DØ SOLENOID UPGRADE PROJECT

**Control Dewar Subcooler
Heat Exchanger Calculations**

D-ZERO ENGINEERING NOTE # 3823.111 EN-351

Oct. 4, 1993

Russ Rucinski
RD/D-Zero Mechanical Group

INTRODUCTION

The calculations done to size the control dewar subcooler were done to obtain a sufficient subcooler size based on some conservative assumptions. The final subcooler design proposed in the design report will work even better because 1) It has more tubing length, and 2) will have already subcooled liquid at the inlet due to the transfer line design.

FINAL SUBCOOLER DESIGN

The subcooler design described in the "Design Report of the 2 Tesla Superconducting Solenoid for the Fermilab DØ Detector Upgrade" is the final design proposed. A short description of this design follows.

The subcooler is constructed of 0.50" OD copper tubing with 1.0" diameter fins. It has ten and one half spirals at a 11.375" centerline diameter to provide 31 feet of tubing length. The liquid helium supply for the solenoid flows through the subcooler and then is expanded through a J-T valve. The subcooler spirals are immersed in the return two phase helium process stream. The return stream is directed over the finned tubing by an annulus created by a 10" pipe inside a 12" pipe. The transfer line from the refrigerator to the control dewar is constructed such that the liquid helium supply tube is in the refrigerator return stream, thereby subcooling the liquid up to the point where the u-tubes connect the transfer line to the control dewar. The subcooler within the control dewar will remove the heat picked up in the helium supply u-tube/bayonets.

SUBCOOLER DESIGN CALCULATIONS

The attached subcooler/heat exchanger calculations were done neglecting any subcooling in the transfer line. All heat picked up in the transfer line from the refrigerator storage dewar to the control dewar is absorbed by the supply stream. The subcooler was sized such that the two phase supply fluid is subcooled at 1.7 atm pressure and when expanded through a JT valve to 1.45 atm pressure it is at a saturated liquid state. The calculations apply during steady state operation and at a flow rate of 16 g/s. The analysis of the heat exchanger was broken into two parts relating to the heat transfer mode taking place. The first part is considered the condensing part in which the helium supply stream is changed from two phase fluid to one phase liquid. The second part is the subcooling part where the liquid temperature is lowered, i.e., subcooled. A summary of the calculations and results appears on the next page. The raw calculations follow the summary.

Control Dewar Heat Exchanger Summary

2

	PART I	PART II	TOTAL
Inside mode	Condensing	Subcooling	
Outside mode	Boiling	Boiling	
Temperature of fluid, inside	4.84 K	4.84 K to 4.64 K	
Temperature of fluid, outside	4.51K	4.51 K	
Convection coefficient, inside	1740 W/m ² -K	1930 W/m ² -K	
Convection coefficient, outside	736 W/m ² -K	416 W/m ² -K	
Surface area, inside	0.075 m ²	0.154 m ²	
Surface area, outside	0.176 m ²	0.402 m ²	
Fin efficiency on outside	52%	64%	
h*A, inside	130 W/K	297 W/K	
h*A, outside	130 W/K	167 W/K	
Length of finned tubing	2.2 m	4.5 m	6.7 m
Heat transferred between fluids	21.3 W	24.6 W	45.9 W

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/8/93

REVISION DATE

2/22/93

HEAT LOAD REQ'Y.

STATE ①

$P = 1.8 \text{ ATM}$
SATURATED LIQUID
 $T = 4.91 \text{ K}$
 $h_1 = 14.86 \frac{\text{J}}{\text{g}}$

STATE ②

$P = 1.7 \text{ ATM}$
 $h_2 = 15.47 \frac{\text{J}}{\text{g}}$
 $T = 4.835 \text{ K}$
 $x_2 = .088$

STATE ③

$P = 1.7 \text{ ATM} = .172 \text{ MPa}$

STATE ④

$P = 1.45 \text{ ATM}$
 $h_4 = h_3$

STATE ⑤/⑥

$P = 1.3 \text{ ATM} = .1317 \text{ MPa}$
 $L - V$
 $T = 4.51 \text{ K}$
 $h_{fg} = 18.74$
TOTAL $Q_{1 \rightarrow 2} = 9.8 \text{ WATTS}$

