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A Division of North American Aviation Inc.

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REPORT TITLE

Operating Requirements for SCTI 35 MW Sodium Heater in
the Event of Sodium Leak

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ATOMICS INTERNATIONAL A Division of North American Aviation, Inc.		NAA-SR- TDR NO 10250		APPROVALS 	
TECHNICAL DATA RECORD		PAGE 1 OF 12			
AUTHOR R. Cygan		DEPT & GROUP NO 712 220		DATE 7-23-64	
				GO NO 7593	
TITLE Operating Requirements for SCTI 35 MW Sodium Heater in the Event of Sodium Leak		S A NO 13222		TWR	
		SECURITY CLASSIFICATION			
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PROGRAM Sodium Component Development		SUBACCOUNT TITLE Operation and Maintenance of the SCTI			
DISTRIBUTION					
Cochran, J.C. FB					
Casey, D. F. FB					
Cygan, R. SS6		STATEMENT OF PROBLEM A significant amount of heat energy is stored in the refractory lining of the 35 MW SCTI sodium heater. This energy must be dissipated before the unit can be secured. The possible consequences of various operating conditions during an emergency shutdown are evaluated herein.			
Eggen, D.T. FB					
Griffin, C.W. FB					
Hallett, W.J. SS6					
Johnson, L.L. SS6					
McSweeney, W.T. SS6					
Rumpf, N.K. FB		ABSTRACT The heat energy stored in the refractory lining of the 35 MW sodium heater is about 29×10^6 Btu. Most of this heat ($\sim 26 \times 10^6$ Btu) is stored in the brickwork surrounding the radiant section of the heater. Because the radiant section contains only a small portion of the total tubing in the heater and concomitantly a low sodium inventory, the radiant section requires supplementary cooling to remove the heat from the firebrick until the latter is brought to a temperature about 1600°F. Based on the analysis covered herein, draining the heater tubes before the brickwork has cooled down is not feasible because the empty metal tubes do not have adequate heat capacity to absorb the residual heat before reaching excessive metal temperatures. The forced draft fan should be operated until such time as the tube temperatures in the radiant section have passed their peak and have started decreasing. Because the heat release rate is limited by the conductivity of the firebrick, this may take about one hour. Although rapid heat removal can be achieved by maintaining sodium circulation, it is not advisable since the leak rate is more than doubled when sodium circulation is maintained and the air flow supplied by the fan is capable of removing the heat released by the refractory. Complete furnace cooling (to 1600°F) will take 4 or 5 hours.			
Withers, T.W. SS6					

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Sodium leakage rates for various sizes of postulated hole sizes have been calculated. The range of leakage rates found was from 340 to 0.3 gpm, which cover holes from 1.06 to 0.0625 inch diameter. The time to drain the heater with gravity drainage has been calculated as 21 minutes.

INTRODUCTION

In order to limit the sodium fire that would result from a leak in the sodium heater, it has been proposed that the burners would be turned off and the fan stopped to limit the oxygen supply to the burning sodium. The block valves would be operated to isolate the heater from the system and draining of the sodium from the unit started immediately.

The various components that would be affected by such action have been superficially examined and evaluated in this study. No attempt has been made to study the transient heat transfer aspects rigorously in this evaluation, since the overall gross effects adequately scope the anticipated problems.

HEAT STORAGE

In order to determine the heat energy stored in the firebrick lining, the inside of the sodium heater is divided into the two functional areas, the radiant section and the convection section. The primary concern for this study is in the radiant section which contains the largest volume of firebrick exposed to the highest temperature. Two types of refractory material are utilized in the radiant section. The front (or burner) wall is made from 13½" thick B-W Kaocast Cement. The other portions of the combustion chamber are lined with 9" of B-W FB brick backed up with 4½" of B-W K-20 brick.

