Title
FILM HEAT TRANSFER EQUATIONS FOR TURBULENT WATER FLOW

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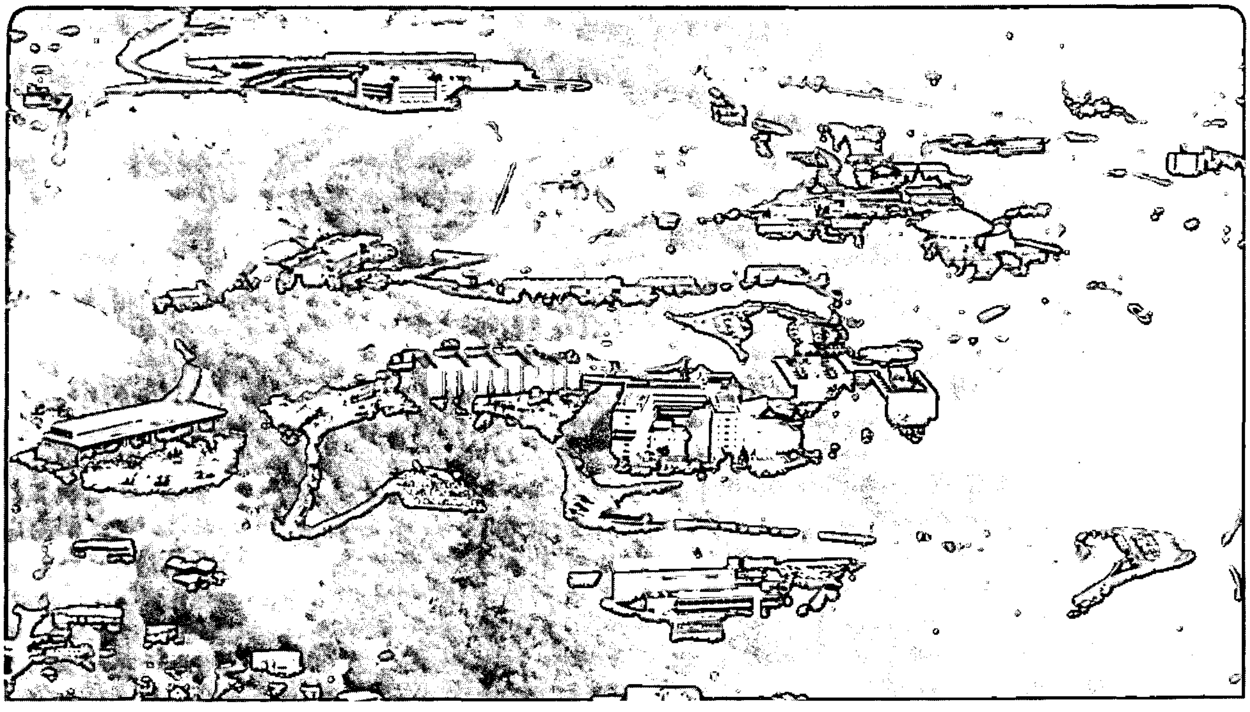

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PROGRAM — PROJECT — JOB
SYNCHROTRON LIGHT FACILITIES
BEAM LINE VI - STOPPERS, MASKS, SHUTTERS

TITLE
FILM HEAT TRANSFER EQUATIONS FOR TURBULENT WATER FLOW

A. INTRODUCTION

THE WIGGLER MAGNET WILL PRODUCE INTENSE SYNCHROTRON RADIATION WHICH WILL BE DIRECTED DOWN BEAM LINE VI. MASKS WILL BE LOCATED ALONG THIS BEAM LINE TO ABSORB UNWANTED SYNCHROTRON RADIATION. THESE MASKS WILL ABSORB HIGH HEAT LOADS AND WILL BE COOLED BY WATER AT HIGH HEAT TRANSFER RATES.

THE LITERATURE CONTAINS SEVERAL DIFFERENT EQUATIONS FOR HEAT TRANSFER TO A MOVING FLUID. THESE EQUATIONS ARE REVIEWED IN THIS ENGINEERING NOTE AND THEN ONE IS SELECTED FOR USE IN DESIGNING THE MASKS FOR BEAM LINE VI.

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S.L.F. - FILM HEAT TRANSFER EQUATIONS

B. NOMENCLATURE

A = FLOW AREA [inch^2]

c_p = SPECIFIC HEAT [BTU/lbm - °F]

d = DIAMETER [inch]

D = DIAMETER [feet]

h_L = HEAT TRANSFER COEF. [BTU/hr - ft^2 - °F]

h = HEAT TRANSFER COEF [watts/inch^2 - °C]

k = THERMAL CONDUCTIVITY [BTU/hr - ft - °F]

P = FLOW PASSAGE PERIMETER [inch]

t = TEMPERATURE [°F]

T = TEMPERATURE [°C]

V = VELOCITY [ft/sec]

ρ = FLUID DENSITY [lbm/ft^3]

μ = FLUID VISCOSITY [lbm/ft - sec]

n = DEISSLER EXPONENT [Dimensionless]

$Nu = h_L D/k$ = NUSSELT NO. [Dimensionless]

$Pr = C_p \mu/k$ = PRANDTL NO. "

$Re = DV\rho/\mu$ = REYNOLDS NO. "

$St = h_L \cdot C_p / V \cdot \rho$ = STANTON NO. "

SUBSCRIPTS:

b = BULK (MIXED) WATER

f = FILM (TAKEN AS ARITH. AVERAGE OF b & w)

w = WALL

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S.L.F. - FILM HEAT-X EQNS.