HEAT LOAD ESTIMATES FROM CDF DESIGN REPORT:

$B1 = 1.3 \text{ W}$

$TL = 2 \text{ W}$

$B4 = 1.3 \text{ W}$

$UT1 = 1.3 \text{ W}$

$B3 = 1.3 \text{ W}$

$UT2 = 1.3 \text{ W}$

$B2 = 1.3 \text{ W}$

1ST LAW STEADY STATE, STEADY FLOW (+ DROP NEGLECT TERMS)

$$Q_{1 \rightarrow 2} = \dot{m} (h_2 - h_1)$$

$$h_2 = \frac{Q_{1 \rightarrow 2}}{\dot{m}} + h_1$$

MUST ASSUME $\dot{m}$, SAY $\dot{m} = 16 \text{ g/s}$

$$h_2 = \frac{9.8 \text{ W}}{16 \text{ g/s}} + 14.86 \frac{\text{J}}{\text{g}} = 15.47 \frac{\text{J}}{\text{g}}$$

FIGURE OUT x_2 :

FOR $P = 1.7 \text{ ATM}$, $h_f = 14.14 \frac{\text{J}}{\text{g}}$ $h_g = 29.25 \frac{\text{J}}{\text{g}}$

$$x_2 = \frac{h_2 - h_f}{h_g - h_f} = \frac{15.47 - 14.14}{29.25 - 14.14} = 0.088$$

* R.B. SCOTT, "CRYOGENIC ENGINEERING", D. VAN NOSTRAND, PRINCETON N.J., (1967), p. 23.

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/10/93

REVISION DATE

THE TEMPERATURE AT STATE (3), $T_3 \geq T_5 = 4.51\text{K}$ FOR STATE (4) TO BE $x=0$, $h_4 = h_{f4} = 12.606 \frac{\text{J}}{\text{g}}$ (ARBITRARY)THEN $h_3 = h_4 = 12.606 \frac{\text{J}}{\text{g}}$, WHAT IS REQ'D T_3 ? (SUBCOOLED)

$$P = 1.7 \text{ ATM} = .172 \text{ MPa}$$

CONSTRUCTING A TABLE,

$$P = .160 \text{ MPa}$$

T (K)	h (J/g)
(SAT. LIQ.) 4.744	13.38
4.500	11.59

$$P = .180 \text{ MPa}$$

T (K)	h (J/g)
(SAT. LIQ.) 4.891	14.67
4.800	13.69
4.500	11.59
4.744	13.30 INTERPOLATED

INTERPOLATING FOR $P = .172 \text{ MPa}$

T (K)	h (J/g)
4.744	13.34
4.500	11.59

$$T_3 = 4.64 \text{ K} \quad \text{REQ'D FOR } x_4 = 0$$

$$T_3 > T_5 \quad \text{O.K.}$$

REQ'D q FOR SUBCOOLER

$$q = \dot{m} (h_3 - h_2) = 16 \frac{\text{g}}{\text{s}} (12.60 \frac{\text{J}}{\text{g}} - 15.47 \frac{\text{J}}{\text{g}})$$

$$= -45.9 \text{ WATTS}$$

HEAT EXCHANGER

$$Q = U_o A_o (T_i - T_o)$$

WHERE:

$$U_o = \frac{1}{\frac{A_o}{h_i A_i} + \frac{A_o \ln(r_o/r_i)}{2\pi L K_w} + \frac{1}{h_o}}$$

FOWLING IS NEGLECTED.