Based on the expected gas flame temperature and the application data for the firebrick used, the estimated hot face temperature for the exposed brick in the radiant section is 2800°F. The hot face temperature of the refractory behind the tubewall at the top and back of the furnace has been calculated using the following equation:

$$T_R = \left[\frac{(A_1 - A_1 F_{12}) T_1^4 + (A_2 - A_1 F_{12}) T_2^4}{(A_1 - A_1 F_{12}) + (A_2 - A_1 F_{12})} \right]^{1/4}$$

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where T_R = refractory wall temperature
 A_1 = wall area = 224 ft²
 A_2 = tube area = 153 ft²
 T_1 = gas temperature 3000°F
 T_2 = tube wall temperature 1300°F
 F_{12} = radiation shape factor

F_{12} was obtained from a graph¹ relating shape factor to ratio tube centerlines/diameter for a plane with parallel tubes. The F_{12} value applicable to the configuration occurring in the sodium heater is 0.97. Evaluating the expression gives a resulting refractory temperature of 2595°F. For the subsequent calculations this has been rounded off to 2600°F.

The heat storage for various hot face temperatures with 80°F ambient on the opposite face has been compiled by B-W for the various brick combinations used in furnaces⁴. This permits calculating the expected heat given up for a given change in hot face temperature from these tables. The furnace contains 420 ft² of shielded refractory, 393 ft² of bare FB - K-20 combination and 117 ft² of 13½" Kaocast.

Heat given up when hot face is cooled to 1600°F

393 ft² of bare combination at 2800°F = 12.1X10⁶ Btu
420 ft² of shielded combination at 2600°F = 10.8X10⁶ Btu
117 ft² of bare Kaocast @ 2800°F = 3.2X10⁶ Btu

Total heat in radiant section firebrick = 26.1X10⁶ Btu

Heat stored in firebrick of convection section to reduce to 1600°F

112 ft² of FB - K-20 combination @ 2400°F = 2.3X10⁶ Btu
196 ft² of K-20 @ 2000°F = 0.12X10⁶
280 ft² of K-23 @ 2200°F = 0.28X10⁶

Total heat stored in convection section refractory = 2.7X10⁶ Btu

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HEAT ABSORBERS

Condition A - Fan off, burners out, sodium immediately drained from coils: The smallest heat sink for the energy stored in the firebrick exists when empty tubing of the radiant section is the only cold surface available. The length of tubing that "sees" the radiant section is 21 feet. Tubing is 304SS of 1 1/4" O.D. and 0.095" wall thickness. This tubing has a weight of 1.183 #/ft.

$$\text{Total weight of tubing} = 21 \times 183 \times 1.183 = 4550\#$$

$$\text{Specific heat of 304 SS} = 0.12 \text{ Btu/\# } ^\circ\text{F}$$

To raise the tubing from an operating temperature of 1200°F to the melting point of 304 (2600°F) requires

$$4550 (.12)(2600-1200) = 0.764 \times 10^6 \text{ Btu}$$

It is apparent that empty stainless tubes will be seriously damaged if exposed to firebrick with an initial hot face temperature of 2800°F.

Condition B - Fan off, burners out, sodium left in coils no flow, lower block valve closed, upper block valve open: The heat sink can be improved by maintaining the furnace tubing full of sodium. Only the sodium in the radiant section and higher will be effective. With the sodium in the convection coils cooler, there will be no drive to establish any circulation between the radiant and convection coils of the heater. Both sensible heating of sodium and evaporation at the sodium boiling point (1621°F) are utilized. The volume of sodium in piping and coils up to the heater outlet block valve available for cooling is 65.1 ft³ comprised as follows:

Tubing in radiant section	24.6
Upper heater headers	14.1
Header connecting loops	22.6
Piping to block valve	<u>3.8</u>
	65.1

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Piping from block valve to IHX inlet contains 53.4 ft^3 of sodium. Because piping slopes upward toward IHX from heater outlet, natural circulation should occur through the entire pipe with the outlet block valve open.

Heating sodium from 1200°F to 1621

$$49.7 \times 118.5 (1621-1200) 0.3 = 737,000 \text{ Btu}$$

Heating contact metal from bottom of radiant section to IHX inlet
12,000# stainless steel

$$12,000 (1621-1200) .12 = 606,000 \text{ Btu}$$

Total heat to bring metal and contained sodium
to $1621^\circ\text{F} = 1.34 \times 10^6 \text{ Btu}$

Vaporization sodium at 1621°F

$$1613.6(49.7)118.5 = 9.52 \times 10^6 \text{ Btu}$$

Total probable heat absorbed by pipe plus sodium
vaporization

$$10.8 \times 10^6 \text{ Btu}$$

Condition C - Burners off, sodium in coils, lower block valve closed, upper block valve open, fan operating normal speed

Normal air flow through heater 50,000 cfm
@ 80°F 28" Hg abs.