C. PROPERTIES OF WATER

Properties of Water

T	ρ	c_p	μ	ν	k	N_{pr}
32	62.4	1.01	1.20 EE-3	1.93 EE-5	.319	13.7
40	62.4	1.00	1.04 EE-3	1.67 EE-5	.325	11.6
50	62.4	1.00	.88 EE-3	1.40 EE-5	.332	9.55
60	62.3	.999	.76 EE-3	1.22 EE-5	.340	8.03
70	62.3	.998	.658 EE-3	1.06 EE-5	.347	6.82
80	62.2	.998	.578 EE-3	.93 EE-5	.353	5.89
90	62.1	.997	.514 EE-3	.825 EE-5	.359	5.13
100	62.0	.998	.458 EE-3	.740 EE-5	.364	4.52
150	61.2	1.00	.292 EE-3	.477 EE-5	.384	2.74
200	60.1	1.00	.205 EE-3	.341 EE-5	.394	1.88
250	58.8	1.01	.158 EE-3	.269 EE-5	.396	1.45
300	57.3	1.03	.126 EE-3	.220 EE-5	.395	1.18
350	55.6	1.05	.105 EE-3	.189 EE-5	.391	1.02
400	53.6	1.08	.091 EE-3	.170 EE-5	.381	.927
450	51.6	1.12	.080 EE-3	.155 EE-5	.367	.876
500	49.0	1.19	.071 EE-3	.145 EE-5	.349	.87
550	45.9	1.31	.064 EE-3	.139 EE-5	.325	.93
600	42.4	1.51	.058 EE-3	.137 EE-5	.292	1.09

Units for Appendix 3.3

T is in °F
ρ is in lbm/ft^3
c_p is in BTU/lbm-°F
μ is in lbm/ft-sec

ν is in ft^2/sec
k is in BTU/hr-ft-°F
N_{pr} is dimensionless

SOURCE:

Parker, J.D., Boggs, J.H., and Blick, E.F., Introduction to Fluid Mechanics and Heat Transfer, Addison-Wesley Publishing Company, Reading, MA, 1969.

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S.L.F. - FILM HEAT-X EQNS.

D. DITTUS-BOELTER EQUATION

McADAMS, "HEAT TRANSMISSION", 3rd Edition, McGraw-Hill, 1954, p. 219 & p. 228 PRESENTS SEVERAL EQUATIONS FOR PRANDTL NO. FROM 0.7 TO 120, REYNOLDS NO. FROM 10 000 TO 120 000 AND FOR LENGTH/DIAMETER OF 60 OR MORE. THE FIRST EQUATION DUE TO DITTUS & BOELTER (1930), McAdams Equ. (9-10a) *

$$Nu = 0.023\ Re^{0.8}\ P_r^{0.4} \qquad (1a)$$

OR

$$\frac{h_L D}{k_b} = 0.023\left(\frac{DV\rho_b}{\mu_b}\right)^{0.8}\left(\frac{c_p\mu}{k}\right)_b^{0.4} \qquad (1b)$$

WHERE FLUID PROPERTIES ARE EVALUATED AT THE BULK TEMPERATURE. USING WATER PROPERTIES FROM PAGE 3 AND CONVERTING TO RAD LAB UNITS GIVES, FOR $T_b = 10°C$ & $40°C$:

@ $T_b = 10°C$: $$h_{10} = 0.86\ \frac{V^{0.8}}{d^{0.2}} \qquad (1c)$$

@ $T_b = 40°C$: $$h_{40} = 1.19\ \frac{V^{0.8}}{d^{0.2}} \qquad (1d)$$

FOR WATER AT MODERATE PRESSURES AND TEMPERATURES (40-220°F), McADAMS (1954, p. 228) A SIMPLIFIED FORM OF EQ. (1b) AS:

$$h_L = 150\ (1 + 0.011\ t_b)\frac{V^{0.8}}{d^{0.2}} \qquad (1e)$$

CONVERTING TO RAD LAB UNITS

$$h = 0.743\,(1 + 0.0146\ T_b)\frac{V^{0.8}}{d^{0.2}} \qquad (1f)$$

ON THE ACCOMPANYING GRAPHS FOR BULK WATER TEMPERATURES OF $T_b = 10°C$ & $T_b = 40°C$, EQUATIONS (1c) & (1d) ARE PLOTTED AS LINE # ① WHILE EQUATION (1f) IS PLOTTED AS LINE # (1.A). THEY AGREE WITHIN ~1%.

* NOTE: McADAMS (1942, p. 167) INDICATES THAT COEFFICIENT IN DITTUS-BOELTER EQUATION ORIGINALLY WAS 0.0243 OR 5.6% GREATER.