THE TEMPERATURE PROFILE FOR THE HX

CHECK IF COLD STREAM HAS ENOUGH CAPACITY P.

$$Q_{\text{MAX. POSS.}} = \dot{m} h_{f5}$$

$$= 16 \frac{\text{g}}{\text{s}} (18.74 \frac{\text{J}}{\text{g}})$$

$$= 300 \frac{\text{J}}{\text{s}} = 300 \text{ W}$$

$$\text{O.K.}$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/10/93

REVISION DATE

HOW MUCH HEAT TRANSFER IS REQ'D TO BRING STATE (2) TO $x = 0$?

$$Q = \dot{m} (h_2 - h_f) = 16 \frac{9}{5} (15.47 - 14.14 \frac{1}{2}) = 21.3 \text{ W}$$

IF WE ASSUME $Q/L = \text{CONSTANT}$ THEN THE FIRST $\frac{21.3}{45.9} = 0.46 \text{ l}$ OF THE HEAT EXCHANGER $T_w = T_2 = 4.835 \text{ K}$. THE LAST 0.54 l IS USED TO SUBCOOL AND REDUCE T_w .

ASSUMING THE HEAT EXCHANGER WILL BE ONE PASS, I CAN BREAK IT INTO TWO PARTS. THE FIRST PART $T_i = \text{CONSTANT}$ AND THE SECOND PART T_i IS REDUCED

FOR PART I:

$$Q_{\text{REQ'D}} = 21.3 \text{ W}, \quad T_i - T_o = 4.835 \text{ K} - 4.51 \text{ K} = .325 \text{ K}$$

$$\text{AND } U_o A_o = \frac{Q}{T_i - T_o} = \frac{21.3 \text{ W}}{.325 \text{ K}} = 65 \frac{\text{W}}{\text{K}} \quad (\text{PART I})$$

FOR PART II

$$Q_{\text{REQ'D}} = 45.9 \text{ WATTS} - 21.3 \text{ W} = 24.6 \text{ W}$$

$$T_i - T_o = .325 \text{ K TO } 0.130 \text{ K.}$$

DETERMINING THE HEAT TRANSFER COEFFICIENTS:

$$Nu_L = 0.023 (Re_L)^{0.8} (Pr_L)^{0.4} (1-x)^{0.8}$$

REF. HELIUM CRYOGENICS
STEVE VANSIVER
EQ. 7.50 & 7.51

$$\frac{Nu_{\text{EXP}}}{Nu_L} = AX_{++}^{-n}$$

WE ARE IN A VERY LOW x THEREFORE THE EQUATION REDUCES TO

$$Nu = 0.023 (Re_L)^{0.8} (Pr)^{0.4}$$

$$\frac{hD}{k} = 0.023 \left(\frac{D \dot{m}}{MA} \right)^{0.8} \left(\frac{C_p \mu}{k} \right)^{0.4}$$

ASSUME WE ARE USING $1/2'' \text{ O.D.} \times 0.035'' \text{ WALL} \times 1'' \text{ FINNED COPPER TUBING.}$

$$Re = \frac{D \dot{m}}{MA} = \frac{(0.0109 \text{ m})(16 \frac{9}{5})}{(3.133 \times 10^{-6} \text{ Pa} \cdot \text{s})(9.33 \times 10^{-5} \text{ m}^2)} \times \frac{1 \text{ Kg}}{1000 \text{ g}} \times \frac{1 \text{ Pa}}{\text{N/m}^2} \times \frac{1 \text{ N}}{\text{Kg} \frac{\text{m}}{\text{s}^2}}$$

$$= 5.966 \times 10^5$$

$$Pr = \frac{C_p \mu}{k} = \frac{6.82 \frac{1}{2} \text{ g/K} (3.133 \times 10^{-6} \text{ Pa} \cdot \text{s})}{.0188 \frac{\text{W}}{\text{mK}}} \times \frac{\text{N/m}^2}{\text{Pa}} \times \frac{1000 \text{ g}}{1 \text{ Kg}} \times \frac{\text{Kg} \cdot \text{m}}{\text{s}^2} \times \frac{\text{W}}{\text{J/s}}$$

$$Pr = 1.137 \quad \text{MATCHES TABLES}$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/10/93