For 100°F ambient, density = $0.0700 \text{ \#/ft}^3$

Dynamic viscosity μ = $.0472 \text{ \#/hr-ft}^2$

Conductivity K = $.0156 \text{ Btu/ft-hr}^\circ\text{F}$

Specific heat C = $0.238 \text{ Btu/\#}^\circ\text{F}$

Heater air flow area is 28 feet wide and 7
feet high = 196 ft^2

$$\text{Equivalent diameter } D_e = 4 \times \frac{A}{W_p} = 4 \times \frac{196}{70} = 11.2$$

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$$\text{Flow velocity } V = \frac{50,000}{196} \times 60 = 15,300 \text{ ft/hr}$$

$$Re = \frac{\rho DV}{\mu} = \frac{.07 \times 11.2 \times 15,300}{.0472} = 254,000$$

$$Pr = \frac{c\mu}{K} = \frac{.238(.0472)}{.0156} = 0.720$$

Because the duct varies in cross section along the entire length of the radiant region, the heat transfer may be evaluated on the basis of turbulent flow along flat plate².

$$\begin{aligned} Nu &= 0.037 (Pr)^{1/3} R_e^{0.8} - 4200 \\ &= 0.037 (.72)^{1/3} (2.54 \times 10^5)^{0.8} - 4200 \\ &= 0.037 (.893) (21080 - 4200) \\ &= 558 \\ &= \frac{hD_e}{K} \\ h &= \frac{558(.0156)}{11.2} = 0.78 \end{aligned}$$

Evaluating the heat transfer coefficient for a rectangular duct using the equation

$$Nu = C (Re)^{.8} (Pr)^{1/3}$$

gives a low value of h because of the large equivalent diameter. The values are lower than for the plate analogy used previously. These values appear too low because higher h values can be obtained by assuming free convection phenomena to be predominant. Simplified equations for free convection are used. All these are of the form $h = C (\Delta t)^{.25}$ where various C values correct for the surface orientation. Evaluating these we obtain:

<u>Plate Orientation</u>	<u>for 2700° t</u>	<u>for 1500° t</u>	<u>Average</u>
Vertical	1.95	1.68	1.81
Horizontal face down	1.44	1.24	1.34
Horizontal face up	2.74	2.36	2.55

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Refractory areas in furnace radiant section are as follows:

Vertical	510 ft ²
Horizontal down	308 ft ²
Horizontal up	112 ft ²

Assuming that the brickwork cools to a hot face temperature of 2400°F during first hour, the average Δt between incoming 100°F air and refractory (average initial temperature 2700°F) is 2500°F.

Convection heat transfer during first hour

$$\begin{aligned}h_v &= 510 (1.81) 2500 = 2.31 \times 10^6 \\h_{hd} &= 308 (1.34) 2500 = 1.03 \times 10^6 \\h_{hu} &= 112 (2.55) 2500 = .71 \times 10^6\end{aligned}$$

Total heat absorbed by convection from
walls to air = 4.05×10^6 Btu during
first hour

Additional heat will be removed from the tubes that take up heat by radiation from brickwork. Probable tube temperature at end of one hour will be $\sim 1600^\circ\text{F}$ based on calculations in TDR 6260.

Heat transfer to air from heated tubes will take place by two methods. A portion will occur by air flow parallel to the tube axis. This condition exists at the top and rear wall.

$$\text{Re for parallel air flow} = \frac{\rho DV}{\mu} = \frac{.07 \frac{1.25}{12} 15,300}{.0472} = 2360$$

This relatively low Reynolds number suggests use of the equation for flow in the transition region between laminar and turbulent. For flow parallel to tubes, the following equation may be used

$$Nu = 0.028 (N_{Re})^{0.9^3}$$

Evaluating gives an $h = 4.5$ Btu/hr ft²·°F. The k value is based on the incoming air heated 85°F by convection from the refractory walls.