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E. COLBURN EQUATION

THE SECOND EQUATION GIVEN BY McADAMS AS EQN. (9-10b) IS THAT DUE TO COLBURN (1933)

$$St \cdot Pr^{2/3} = 0.023\, Re^{-0.2} \qquad (2a)$$

OR $$\left(\frac{h_L}{c_p \cdot V \cdot \rho}\right)_b \left(\frac{c_p \mu}{k}\right)_f^{2/3} = 0.023 \left(\frac{DV\rho}{\mu}\right)_f^{-0.2} \qquad (2b)$$

WHERE THE STANTON NUMBER IS EVALUATED AT THE BULK WATER TEMPERATURE t_b BUT THE PRANDTL AND REYNOLDS NUMBERS ARE EVALUATED AT THE FILM TEMPERATURE t_f DEFINED AS THE ARITHMETIC AVERAGE OF t_b AND t_w.

FOR WATER, McADAMS GIVES SIMPLIFIED FORM OF THIS AS EQUATION (9-20):

$$h_L = 120\,(1 + 0.013\, t_f)\, \frac{V^{0.8}}{d^{0.2}} \qquad (2c)$$

McADAMS STATES THAT THE COLBURN EQUATION IS TO BE PREFERRED OVER THE DITTUS-BOELTER EQUATION FOR HIGH ΔT.

CONVERTING TO RAD LAB UNITS GIVES

$$h = 0.6225\,(1 + 0.00826\, T_f)\, \frac{V^{0.8}}{d^{0.2}} \qquad (2d)$$

THIS IS PLOTTED AS CURVE ② ON THE ACCOMPANYING GRAPHS.

S.L.F. - FILM HEAT-X EQNS.

F. SIEDER-TATE EQUATION

THE THIRD EQUATION GIVEN BY McADAMS AS EQN. (9-10c) IS THAT DUE TO SIEDER & TATE (1936):

$$\left(\frac{h_L}{c_p V \rho}\right)\cdot\left(\frac{c_p \mu}{k}\right)_b^{2/3}\left(\frac{\mu_w}{\mu_b}\right)^{0.14} = 0.027\left(\frac{DV\rho}{\mu}\right)_b^{-0.2} \qquad *(3a)$$

WHICH CAN BE CONFIGURED AS:

$$\frac{h_L D}{k_b} = 0.027\left(\frac{DV\rho}{\mu}\right)_b^{0.8}\left(\frac{c_p \mu}{k}\right)_b^{1/3}\left(\frac{\mu_w}{\mu_b}\right)^{-0.14} \qquad *(3b)$$

THE ABOVE EQUATION IS SIMILAR TO THE COLBURN EQUATION EXCEPT THAT THE PRANDTL AND REYNOLDS NUMBERS ARE EVALUATED AT THE BULK TEMPERATURE t_b AND THE TEMPERATURE PROPERTIES ARE TAKEN INTO ACCOUNT ONLY BY THE VISCOSITY RATIO TERM $(\mu_w/\mu_b)^{0.14}$.

McADAMS GIVES NO SIMPLIFIED FORM OF THIS EQUATION.

CONVERTING TO RAD LAB UNITS (USING UNITS AS GIVEN IN NOMENCLATURE):

$$h = 0.1138\, c_{pb}^{0.333} \cdot \rho_b^{0.8} \cdot \mu_b^{-0.467} \cdot k^{0.667} \cdot \frac{V^{0.8}}{d^{0.2}}\left(\frac{\mu_w}{\mu_b}\right)^{-0.14} \qquad (3c)$$

AT $T_b = 10°C$ (50°F):

$c_p = 1.00$, $\rho_b = 62.4$, $\mu_b = (.00088)(3600) = 3.168$, $k_b = .332$

$$h = 0.869\,\frac{V^{0.8}}{d^{0.2}}\left(\frac{\mu_w}{\mu_b}\right)^{-0.14} \qquad (3d)$$

AT $T_b = 40°C$ (104°F):

$c_p = 0.998$, $\rho_b = 62.0$, $\mu_b = (.000437)(3600) = 1.574$, $k_b = .366$

$$h = 1.278\,\frac{V^{0.8}}{d^{0.2}}\left(\frac{\mu_w}{\mu_b}\right)^{-0.14} \qquad (3e)$$

EQUATIONS (3d) & (3e) ARE PLOTTED ON THE ACCOMPANYING GRAPHS AS CURVE ③.

* NOTE: McADAMS (1942) GIVES ORIGINAL VALUE OF SIEDER-TATE COEF. AS 0.027 AS USED HERE. HDBK. OF HEAT TRANSFER (ROSHENOW & HARTNETT, 1973) SAYS 0.027 COEF. IS BETTER FOR WATER WHILE 0.023 COEF. IS BETTER FOR GASSES.

