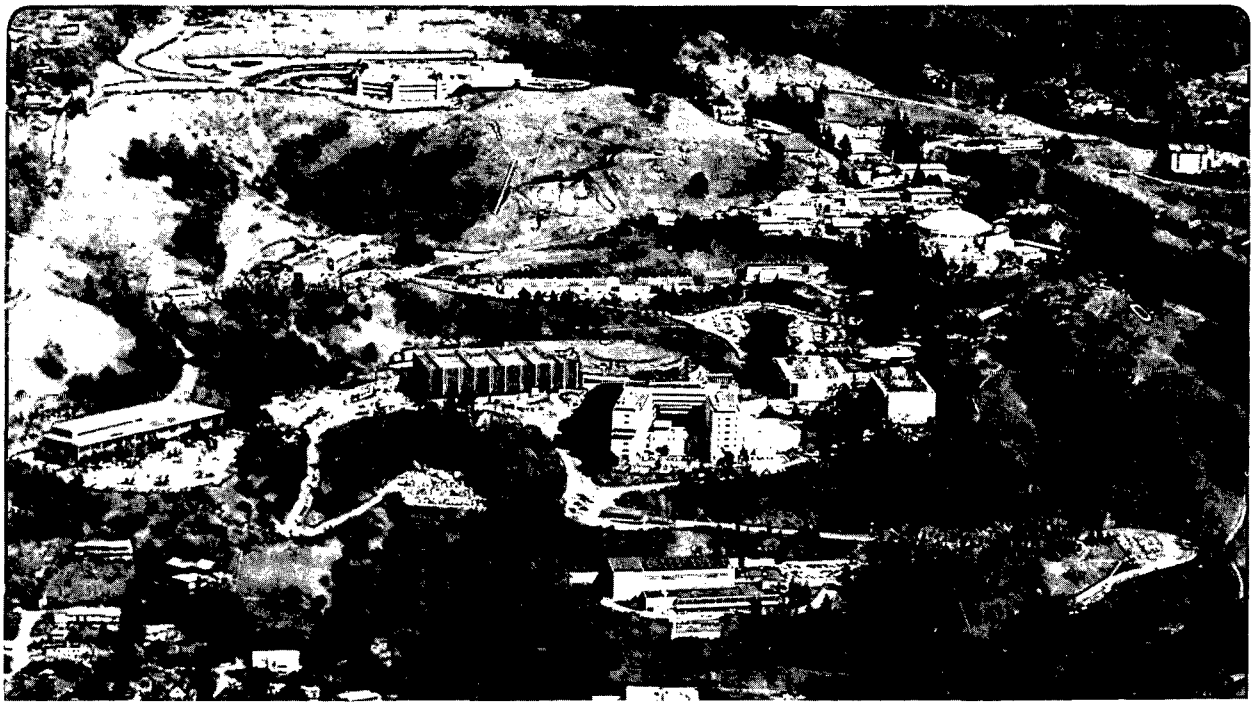

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ENGINEERING NOTE

CODE	SERIAL	PAGE
D32291	M5497	1 of 10

AUTHOR	DEPARTMENT	LOCATION	DATE
ROBERT M. YAMAMOTO	MECHANICAL ENGINEERING	BERKELEY	April 4, 1980

PROGRAM — PROJECT — JOB

DOUBLET III NEUTRAL BEAM INJECTOR SYSTEM

NBIS CRYOPANELS

TITLE

FRONT & REAR CRYOPANELS; TWO PHASE FLOW

SUMMARY:

The two-phase flow regimes for both liquid helium and liquid nitrogen were evaluated for the Doublet III Front & Rear Cryopanels.

By using the Lockhart-Martinelli Empirical Relationship for two-phase flow in conjuction with the Baker diagram, the flow regimes for the cryofluids can be determined.

The attached graphs show these flow regimes as a function of temperature mass flow rate, inside tube diameter and quality.