REVISION DATE

$$Nu = 0.023 (5.966 \times 10^5)^{0.8} (1.137)^{0.4} = 1010$$

$$h_i = \frac{k}{D} (Nu) = \frac{(0.0188 \text{ W/mK})}{(0.0109 \text{ m})} (1010) = 1742 \text{ W/m}^2\text{K}$$

$$h_i = 1740 \text{ W/m}^2\text{K} \quad (\text{PART I})$$

$$Q/A = h \Delta T \Rightarrow h_o = \frac{q''}{\Delta T} = \frac{q''}{T_w - T_\infty}$$

FOR PART I $T_i - T_o = 0.325 \text{ K}$, ASSUMING A BALANCED $U_o \approx U_i$
AND SMALL ΔT ACROSS WALL,

$$T_w - T_\infty = \frac{1}{2} (T_i - T_o) = \frac{1}{2} (0.325 \text{ K}) = 0.163 \text{ K}$$

USING A GRAPH FOR NUCLEATE BOILING HEAT TRANSFER (FIG. 6.8 IN HELIUM THERMODYNAMICS)
AND IT'S CONSERVATIVE CURVE FIT VAN SCIVER

$$Q \left(\frac{\text{W}}{\text{cm}^2} \right) = 1.0 \Delta T^{2.5} \\ = 1.0 (0.163 \text{ K})^{2.5} = 0.0107 \frac{\text{W}}{\text{cm}^2}$$

NOTE: THIS DATA IS FOR
A HORIZONTAL
COPPER PLATE
NOT TUBES

$$\text{THEN } h_o = \frac{q''}{T_w - T_\infty} = \frac{0.0107 \text{ W/cm}^2}{0.163 \text{ K}} \left[\frac{100 \text{ cm}}{1 \text{ m}} \right]^2 = 658 \text{ W/m}^2\text{K} \quad (\text{PART I})$$

FOR PART II, h_i K DOESN'T VARY MUCH WITH SMALL T.
 C_p CHANGES QUITE A BIT AS YOU SUBCOOL.
 μ CHANGES A LITTLE.

I WILL CALCULATE h_i FOR THE MIDDLE OF PART II

$$T = \frac{4.84 \text{ K} + 4.64 \text{ K}}{2} = 4.74 \text{ K} \quad \text{SAT } P = 0.17 \text{ MPa}$$

INTERPOLATED

$$P = 0.16 \text{ MPa}$$

$$P = 0.17 \text{ MPa}$$

$$P = 0.18 \text{ MPa}$$

T	C_p	Pr	T	C_p	Pr	T	C_p	Pr
4.5 K (SUB)	6.027	1.02	4.5 K	5.86		4.5 K SUB	5.696	0.9725
4.744 K (SAT L.)	9.439	1.489	4.744 K	8.99	1.424	4.744 K	8.538	1.358 ← INTERP.
						4.80 K SUB	9.190	1.447

$$Re_{\text{PART II}} = Re_{\text{PART I}} = 5.966 \times 10^5 \quad Pr_{\text{PART II}} = 1.424$$

$$Nu_{\text{PART II}} = 0.023 (5.966 \times 10^5)^{0.8} (1.424)^{0.4} = 1106$$

$$h_i = \frac{k}{D} (Nu) = \frac{0.0190 \text{ W/mK}}{(0.0109 \text{ m})} (1106) = 1928 \frac{\text{W}}{\text{m}^2\text{K}} = 1930 \frac{\text{W}}{\text{m}^2\text{K}} \quad (\text{PART II})$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/10/93

REVISION DATE

FOR PART II h_o |
MIDDLE
OF
PART II

TO BE CONSERVATIVE, FOR PART II,
 $T_i - T_o \geq 4.64K - 4.51K = .13K$

$$\text{USE } T_w - T_o = \frac{1}{2}(.13K) = .065K$$

USING CONSERV. EQ'N;

$$Q \left(\frac{W}{CM^2} \right) = 1.0 \Delta T^{2.5} = 1.0 (.065)^{2.5} = .00108 \frac{W}{CM^2}$$

$$h_o = \frac{q''}{T_w - T_o} = \frac{.00108 \frac{W}{CM^2}}{.065K} \cdot \left[\frac{100 CM}{1 IN} \right]^2 = 166 \frac{W}{M^2K} \text{ PART II}$$

IN ORDER TO BALANCE THE THERMAL RESISTANCES, IT IS CLEAR THE
EXTRA SURFACE AREA IS REQUIRED ON THE OUTER SURFACE.