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G. HINTON EQUATION

McADAMS (1942, p. 167) GIVES EQUATION DUE TO HINTON (1928) AS:

$$\frac{hD}{k} = 0.0281\left(\frac{DV\rho}{\mu}\right)^{0.8}\left(\frac{c_p\mu}{k}\right)^{0.355} \qquad (4a)$$

FOR WATER, McADAMS (1942, p. 183, equ. 9d) GIVES A SIMPLIFIED FORM OF THIS EQUATION AS:

$$h_L = 160(1+0.012\,t_b)\,\frac{V^{0.8}}{d^{0.2}} \qquad (4b)$$

THE MECHANICAL ENGINEERS HANDBOOK, (MARKS', 1958, p. 4-101) & (BAUMEISTERS', 1978 p. 4-64) GIVES ONLY ONE SIMPLIFIED EQUATION FOR HEAT TRANSFER TO TURBULENT WATER FLOW IN TUBES AND IT IS SAME AS ABOVE EXCEPT THE FILM TEMPERATURE IS USED:

$$h_L = 160(1+0.012\,t_f)\,\frac{V^{0.8}}{d^{0.2}} \qquad (4c)$$

ON THE ACCOMPANYING GRAPHS, EQN. (4b) IS PLOTTED AS CURVE (4B) WHILE EQN. (4c) IS PLOTTED AS CURVE (4C)

* NOTE: IN EQUATION (4b), McADAMS (1942) GAVE THE TEMPERATURE AS t_b WHEREAS MARKS'/BAUMEISTERS' HANDBOOK GIVES IT AS t_f.

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H. DEISSLER EQUATION

DEISSLER (1954) CALCULATED THE VELOCITY AND TEMPERATURE PROFILES FOR FULLY-DEVELOPED LAMINAR FLOW WITH VISCOSITY A FUNCTION OF TEMPERATURE. IN THE "HANDBOOK OF HEAT TRANSFER", ROHSENOW & HARTNETT (1973, p. 7-158) STATE THAT WHEN DEISSLER'S RESULTS ARE PUT IN THE FORM

$$Nu = Nu_{c.p.} \left(\frac{\mu_w}{\mu_b} \right)^n \qquad (5a)$$

WHERE $Nu_{c.p.}$ IS THE CONSTANT PROPERTY SOLUTION (e.g. THE DITTUS-BOELTER EQUATION), THAT THE FOLLOWING VALUES OF n ARE OBTAINED.

PRANDTL NO. Pr	1	3	10	30	100	300
$\left(\frac{\mu_w}{\mu_b}\right) > 1.0$ $(T_w < T_b)$	-0.19	-0.21	-0.22	-0.21	-0.20	-0.20
$\left(\frac{\mu_w}{\mu_b}\right) < 1.0$ $(T_w > T_b)$	-0.20	-0.27	-0.36	-0.39	-0.42	-0.46

THE LATTER VALUES $(T_w > T_b)$ ARE PLOTTED IN FIGURE 3 FOR THE RANGE OF PRANDTL NUMBERS OF INTEREST. FOR $T_b = 10°C$ & $T_b = 40°C$, THE VALUES OF n ARE FOUND TO BE -0.36 AND -0.30 RESPECTIVELY. APPLYING THESE TO EQUATIONS (1c) & (1d) GIVES:

@ $T_b = 10°C$: $$h_{10} = 0.86 \frac{V^{0.8}}{d^{0.2}} \left(\frac{\mu_w}{\mu_b} \right)^{-0.36} \qquad (5b)$$

@ $T_b = 40°C$: $$h_{40} = 1.19 \frac{V^{0.8}}{d^{0.2}} \left(\frac{\mu_w}{\mu_b} \right)^{-0.30} \qquad (5c)$$

ON THE ACCOMPANYING GRAPHS, THESE EQUATIONS ARE PLOTTED AS CURVE ⑤.