DISTRIBUTION
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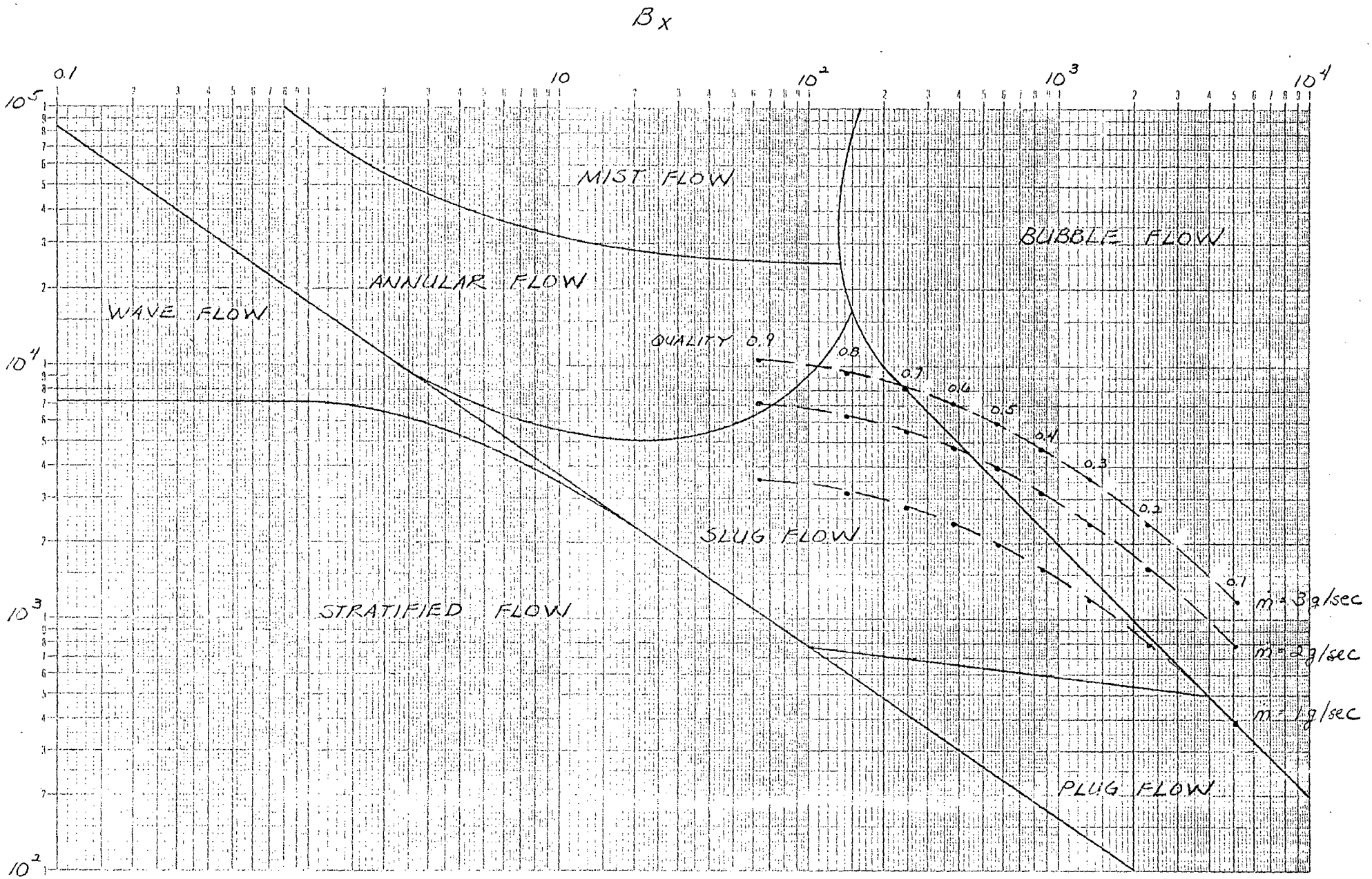
