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PRELIMINARY DESIGN OF ANNULAR TUBE HEAT EXCHANGERS FOR CIRCULATING FUEL SYSTEMS

by

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SUMMARY

This paper follows up one of the suggestions in AAEC/E. 2, and shows that the annular tube heat exchanger for circulating fuel systems is practical, compact and has a reasonable out-of-core holdup.

It appears at first sight from AAEC/E. 1 and E. 2 that no real advantage is obtained by using coolant flows in excess of 300 cm/sec. For an annular tube heat exchanger with the primary coolant tubes inside the secondary coolant tubes, it is reasonable to use the same flow velocity for both coolants. On this basis for a primary coolant tube 1.0 cm. inside diameter and a wall thickness of 0.10 cm., the inside diameter of the outer tube = 1.56 cm.

Applying the expression

$$h_{ann} \frac{Deq}{k} = 0.75 \quad \frac{h\ tube\ \ D_{eq.}}{k} \; R_o^{\;0.30}$$

(See p. 5, AAEC/E. 2).

and h_{tube} calculated from $\frac{hD}{k} = 7.0 + 0.025 \left(\frac{Dvc\rho}{k}\right)^{0.8}$

and we have for v = 300 cm/sec.

$$\text{(i)} \quad h_{tube} \times \frac{0.36}{0.683} = 7.0 + 0.025 \left(\frac{0.36 \times 300 \times 1.272 \times 0.841}{0.683}\right)^{0.8}$$

$$= 7.0 + 0.025 \times 61.6$$

$$= 7.0 + 1.54 = 8.54$$

and h_{tube} $= \frac{8.54 \times 0.683}{0.36} = 16.2$ watts/(cm^2)(^{o}C)

$$\text{(ii)} \quad R_o = \frac{Do}{Di} = \frac{1.56}{1.2} = 1.30$$

$$\text{(iii)} \quad h_{ann} = 0.75 \times h_{tube} \times R_o^{\;0.30}$$

$$= 0.75 \times 16.2 \times (1.3)^{0.30}$$

$$= 0.75 \times 16.2 \times 1.08$$

$= 13.12$ watts/(cm^2)(^{o}C)

$= 23,100$ BThU/(hr)(ft^2)(^{o}F)

(iv) for $v = 300$ cm/sec.

Thermal Resistance	Na/SS	Equiv. Temp. Drop	Na/Nb	Equiv. Temp. Drop
primary coolant $1/h$	0.140	11.3° C	0.140	19.7° C
tube wall $\frac{d_i \ln d_o/d_i}{2k}$	0.414	33.5° C	0.152	21.3° C
secondary coolant $\frac{d_i}{h_f \cdot d_o}$	0.064	5.2° C	0.064	9.0° C
	Total =	50° C	Total =	50° C

$\frac{1}{U} = 0.618$ $\qquad$ $\frac{1}{U} = 0.356$

$U = 1.62$ watts/(cm^2)(°C) $\qquad$ $U = 2.80$ watts/(cm^2)(°C)

(v)

	Na/SS		Na/Nb	
	Annular	Tube/Shell	Annular	Tube/Shell
$S = \frac{2}{U}$ m^2/MW	1.24	2.09	0.71	1.56
$v = \frac{5}{U} d_i$ litres/MW	3.09	5.22	1.78	3.91
n per MW (as before)	10	10	10	10
$L = \frac{642}{U}$ cm	396	670	228	502
$R = \frac{12}{V}$ MW/kg	3.88	2.30	6.75	3.07
$RH = 2.5V$	7.7	13.0	4.5	9.8

(vi) Summarising then we see that the number of tubes and length of each tube required will be :-

(a) for 500 MW Heatload	5000 x 3.96 m lg.	5000 x 6.70 m lg.	5000 x 2.28 m lg.	5000 x 5.02 m lg.

(b) for 25 MW Heatload	250 x 3.96 m lg.	250 x 6.70 m lg.	250 x 2.28 m lg.	250 x 5.02 m lg.
(c) for 10 MW Heatload	100 x 3.96 m lg.	100 x 6.70 m lg.	100 x 2.28 m lg.	100 x 5.02 m lg.

The calculations are now repeated for a velocity of 800 cm/sec which is probably the highest desirable velocity to use.