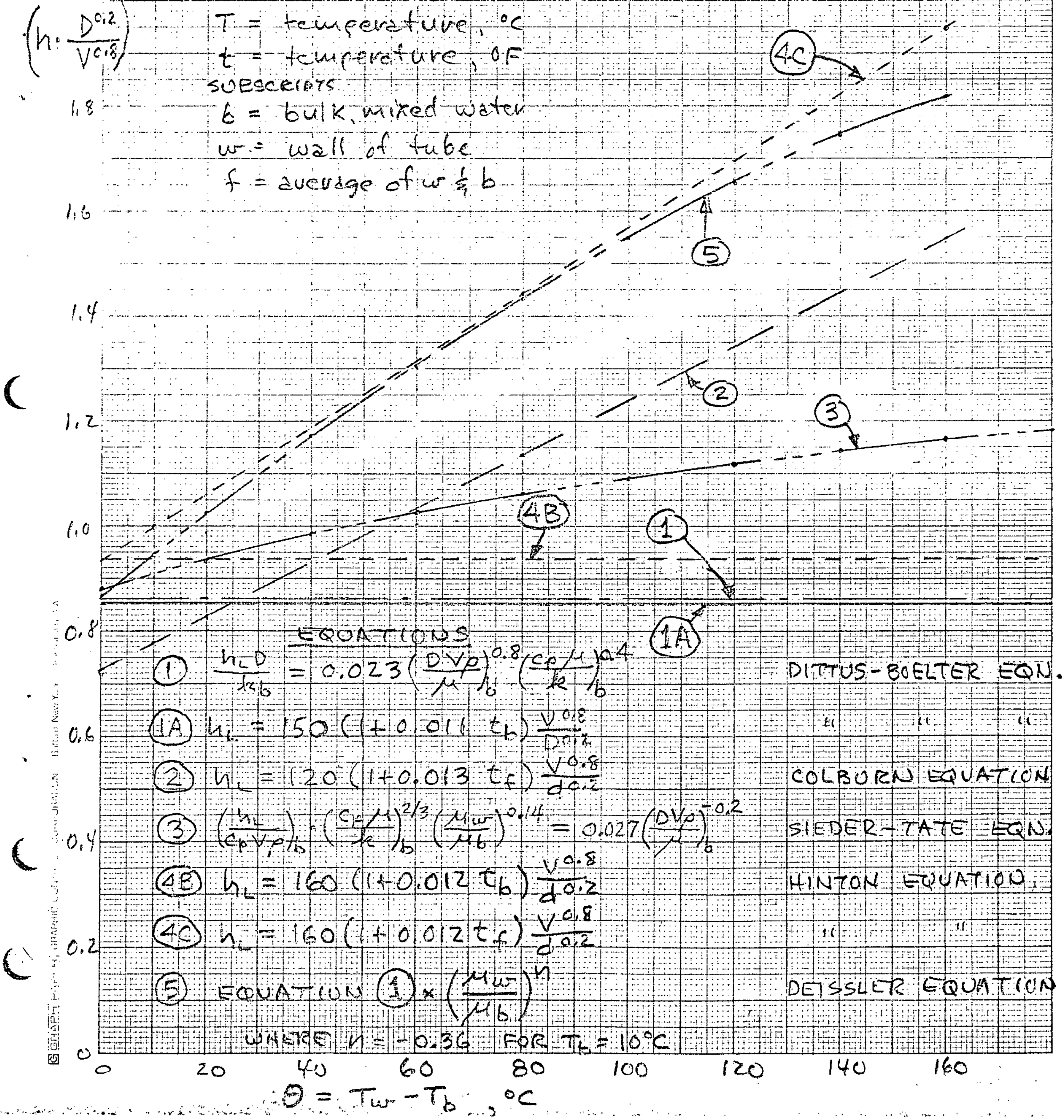
COMPARISON OF EQUATIONS FOR HEAT TRANSFER TO TURBULENT WATER FLOW IN TUBES

R. T. AVERY
8-25-82

FIGURE 1

FOR $T_b = 10°C$

h = coef. of heat transfer, watts/inch^2 · °C
h_L = coef. of heat transfer, BTU/hr·ft^2 °F
V = mean water velocity, feet/second
D = tube diameter, inches
T = temperature, °C
t = temperature, °F
SUBSCRIPTS
b = bulk, mixed water
w = wall of tube
f = average of w & b



EQUATIONS

① $\frac{h_L D}{k_b} = 0.023 \left(\frac{DV\rho}{\mu}\right)_b^{0.8} \left(\frac{c_p \mu}{k}\right)_b^{0.4}$ DITTUS-BOELTER EQN.

(1A) $h_L = 150 (1 + 0.011\, t_b) \frac{V^{0.8}}{D^{0.2}}$ " " "