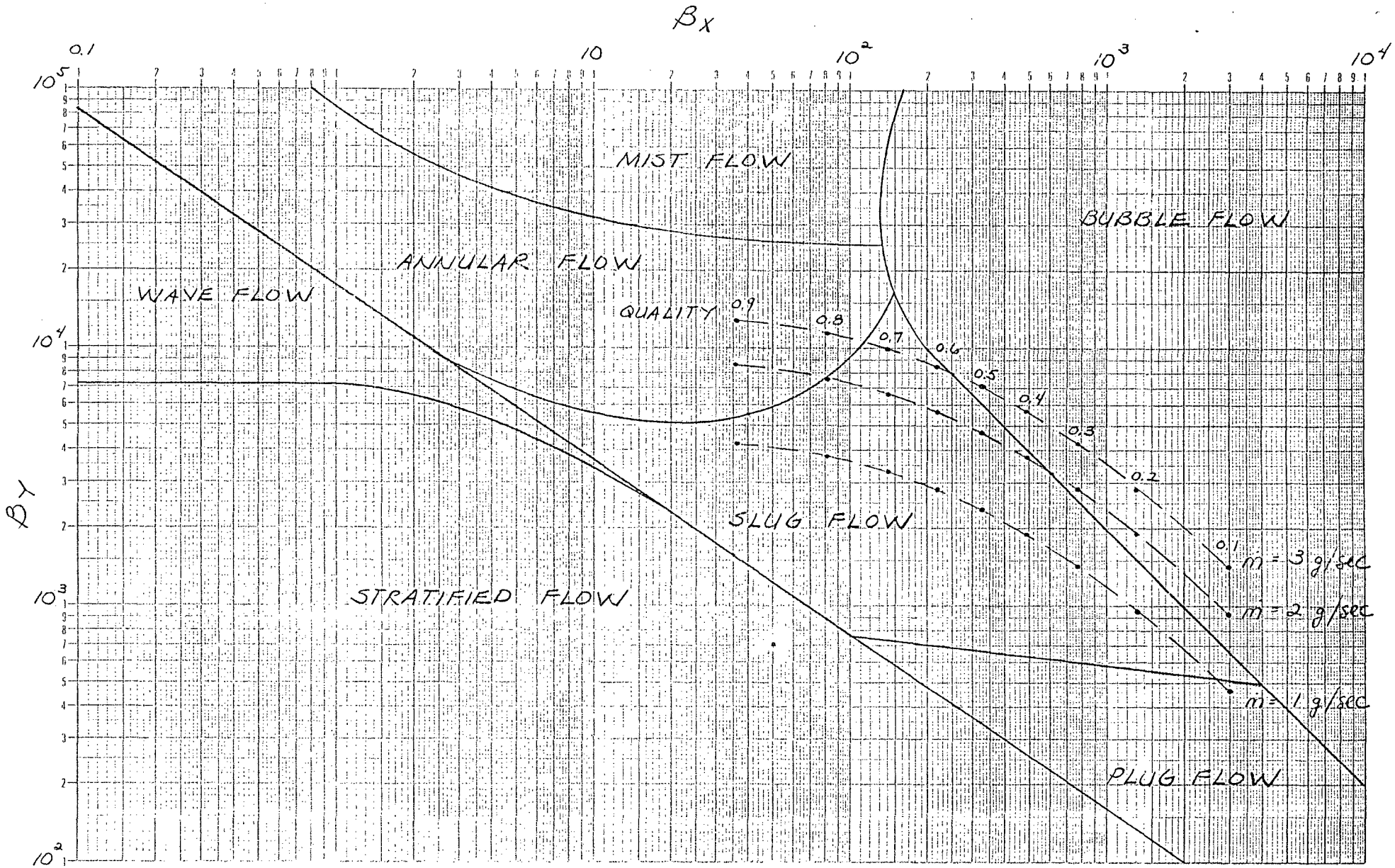
3 CYCLES X 5 CYCLES AL-6254 GD