(vii) <u>for v = 800 cm/sec.</u>

(a) we have $h_{tube}\frac{D_i}{k} = 7.0 + 0.025 \left(\frac{0.36 \times 800 \times 1.272 \times 0.841}{0.683}\right)^{0.8}$

$= 7.0 + 0.025 \times 135$

$= 7.0 + 3.38 = 10.38$

so $h_{tube} = \frac{10.38 \times 0.683}{0.36} = 19.72$ watts/(cm^2)($^\circ$C)

and $h_{ann} = 0.75 \times 19.72 \times (1.3)^{0.30}$

$= 0.75 \times 19.72 \times 1.08$

$= 15.97$ watts/(cm^2)($^\circ$C)

$= 28,100$ BThU/(hr)(ft^2)($^\circ$F)

(b)	Na/SS	Equiv. Temp. Drop	Na/Nb	Equiv. Temp. Drop
<u>Thermal resistance</u>				
primary coolant 1/h tube	0.101	8.0° C	0.101	13.7° C
wall $\frac{d_i \ln d_o/d_i}{2k}$	0.414	32.9° C	0.152	20.7° C

Secondary Coolant	0.052	9.1° C	0.052	15.6° C
$\frac{di}{h_f \cdot d_o}$		50.0° C		50.0° C

$\frac{1}{U}$ = 0.567 $\qquad$ $\frac{1}{U}$ = 0.305

U = 1.77 watts/$(cm^2)(^{\circ}C)$ $\qquad$ U = 3.28 watts/$(cm^2)(^{\circ}C)$

	Na/SS		Na/Nb	
	Annular	Tube/Shell	Annular	Tube/Shell
$S = \frac{2}{U}$ m^2/MW	1.13	2.01	0.61	1.49
$V = \frac{5}{U}$ di litres/MW	2.84	5.03	1.53	3.72
n per MW (as before)	3.7	3.7	3.7	3.7
$L = \frac{1712}{U}$ cm	973	1722	522	1271
$R = \frac{12}{V}$ MW/kg	4.22	2.38	7.84	3.23
RH = 2.5V	7.1	12.6	3.8	9.3

(c) Summarising as before, the number of tubes and length of each tube required will be

	Na/SS		Na/Nb	
	Annular	Tube/Shell	Annular	Tube/Shell
(a) for 500 MW Heatload	1850 x 9.73 m lg.	1850 x 17.2 m lg.	1850 x 5.22 m lg.	1850 x 12.7 m lg.
(b) for 25 MW Heatload	93 x 9.73 m lg.	93 x 17.2 m lg.	93 x 5.22 m lg.	93 x 12.7 m lg.
(c) for 10 MW Heatload	37 x 9.73 m lg.	37 x 17.2 m lg.	37 x 5.22 m lg.	37 x 12.7 m lg.

(viii) <u>Repeating the calculations for 2 cm i.d. and 0.10 cm wall thickness,</u> we have :-

As before, $D_o^2 = D_i^2 + D_i^2$

$$= 2^2 + 2.2^2$$

$$= 8.84$$

and $D_o = \sqrt{8.84} = 2.97$

and Ro $= \dfrac{Do}{Di} = \dfrac{2.97}{2.2} = 1.35$

(ix) <u>for v = 300 cm/sec</u>

(a) Again $h_{tube} \dfrac{Deq}{K} = 7.0 + 0.025 \left(\dfrac{0.57 \times 300 \times 1.272 \times 0.841}{0.683}\right)^{0.8}$

$$= 7.0 + 0.025 \times 87.5$$

$$= 7.0 + 2.19 = 9.19$$

so $h_{tube} = \dfrac{9.19 \times 0.683}{0.57} = 11.02$ watts/(cm^2)($^\circ$C)

and $h_{ann} = 0.75 \times 0.57 \times (1.35)^{0.30}$

$$= 0.75 \times 11.02 \times 1.093$$

$= 9.03$ watts/(cm^2)($^\circ$C)

$= 15,900$ BThU/(hr)(ft^2)($^\circ$F)

(b)

<u>Thermal Resistance</u>	Na/SS	Equiv. Temp. Drop.	Na/Nb	Equiv. Temp. Drop.
primary coolant 1/h	0.226	12.2°C	0.226	17.4° C
tube wall $d_i \dfrac{\ln d_o/d_i}{2k}$	0.432	23.4° C	0.158	12.2° C
secondary coolant $\dfrac{d_i}{h_f\ d_o}$	0.101	14.4° C	0.101	20.4° C

$$\underline{\underline{50.0^{\circ}\,C}} \qquad\qquad \underline{\underline{50.0^{\circ}\,C}}$$

$\frac{1}{U} = 0.759$ $\qquad$ $\frac{1}{U} = 0.485$

$U = 1.32$ watts/(cm^2)($^{\circ}$C) $\qquad$ $U = 2.06$ watts/(cm^2)($^{\circ}$C)