② $h_L = 120 (1 + 0.013\, t_f) \frac{V^{0.8}}{d^{0.2}}$ COLBURN EQUATION

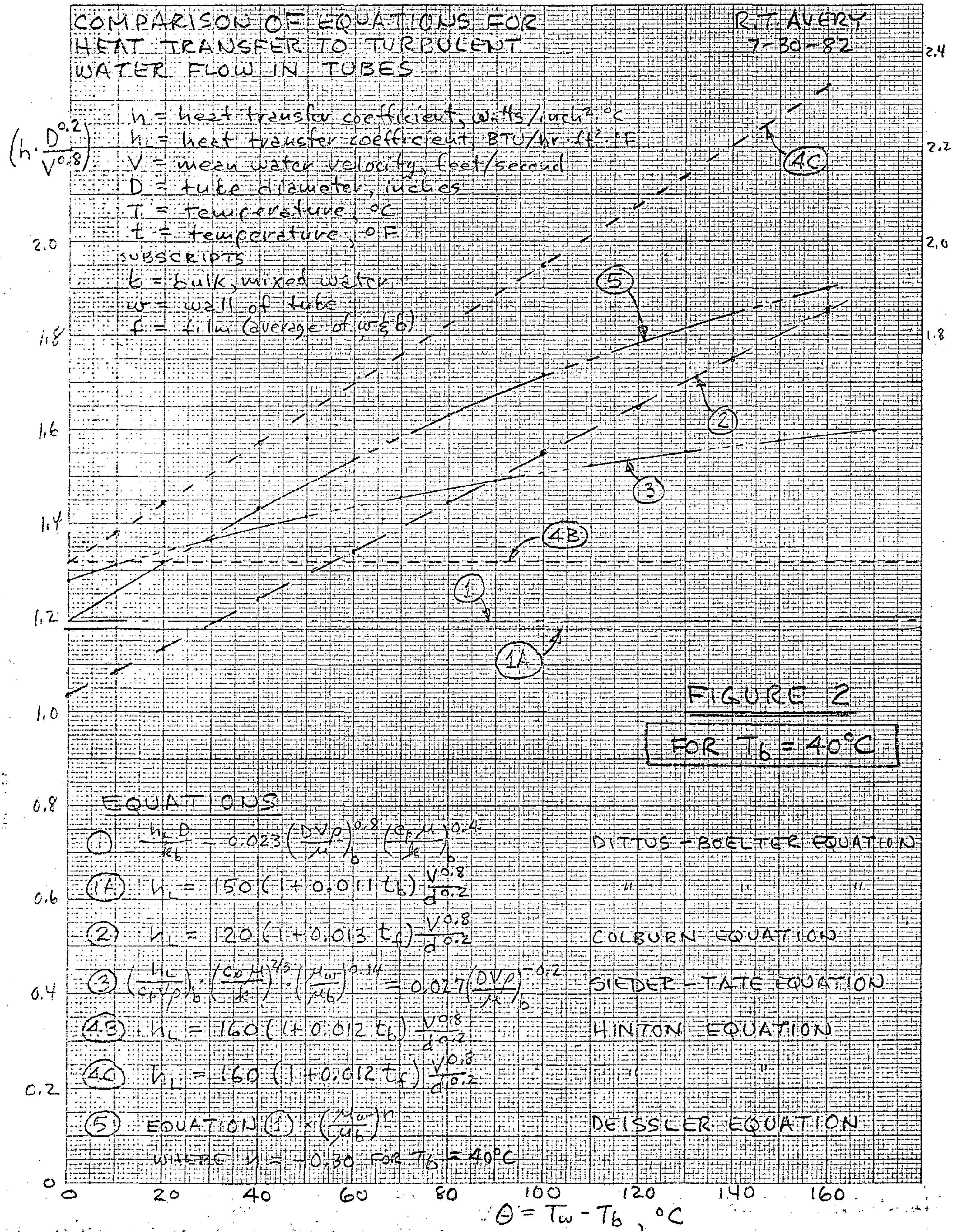
③ $\left(\frac{h_L}{c_p V \rho}\right)_b \cdot \left(\frac{c_p \mu}{k}\right)_b^{2/3} \left(\frac{\mu_w}{\mu_b}\right)^{0.14} = 0.027 \left(\frac{DV\rho}{\mu}\right)_b^{-0.2}$ SIEDER-TATE EQN.

(4B) $h_L = 160 (1 + 0.012\, t_b) \frac{V^{0.8}}{d^{0.2}}$ HINTON EQUATION.

(4C) $h_L = 160 (1 + 0.012\, t_f) \frac{V^{0.8}}{d^{0.2}}$ " "

⑤ EQUATION ① $\times \left(\frac{\mu_w}{\mu_b}\right)^n$ DEISSLER EQUATION

WHERE $n = -0.36$ FOR $T_b = 10°C$



COMPARISON OF EQUATIONS FOR HEAT TRANSFER TO TURBULENT WATER FLOW IN TUBES

R.T. AVERY
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h = heat transfer coefficient, watts/inch²·°C
h_L = heat transfer coefficient, BTU/hr·ft²·°F
V = mean water velocity, feet/second
D = tube diameter, inches
T = temperature, °C
t = temperature, °F

SUBSCRIPTS
b = bulk, mixed water
w = wall of tube
f = film (average of w & b)

FIGURE 2

FOR T_b = 40°C

EQUATIONS

① $\frac{h_L D}{k_b} = 0.023\left(\frac{DV\rho}{\mu}\right)_b^{0.8}\left(\frac{c_p\mu}{k}\right)_b^{0.4}$ DITTUS-BOELTER EQUATION

(1A) $h_L = 150(1+0.011\,t_b)\frac{V^{0.8}}{d^{0.2}}$ " " "

② $h_L = 120(1+0.013\,t_f)\frac{V^{0.8}}{d^{0.2}}$ COLBURN EQUATION

③ $\left(\frac{h_L}{c_pV\rho}\right)_b\left(\frac{c_p\mu}{k}\right)^{2/3}\left(\frac{\mu_w}{\mu_b}\right)^{0.14} = 0.027\left(\frac{DV\rho}{\mu}\right)_b^{-0.2}$ SIEDER-TATE EQUATION

(4B) $h_L = 160(1+0.012\,t_b)\frac{V^{0.8}}{d^{0.2}}$ HINTON EQUATION

(4C) $h_L = 160(1+0.012\,t_f)\frac{V^{0.8}}{d^{0.2}}$ " "