BAKER DIAGRAM FOR TWO-PHASE FLOW

— [illegible] 112°K, 1 ATM —

LOGARITHMIC 3 CYCLES X 5 CYCLES AL 0254 GD

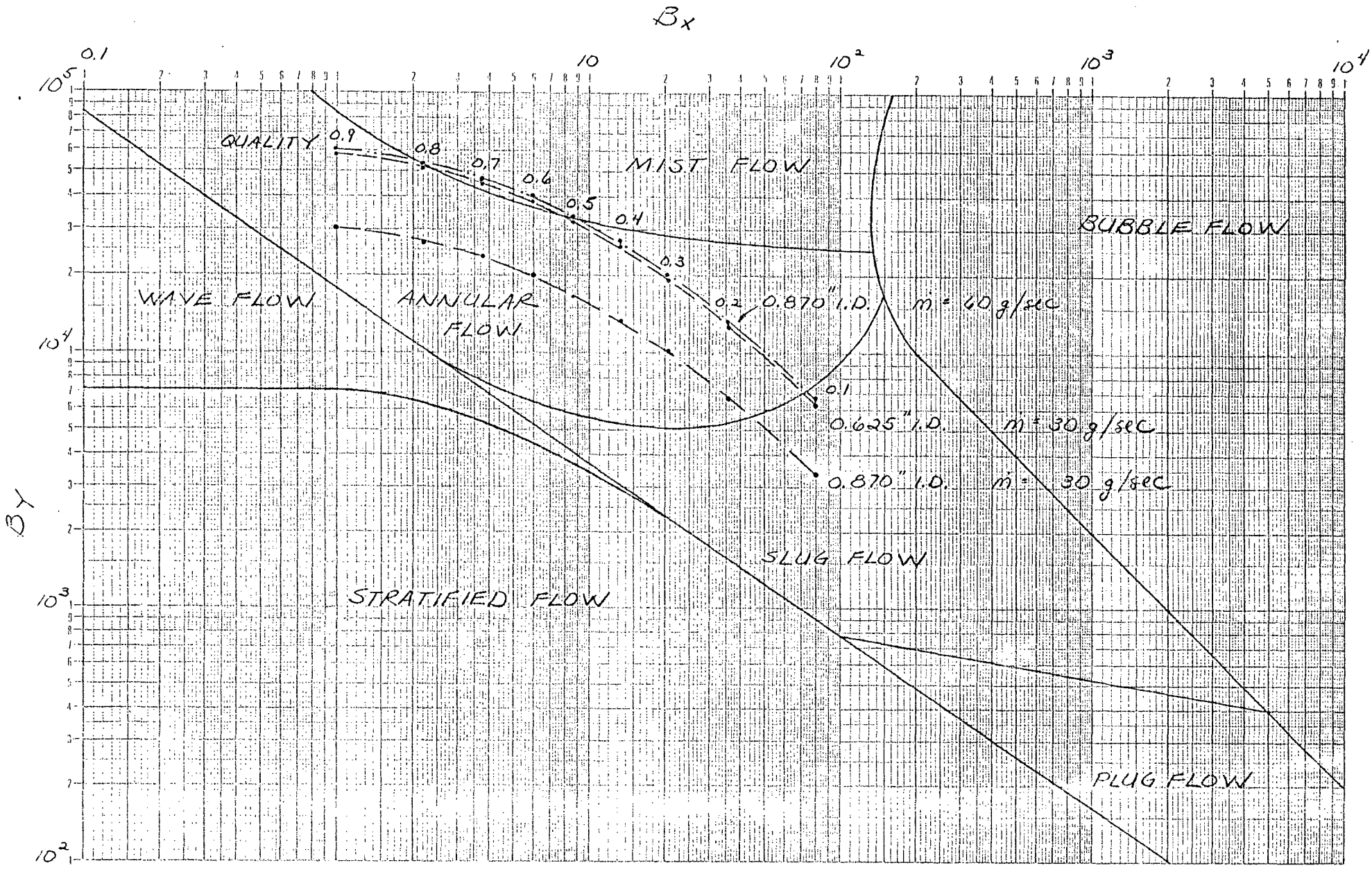


BAKER DIAGRAM FOR TWO-PHASE FLOW

— HELIUM @ 3.8°K, 1 ATM —
1.339 cm I.D TUBE

April 4, 1980

LOGARITHMIC 3 CYCLES X 5 CYCLES AL 0254-60



BAKER DIAGRAM FOR TWO-PHASE FLOW

— NITROGEN @ 77°K, 1 ATM —

HELIUM

TWO PHASE FLOW REGIMES

LOCKHART-MARTINELLI EMPIRICAL RELATIONSHIP USING THE BAKER DIAGRAM:

11.

$$By = \frac{325\ \dot{m}\ x}{D^2\ \psi}$$

$$Bx = 9800\ \frac{(1-x)}{x}\ \psi\ \gamma$$

$$\psi = (\rho_L\ \rho_G)^{1/2}$$

$$\gamma = \frac{1}{\sigma_L}\left[\frac{\mu_L}{\rho_L^{\ 2}}\right]^{1/3}$$

$\dot{m}$ = mass flow rate (g/sec)
x = quality
D = effective dia. of tube (cm)
ρ_L = liquid density (g/cm^3)
ρ_G = vapor density (g/cm^3)
μ_L = liquid viscosity (poise)
σ_L = liquid surface tension (dyne/cm)

FOR HELIUM @ 4.2^{o}K