SUMMARY

PART	INSIDE MODE	OUTSIDE MODE	$h_i \left(\frac{W}{M^2K} \right)$	$h_o \left(\frac{W}{M^2K} \right)$	REQ'D Q (WATTS)
I	CONDENSING	BOILING	1740	660	21.3
II	SUBCOOLING	BOILING	1930	170	24.6

I WILL NOW CALCULATE THE REQ'D LENGTH OF TUBING FOR EACH PART.
CONSIDER A 1M LENGTH & CALC. AMT. OF Q TRANSFERRED

$$A_i = \pi D_i L = \pi (.0109m)(1m) = .0342 m^2 \quad \checkmark \text{ MEASUREMENTS MADE ON WAMUS FINNED TUBING FROM AD/CRYU.}$$

$$A_o = \pi D_o L + \frac{A_{FINS}}{\eta_f}$$

↑
IN ONE METER'S
LENGTH

APPROX. 31 FINS / 6 INCHES OF LENGTH

FINS APPROX. 1" DIA. x 0.50" I.D. DIA. x .027" THK

USE Fig. 3.19 EFFICIENCY OF ANNULAR FINS IN FUNDAMENTALS OF HEAT & MASS X-FER
INCROPERA & DEWITT 3rd EDITION

$$L_c^{3/2} \left(\frac{h}{K A_p} \right)^{1/2}$$

↑
X-AXIS OF
CHART

$$L_c = .25 IN \times .0254 \frac{M}{IN} = 6.35 \times 10^{-3} M$$

$$h_i = 660 \frac{W}{M^2K} \quad \& \quad h_o = 170 \frac{W}{M^2K}$$

PART I PART II

$$K = 34 \frac{W}{MK} \quad \left(\begin{array}{l} \text{ESTIMATE. THIS VALUE IS FOR AL 6063-T5} \\ \text{AT 4K. COULDN'T FIND DATA FOR CU ALLOY} \end{array} \right)$$

$$A_p = L_c t = 6.35 \times 10^{-3} M (.027 IN \times .0254 \frac{M}{IN}) = 4.35 \times 10^{-6} M^2$$

$$r_{2c} = r_2 + \frac{t}{2} = \left[.05 IN + \frac{.027 IN}{2} \right] \cdot \frac{.0254 M}{IN} = 1.304 \times 10^{-2} M$$

$$r_1 = (.025 IN) \left(\frac{.0254 M}{IN} \right) = 6.35 \times 10^{-3} M$$

$$r_{2c/r_1} = \frac{1.304 \times 10^{-2}}{6.35 \times 10^{-3}} = 2.05$$

$$\eta_f = \frac{q_f}{q_{MAX}}$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/11/93

REVISION DATE

$$L_c^{3/2} \left(\frac{h}{KA_f} \right)^{1/2} \Big|_{\text{PART I}} = (6.35 \times 10^{-3} \text{ m})^{3/2} \left(\frac{660 \text{ W/m}^2\text{K}}{34 \text{ W/m}^2\text{K} (4.35 \times 10^{-6} \text{ m}^2)} \right)^{1/2} = 1.1 \text{ PART I}$$

$$L_c^{3/2} \left(\frac{h}{KA_f} \right)^{1/2} \Big|_{\text{PART II}} = 0.54$$

READING FIG. 3.19, $\eta_{\text{PART I}} = 0.52$ $\eta_{\text{PART II}} = .82$

FOR PART I

$$Q \Big|_{1 \text{ METER LENGTH}} = U_o A_o (T_i - T_o)$$

$$\text{FINS W } 1 \text{ m} = 31 \frac{\text{FINS}}{\text{m}} \times 1 \text{ m} \times \frac{1 \text{ in.}}{.0254 \text{ m}} = 203.4$$