⑤ EQUATION (1) × $\left(\frac{\mu_w}{\mu_b}\right)^n$ DEISSLER EQUATION

WHERE n = −0.30 FOR T_b = 40°C

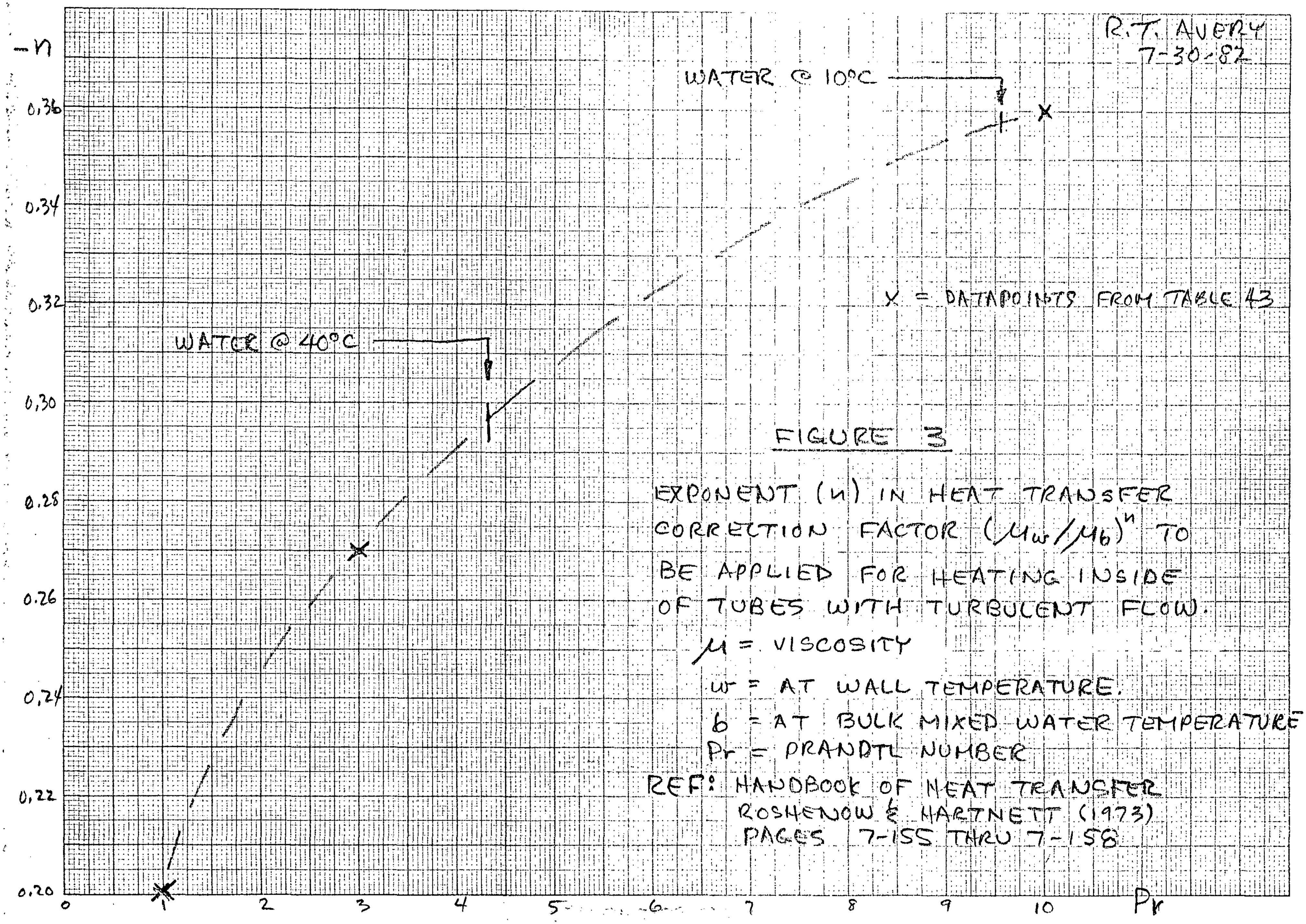

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FIGURE 3

EXPONENT (n) IN HEAT TRANSFER CORRECTION FACTOR $(\mu_w/\mu_b)^n$ TO BE APPLIED FOR HEATING INSIDE OF TUBES WITH TURBULENT FLOW.

μ = VISCOSITY
w = AT WALL TEMPERATURE.
b = AT BULK MIXED WATER TEMPERATURE.
Pr = PRANDTL NUMBER

REF: HANDBOOK OF HEAT TRANSFER
ROSHENOW & HARTNETT (1973)
PAGES 7-155 THRU 7-158

S.L.F. - FILM HEAT-X EQNS

J. NON-ROUND TUBES

IN THE "HANDBOOK OF HEAT TRANSFER", ROHSENOW & HARTNETT PRESENT CONSIDERABLE DATA FOR HEAT TRANSFER TO NON-ROUND TUBES. AN EQUIVALENT HYDRAULIC DIAMETER CAN BE CALCULATED AS

$$D_e = \frac{4A}{P}$$

FOR TURBULENT FLOW IN SQUARE & TRIANGULAR DUCTS (pages 7-119 thru 7-122), THE RESULTS ARE SUBSTANTIALLY THE SAME AS FOR ROUND TUBES, PARTICULARLY WHEN THE WALL IS A GOOD THERMAL CONDUCTOR (i.e. WHEN HEAT CAN FLOW CIRCUMFERENTIALLY IN THE WALL). FOR TURBULENT FLOW IN RECTANGULAR DUCTS WITH ROUNDED CORNERS, ROHSENOW & HARTNETT STATE "THE AVERAGE HEAT TRANSFER RESULTS OF GAMBILL & BUNDY ARE WELL CORRELATED BY THE ORIGINAL SIEDER-TATE EQUATION (EQNS. 3a THRU 3e HEREIN). FOR A HALF-ROUND CROSS-SECTION, WITH LAMINAR FLOW, ROHSENOW & HARTNETT (p. 7-140, 141) PRESENT DATA THAT THE HEAT TRANSFER IS ENHANCED BY FACTOR 1.16 BUT, FOR TURBULENT FLOW, I WOULD EXPECT THE ENHANCEMENT FACTOR TO BE MUCH CLOSER TO UNITY,

FOR TURBULENT FLOW, IT APPEARS THAT THE HEAT TRANSFER EQUATIONS FOR ROUND TUBES OF EQUIVALENT DIAMETER CAN BE USED

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K. ENTRANCE EFFECTS.