Effective diameter = .625" - 2 (.049" wall) = .527" = (.527 in) (2.54 $\frac{cm}{in}$) = 1.339 cm

12.

ρ_L = .125 g/cc

ρ_G = .01689 g/cc

σ_L = .0997 dynes/cm

μ_L = 31.7 x 10^{-6} poise (g/cm-sec)

ψ = (.125 g/cc x .01689 g/cc)$^{\frac{1}{2}}$ = .04595

$$\gamma = \frac{1}{.0977}\ \frac{\text{dynes}}{\text{cm}}\left[\frac{31.7 \times 10^{-6}\ \text{poise}}{(.125\ \text{g/cc})^2}\right]^{1/3} = 1.2697$$

$$By = \frac{325\ \dot{m}\ x}{(1.339\ \text{cm})^2\ (.04595)} = 3944.9\ \dot{m}\ x$$

$$Bx = 9800\ \frac{(1-x)}{x}\ (.04595)\ (1.2697) = 571.76\ \frac{(1-x)}{x}$$

FOR 4.2°K

x	Bx	By ṁ 3 g/sec	By ṁ 2 g/sec	By ṁ 1 g/sec
.1	5145.8	1183.5	789.0	394.5
.2	2287.0	2366.9	1578.0	789.0
.3	1334.1	3550.4	2366.9	1183.5
.4	857.6	4733.9	3155.9	1578.0
.5	571.8	5917.4	3944.9	1972.5
.6	381.2	7100.8	4733.9	2366.9
.7	245.0	8284.3	5522.9	2761.4
.8	142.9	9467.8	6311.9	3155.9
.9	63.5	10651.3	7100.8	3550.4
1.0	0	11834.7	7889.8	3944.9