$$A_o = \pi (0.50 \text{ in.}) \left(\frac{.0254 \text{ m}}{1 \text{ in.}} \right) (1 \text{ m}) + \frac{\pi (1 \text{ in.}^2 - 0.5 \text{ in.}^2)}{4} \times \left(\frac{.0254 \text{ m}}{1 \text{ in.}} \right)^2 (203.4 \text{ FINS}) \cdot 0.52$$

$$= 0.08 \text{ m}^2$$

$$U_o = \frac{1}{\frac{A_o}{h_i A_i} + \frac{1}{h_o}} = \left(\frac{0.08 \text{ m}^2}{(1740 \frac{\text{W}}{\text{m}^2\text{K}}) (.0342 \text{ m}^2)} + \frac{1}{660 \frac{\text{W}}{\text{m}^2\text{K}}} \right)^{-1} = (.00135 + .00152)^{-1}$$

$$U_o = 349.5 = 350 \frac{\text{W}}{\text{m}^2\text{K}} \quad \text{PART I}$$

$$Q \Big|_{1 \text{ m LENGTH}} = (350 \frac{\text{W}}{\text{m}^2\text{K}}) (.08 \text{ m}^2) (4.84 \text{ K} - 4.51 \text{ K}) = 9.2 \text{ W} \quad \text{PART I}$$

$$L_{\text{REQ'D PART I}} = 21.3 \text{ W} \times \frac{1 \text{ m}}{9.2 \text{ W}} = 2.3 \text{ m}$$

FOR PART II

$$A_o = 0.0399 \text{ m}^2 + .0634 \text{ m}^2 = 0.1033 \text{ m}^2$$

$$U_o = \left(\frac{0.1033 \text{ m}^2}{1930 \frac{\text{W}}{\text{m}^2\text{K}} (.0342 \text{ m}^2)} + \frac{1}{170 \frac{\text{W}}{\text{m}^2\text{K}}} \right)^{-1} = (.00156 + .00588)^{-1}$$

$$= 134.3 \frac{\text{W}}{\text{m}^2\text{K}} \quad \text{PART II}$$

$$Q \Big|_{1 \text{ m LENGTH}} = 134.3 \frac{\text{W}}{\text{m}^2\text{K}} (.1033 \text{ m}^2) (4.74 \text{ K} - 4.51 \text{ K}) = 3.19 \text{ W} = 3.2 \text{ W} \quad \text{PART II}$$

$$L_{\text{REQ'D PART II}} = 24.6 \text{ W} \times \frac{1 \text{ m}}{3.2 \text{ W}} = 7.7 \text{ m}$$

$$\text{TOTAL MINIMUM LENGTH REQ'D FOR SUBCOOLER} = 2.3 + 7.7 = 10 \text{ m}$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/11/93

REVISION DATE

NOW WITH 1ST PASS SOLUTION I WILL GO BACK AND CHECK THE ASSUMPTIONS MADE TO GET AN h_o .

FOR PART I, CALCULATE T_{WALL}

$$T_i \xrightarrow[4.84K]{\frac{A_o}{h_i A_i}} T_W \xrightarrow[4.685K]{\frac{1}{h_o}} T_o \rightarrow q'' = \frac{Q}{A_o}$$

$$\frac{Q}{A_o} = \frac{h_i A_i}{A_o} [T_i - T_W]$$

$$T_W = T_i - \frac{Q}{h_i A_i} = 4.84K - \frac{9.2W}{(1740 \frac{W}{m^2K})(.0342m^2)} = 4.685K$$

$$T_W - T_o = 4.685K - 4.51K = 0.175K \leftarrow \text{IN 1ST PASS I USED .163K}$$

GETTING BETTER ESTIMATE FOR h_o

$$Q (W/cm^2) = 1.0 \Delta T^{2.5} = 1.0 (.175K)^{2.5} = .0129 W/cm^2$$

$$h_o = \frac{q''}{T_W - T_o} = \frac{.0129 W/cm^2}{.175K} \left(\frac{100cm}{1m} \right)^2 = 736 \frac{W}{m^2K}$$