IN "THE HANDBOOK OF HEAT TRANFER", RONSENOW & HARTNETT (EDITORS), DATA IS PRESENTED (p. 7-33 thru 7-38) THAT THE HEAT TRANSFER COEFFICIENT IS ENHANCED IN THE ENTRANCE REGION FOR A DISTANCE UP TO APPROX. 10 TO 40 DIAMETERS DOWNSTREAM.

SINCE THIS FACTOR IS AN ENHANCEMENT OF HEAT TRANSFER RATE, IGNORING IT WOULD BE ON THE CONSERVATIVE SIDE.

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L. DISCUSSION & CONCLUSIONS

REVIEWING FIGURES 1 & 2, IT CAN BE SEEN, FOR TEMPERATURE DIFFERENCE $\theta = T_w - T_b$ OF LESS THAN ~25°C, THAT ALL EQUATIONS AGREE WITHIN ±13%. THIS PROBABLY IS COMPARABLE TO THE SPREAD IN THE ORIGINAL EXPERIMENTAL DATA. OVER THIS RANGE, ALMOST ANY OF THE EQUATIONS WOULD SUFFICE.

FOR $\theta > 25°C$, THE FILM TEMPERATURE RISES SIGNIFICANTLY AND THEREFORE THE VISCOSITY AND THE FILM THICKNESS DECREASE WHICH SHOULD LEAD TO ENHANCED HEAT TRANSFER. CURVES ①, (1A) & (4B) DO NOT VARY WITH TEMPERATURE, SO INTUITIVELY THEY ARE DISCARDED FOR HIGH VALUES OF θ. THE HINTON EQUATION ORIGINALLY APPEARED IN FORM OF EQUATION (4b) AND IT STRIKES ME THAT THE FORM OF EQUATION (4c) MAY BE INCORRECT; THEREFORE DISCARD EQUATION (4c). THIS LEAVES EQUATIONS ②, ③ & ⑤. IN THE "HANDBOOK OF HEAT TRANSFER", PAGE 7-158, IT STATES THAT "ALLEN & ECKERT FIND THE 0.14 POWER ADEQUATE FOR WATER AT $Re = 10^5$ WITH A SMALLER POWER FOR CORRELATION AT LOWER REYNOLDS NUMBERS. SINCE EQUATION ⑤ WAS ANALYTICALLY DERIVED AND APPARENTLY DOES NOT AGREE WITH EXPERIMENTAL RESULTS AS WELL AS EQUATION ③, LET'S DISCARD EQUATION ⑤.

S.L.F. - FILM HEAT-X EQNS.

L. DISCUSSION & CONCLUSIONS Contd.

THIS LEAVES A CHOICE OF EQUATION ② OR ③. INSPECTION SHOWS THAT, AT LOW VALUES OF θ ($< 20°C$), EQN ③ FALLS IN THE MIDDLE OF THE OTHER EQUATIONS AND THAT, AT VERY HIGH VALUES OF θ ($>$ APPROX. 60 TO 90°C), EQN. ③ GIVES MORE CONSERVATIVE VALUES. THEREFORE THE "SIEDER-TATE" EQUATION ③ IS ADOPTED FOR USE IN DESIGNING THE MASKS FOR BEAMLINE VI.

FOR NON-ROUND CROSS-SECTIONS WITH TURBULENT FLOW, CALCULATE THE EQUIVALENT DIAMETER "D_e" AND THEN USE EQUATION ③. IT APPEARS THAT THIS WILL INTRODUCE NO SIGNIFICANT ADDITIONAL ERROR.

NEGLECT THE ENHANCED HEAT TRANSFER THAT OCCURS NEAR THE TUBE ENTRANCE. THIS ASSUMPTION IS CONSERVATIVE.

IF, AT SOME TIME IN THE FUTURE IT SHOULD BECOME NECESSARY TO KNOW THE HEAT TRANSFER COEFFICIENT TO BETTER THAN ±20%, THEN IT MAY BE WORTHWHILE GOING THROUGH THE ORIGINAL EXPERIMENTAL DATA THAT UNDERLIES THE FOREGOING AND USING THAT WHICH IS MOST APPLICABLE TO THE CASE TO BE STUDIED. PERHAPS, THERE ALSO NEWER ADDITIONAL EXPERIMENTAL DATA IN THE LITERATURE. TO DO SO AT THIS TIME DOES NOT APPEAR COST-EFFECTIVE.

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