FOR HELIUM @ 3.8°K

$D = 1.339$ cm

$\rho_L = .1321$ g/cc

$\rho_G = .01109$ g/cc

$\sigma_L = .1430$ dynes/cm

$\mu_L = 33.8 \times 10^{-6}$ poise

$$\psi = (.1321 \text{ g/cc} \times .01109 \text{ g/cc})^{\frac{1}{2}} = 0.03828$$

$$\gamma = \frac{1}{.1430 \frac{\text{dynes}}{\text{cm}}} \left[\frac{33.8 \times 10^{-6} \text{ poise}}{(.1321 \text{ g/cc})^2}\right]^{1/3} = 0.8717$$

$$By = \frac{325 \dot{m}x}{(1.339 \text{ cm})^2 \, (.03828)} = 4735.3 \dot{m}x$$

$$Bx = 9800 \frac{(1-x)}{x} \, (.03828) \, (.8717) = 327 \frac{(1-x)}{x}$$

FOR 3.8°K

x	Bx	By $\dot{m}$ 3 g/sec	By $\dot{m}$ 2 g/sec	By $\dot{m}$ 1 g/sec
.1	2943	1420.6	947.1	473.5
.2	1308	2841.2	1894.1	947.1
.3	763	4261.8	2841.2	1420.6
.4	490.5	5682.4	3788.3	1894.1
.5	327	7103.0	4735.3	2367.7
.6	218	8523.5	5682.4	2841.2
.7	140.1	9944.1	6629.5	3314.7
.8	81.8	11364.7	7576.5	3788.3
.9	36.3	12785.3	8523.6	4261.8
1.0	0	14205.9	9470.7	4735.3

NITROGEN

TWO PHASE FLOW REGIMES

FOR L_N @ 77^oK (138.6^oR)

13.

ρ_L = .808 g/cc

ρ_G = .004415 g/cc

μ_L = .00155 poise

σ_L = 8.8 dynes/cm

$\dot{m}$ = 30 g/sec

$$\psi = (.808 \text{ g/cc} \times .004415 \text{ g/cc})^{\frac{1}{2}} = .05973$$

$$\gamma = \frac{1}{8.8 \frac{\text{dynes}}{\text{cm}}} \left[\frac{.00155 \text{ poise}}{(.808 \text{ g/cc})^2}\right]^{1/3} = .01516$$

$$D_1 = (.870 \text{ in}) \left(2.54 \frac{\text{cm}}{\text{in}}\right) = 2.2098 \text{ cm}$$

$$D_2 = (.625 \text{ in}) \left(2.54 \frac{\text{cm}}{\text{in}}\right) = 1.5875 \text{ cm}$$

$$By = \frac{325 \ (30 \text{ g/sec}) \ x}{D^2 \ (.05973)} = 163234.6 \frac{x}{D^2}$$

$$Bx = 9800 \frac{(1-x)}{x} (.05973) \ (.01516) = 8.874 \frac{(1-x)}{x}$$

FOR 77°K $\dot{m}$ = 30 g/sec

x	Bx	By D_2 .625 in	By D_1 .870 in
.1	79.87	6477.2	3342.8
.2	35.50	12954.3	6685.5
.3	20.71	19431.5	10028.3
.4	13.31	25908.6	13371.1
.5	8.87	32385.8	16713.8
.6	5.92	38863.0	20056.6
.7	3.80	45340.1	23399.4
.8	2.22	51817.3	26742.1
.9	.99	58294.4	30084.9
1.0	0	64771.6	33427.7

Assume series & not paralled flow for front cryopanel:

m = 60g/sec

d = 0.875 inches

$$By = \frac{325}{D^2} \quad \frac{(60\ g/sec)\ x}{(.05973)}$$

x	By
0	0
.1	6685
.2	13371
.3	20057
.4	26742
.5	33428
.6	40113
.7	46799
.8	53484
.9	60170
1.0	66855

Bx is not a function of $\dot{m}$, mass flow rate

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12. "Thermophysical Properties of Helium-4 from 2 to 1500K with Pressures to 1000 Atmosphers," NBS Technical Note 631, November, 1972.

13. Cryogenic Data Table, Cryenco Engineering Co.

/nh

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