FOR PART II, STICK WITH LINEAR TEMP. DISTRIBUTION ASSUMPTION.

$$\rightarrow h_i = 1930 \frac{W}{m^2K} \text{ AS BEFORE}$$

CALCULATE T_{WALL} AT MID POINT OF PART II

$$T_i \xrightarrow[4.74K]{\frac{A_o}{h_i A_i}} T_W \xrightarrow[4.51K]{\frac{1}{h_o}} T_o \rightarrow q'' = \frac{Q}{A_o}$$

$$T_W = T_i - \frac{Q}{h_i A_i} = 4.74K - \frac{3.2W}{1930 \frac{W}{m^2K} (.0342m^2)} = 4.691K$$

$$T_W - T_o = 4.691K - 4.51K = 0.182K \leftarrow \text{IN 1ST PASS I USED .065K!}$$

QUITE DIFFERENT!

$$Q (W/cm^2) = 1.0 (.182K)^{2.5} = .01413 W/cm^2$$

$$h_o = \frac{q''}{T_W - T_o} = \frac{.01413 W/cm^2}{0.182K} \left(\frac{100cm}{1m} \right)^2 = 776 \frac{W}{m^2K}$$

THE RESISTANCES ARE NOT BALANCED AS WELL FOR PART II.

RECALCULATE FIN EFFICIENCIES;

$$L_c^{3/2} \left(\frac{h}{KA_F} \right)^{1/2} \Big|_{\text{PART I}} = 1.13 \Rightarrow \eta_{F \text{ PART I}} = 0.52 \text{ SAME AS 1ST PASS SOL'N}$$

$$L_c^{3/2} \left(\frac{h}{KA_F} \right)^{1/2} \Big|_{\text{PART II}} = 1.16 \Rightarrow \eta_{F \text{ PART II}} = 0.52 \left\{ \begin{array}{l} \text{FOR 1ST PASS} \\ \eta_{F \text{ PART II}} = .82 \end{array} \right\}$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/11/93

REVISION DATE

FOR PART I, $A_o = 0.08 \text{ m}^2$

$$U_o = \left(\frac{A_o}{h_i A_i} + \frac{1}{h_o} \right)^{-1} = \left(0.00135 + \frac{1}{736 \frac{\text{W}}{\text{m}^2 \text{K}}} \right)^{-1} = (.00135 + .00136)^{-1}$$

↑ NOTE VERY BALANCED

$$U_o = 369 \frac{\text{W}}{\text{m}^2 \text{K}}$$

$$Q \Big|_{\substack{\text{in} \\ \text{LENGTH}}} = U_o A_o (T_i - T_o) = 369 \frac{\text{W}}{\text{m}^2 \text{K}} (.08 \text{ m}^2) (4.84 - 4.51 \text{ K})$$

$$= 9.746 \text{ W} = 9.7 \text{ W}$$

$$L_{\text{REQ'D PART I}} = 21.3 \text{ W} \times \frac{1 \text{ m}}{9.7 \text{ W}} = \underline{2.2 \text{ m}}$$

FOR PART II, $A_o = .08 \text{ m}^2$ { LESS THAN 1ST PASS SOLUTION SINCE η_F IS LESS }

$$U_o = \left(\frac{A_o}{h_i A_i} + \frac{1}{h_o} \right)^{-1} = \left(\frac{0.08 \text{ m}^2}{(1930 \frac{\text{W}}{\text{m}^2 \text{K}}) (.0342 \text{ m}^2)} + \frac{1}{776 \frac{\text{W}}{\text{m}^2 \text{K}}} \right)^{-1}$$

$$= (.00121 + .00129)^{-1} = 400 \frac{\text{W}}{\text{m}^2 \text{K}}$$

$$Q \Big|_{\substack{\text{in} \\ \text{LENGTH}}} = U_o A_o (T_i - T_o) = (400 \frac{\text{W}}{\text{m}^2 \text{K}}) (.08 \text{ m}^2) (4.74 \text{ K} - 4.51 \text{ K})$$

$$= 7.36 \text{ W} = 7.4 \text{ W}$$

$$L_{\text{REQ'D PART II}} = 24.6 \text{ W} \times \frac{1 \text{ m}}{7.4 \text{ W}} = \underline{3.3 \text{ m}}$$