	Na/SS		Na/Nb	
	Annular	Tube/Shell	Annular	Tube/Shell
$S = \frac{2}{U}$ m^2/MW	1.52	2.39	4.12	1.84
$V = \frac{5\,d_i}{U}$ litres/MW.	7.6	5.97	4.85	4.60
n per MW	2.5	2.5	2.5	2.5
$L = \frac{1284}{U}$ cm	975	1540	623	1180
$R = \frac{12}{V}$ MW/kg	1.58	2.01	2.47	2.61
RH = 2.5V	19.0	14.9	12.1	11.5

(c) Summarising as before, the number of tubes and length of each tube required will be :-

(a) for 500 MW Heatload	1250 x 9.75 m lg.	1250 x 15.4 m lg.	1250 x 6.23 m lg.	1250 x 11.8 m lg.
(b) for 25 MW Heatload	63 x 9·75 m lg.	63 x 15.4 m lg.	63 x 6.23 m lg.	63 x 11.8 m lg.
(c) for 10 MW Heatload	25 x 9.75 m lg.	25 x 15.4 m lg.	25 x 6.23 m lg.	25 x 11.8 m lg.

(x) $\underline{\text{For } \nu = 800 \text{ cm/sec.}}$

(a)
$$\frac{h_{tube}\,D_i}{k} = 7.0 + 0.025 \left(\frac{0.57 \times 800 \times 1.272 \times 0.841}{0.683}\right)^{0.8}$$

$$= 7.0 + 0.025 \times 192$$

$$= 7.0 + 4.80 = 11.80$$

$$\text{so } h_{tube} = \frac{11.80 \times 0.683}{0.57} = 14.14 \text{ watts}/(\text{cm}^2)(^\circ\text{C})$$

$$\begin{aligned}\text{and } h_{ann} &= 0.75 \times 14.14 \times (1.35)^{0.30} \\ &= 0.75 \times 14.14 \times 1.093 \\ &= 11.60 \text{ watts}/(\text{cm}^2)(^\circ\text{C}) \\ &= 20{,}400 \text{ BThU}/(\text{hr})(\text{ft}^2)(^\circ\text{F})\end{aligned}$$

(b)	Na/SS	Equiv Temp. Drop	Na/Nb	Equiv. Temp. Drop
Thermal Resistance				
primary coolant 1/h	0.145	9.7° C	0.145	15.4° C
tube wall $d_i \frac{\ln do/di}{2k}$	0.432	29.0° C	0.158	16.7° C
secondary coolant $\frac{di}{hf.\ do}$	0.078	11.3° C	0.078	17.9° C
		50.0° C		50.0° C

$\frac{1}{U} = 0.657$ $\qquad$ $\frac{1}{U} = 0.381$

$U = 1.52 \text{ watts}/(\text{cm}^2)(^\circ\text{C})$ $\qquad$ $U = 2.62 \text{ watts}/(\text{cm}^2)(^\circ\text{C})$

	Na/SS		Na/Nb	
	Annular	Tube/Shell	Annular	Tube/Shell
$S = \frac{2}{U}$ m^2/ MW	1.31	2.22	0.76	1.68
$V = \frac{5}{U} d_i$ litres MW	6.57	5.56	3.81	4.19
n per MW (as before)	0.93	0.93	0.93	0.93
$L = \frac{3420}{U}$ cm	2250	3810	1302	2870
$R = \frac{12}{V}$ MW/kg	1.83	2.16	3.15	2.86
RH = 2.5V	16.4	13.9	9.5	10.5

(a) for 500 MW Heatload	465 x 22.5 m lg.	465 x 38.1 m lg.	465 x 13.02 m lg.	465 x 28.7 m lg.
(b) for 25 MW Heatload	24 x 22.5 m lg.	24 x 38.1 m lg.	24 x 13.02 m lg.	24 x 28.7 m lg.
(c) for 10 MW Heatload	10 x 22.5 m lg.	10 x 38.1 m lg.	10 x 13.02 m lg.	10 x 28.7 m lg.

(xi) Summarising we have :-

	di = 1.0 cm				di = 2.0 cm			
ν cm/sec	Na/SS 300	800	Na/Nb 300	800	Na/SS 300	800	Na/Nb 300	800
V litres/MW	3.09	2.84	1.78	1.53	7.6	6.57	4.85	3.81
R MW/kg	3.88	4.22	6.75	7.84	1.58	1.83	2.47	3.15
RH	7.7	7.1	4.5	3.8	19.0	16.4	12.1	9.5

This shows that there is a considerable increase in relative holdup using the larger bore tubes and again that there is not much advantage gained by using a velocity in excess of 300 cm/sec.