{ QUITE DIFFERENT THAN 1ST PASS }

CHECK PART II T_W @ MIDPOINT AGAIN

$$T_W = T_i - \frac{Q}{h_i A_i} = 4.74 \text{ K} - \frac{7.4 \text{ W}}{(1930) (.0342 \text{ m}^2)} = 4.63 \text{ K}$$

$$T_W - T_o = 4.63 \text{ K} - 4.51 \text{ K} = .12 \text{ K}$$

$$Q (\frac{\text{W}}{\text{cm}^2}) = 1.0 (.12 \text{ K})^{2.5} = .005 \frac{\text{W}}{\text{cm}^2}$$

$$h_o = \frac{.005 \frac{\text{W}}{\text{cm}^2} (100 \frac{\text{cm}}{1 \text{ m}})^2}{.12 \text{ K}} = 416 \frac{\text{W}}{\text{m}^2 \text{K}}$$

{ 3rd PASS IS REQ'D FOR PART II }

RECALCULATE FIN EFFICIENCY FOR PART II

$$L_c^{3/2} \left(\frac{h}{K A_p} \right)^{1/2} \Big|_{\text{PART II}} = 0.85 \Rightarrow \eta_{F \text{ PART II}} = 0.64$$

FOR PART II $A_o = .0399 \text{ m}^2 + .04948 \text{ m}^2 = .0894 \text{ m}^2$

$$U_o = \left(\frac{A_o}{h_i A_i} + \frac{1}{h_o} \right)^{-1} = \left(\frac{.0894}{1930 (.0342)} + \frac{1}{416} \right)^{-1} = (.00135 + .0024)^{-1}$$

$$U_o = 266 \frac{\text{W}}{\text{m}^2 \text{K}}$$

SUBJECT

CONTROL DEWAR HEAT EXCHANGER

NAME

RUSS RUCINSKI

DATE

2/11/93

REVISION DATE

PART II,

$$Q_{\text{LENGTH}} = U_o A_o (T_i - T_o) = 266 \frac{\text{W}}{\text{m}^2 \text{K}} (.0894 \text{ m}^2) (4.74 \text{ K} - 4.51 \text{ K})$$

$$= 5.47 = 5.5 \text{ W}$$

$$L_{\text{REQ'D PART II}} = 24.6 \text{ W} \times \frac{1 \text{ m}}{5.5 \text{ W}} = 4.5 \text{ m} \quad \{ 3^{\text{rd}} \text{ PASS AT IT} \}$$

CHECK PART II T_w @ MIDPOINT

$$T_w = 4.74 - \frac{5.5 \text{ W}}{(1930)(.0342)} = 4.66 \text{ K} \quad \text{WITHIN } .03 \text{ K OF LAST TIME CLOSE ENOUGH.}$$

$$\text{MIN. REQ'D LENGTH OF FINNED TUBING} = 2.2 \text{ m} + 4.5 \text{ m} = \underline{6.7 \text{ m}}$$

USING STANDARD SAVER DESIGN OF SPIRALLING, I WILL CALCULATE THE MIN REQ'D SIZE.

$$L_{\text{ONE SPIRAL}} \approx \pi D = \pi (6 \text{ in.}) (.0254 \text{ m/in.}) = 0.478 \text{ m/SPIRAL}$$

$$N_{\text{REQ'D SPIRALS}} = 6.7 \text{ m REQ'D} / 0.478 \text{ m/SPIRAL} = 14 \text{ SPIRALS}$$

FIGURE- LN₂

SUBCOOLER USING
SAVER TYPE
DESIGN. CONTROL
DEWAR CONFIGURATION
WILL BE DIFFERENT.