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The tube length in parallel flow is 13 feet. Tube area is $13 \times 183 \times .3272 = 777 \text{ ft}^2$. A conservative evaluation of the heat transfer from tubes to air results when tube temperature is assumed to be 1200°F .

$$Q = h A \Delta t = 4.5 (777) (1015) = 3.5 \times 10^6 \text{ Btu/hr}$$

Air temperature rise due to this heat absorption is $\sim 70^\circ\text{F}$.

Before leaving the radiant section the air passes over the first layer of tubes in the convection section. The latter "sees" radiation from the refractory surrounding the radiant section of the heater. Heat transfer from these tubes to the air may be evaluated utilizing equation for flow across tubes.

$$N = 0.26 (\text{Re})^{.6} (\text{Pr})^{.3}$$

$$\text{Re} = 4640 \quad \text{Pr} = 0.622$$

$$N = 35.9 \quad h = 9.85$$

$$\text{Area of cross flow tubes} = 420 \text{ ft}^2$$

$$\begin{aligned} \text{Temperature of air entering cross flow} \\ \text{tubes} &= 255^\circ\text{F} \end{aligned}$$

$$Q = 9.85 (420) 1100 - 255 = 3.54 \times 10^6 \text{ Btu/hr}$$

Total heat transferred to 100°F air based on 1200°F tube temperature = 11×10^6 Btu/hr. When the tube temperature reaches 1600°F the heat transfer to air from tubes would increase about 3.0×10^6 Btu. If the convection from the refractory is reduced to one-half the original value the new heat removal rate is 12×10^6 Btu/hr.

The relatively poor conductivity of the firebrick will limit the heat flow to the tubes and the circulating air. It can be shown that for the expected temperatures of the refractory, the heat transfer by radiation from the hot face of the brick will not be limiting, because for all the expected combinations of temperatures of the tubes (1200 to 1600°F) and the firebrick (2800 to 1600°F) the h_r will be in the range of 50 to 80 Btu/hr ft^2 $^\circ\text{F}$. The problem does not lend itself to a simple solution because the surface coefficient is variable at the hot face there is a temperature gradient through the refractory wall and additionally the

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wall is composite, i.e., high density, higher conductivity material for the first 9" and lower density, lower conductivity material for the outer 4½". Because of the limited time available for getting results in this problem, the following approximation will be used. The approach will give a conservative answer i.e., will indicate a heat flow to the inside of the furnace, higher than it is anticipated to be in the actual case.

The brick wall contributing heat energy will be assumed to be 10" thick composed entirely of the high density refractory. The hot face will be assumed to be all at 2700°F (this is a reasonable average because it has been previously shown that part of the bricks are at 2800°F and part at 2600°F). The temperature at the outer face will be assumed to be 1700°F. This yields a gradient of 100°F/inch of refractory. In addition, all the heat energy stored in the composite wall will be assumed to be present in this new hypothetical wall.

By dividing the wall into 10 one inch thick slabs, the average heat path plus the average temperature difference for each slab as a unit will give an approximation of the expected heat loss rate for the wall. The calculation is taken only to the 1600°F point since no catastrophic tube damage will result if the maximum temperature reached by the tubes is kept to this top value. Results of this calculation are shown on Page 10.

The heat flow from each unit slab toward the hot face cannot occur simultaneously because of the reverse initial temperature gradient. As each slab toward the inside of the furnace is cooled down, the temperature gradient for flow in that direction will be established. Some heat will be lost toward the outside face which gives these calculations their conservative evaluation. The heat flow outward will be relatively small because of the low thermal conductivity of the outer layer of brick ($\sim 1/10$ that for inner refractory). Approximately 9.0×10^6 Btu of heat will be given up by the refractory during the first hour. From the previous calculations, this amount of heat can be removed by the normal furnace air flow.

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Slab No.	Avg. Temp. °F	Avg. Distance From Hot Face Inches	K	Avg. Δt in Cooling to 1600°F	Total Heat Transfer Btu X 10 ⁶	Heat Energy in Slab Btu	Time to Transfer Minutes
I	2650	½	28	525	13.7	4.75	21
II	2550	1½	9.67	475	4.27	4.25	60
III	2450	2½	5.6	425	2.21	3.79	103
IV	2350	3½	4.0	375	1.40	3.32	142
V	2250	4½	3.11	325	.94	2.84	181
VI	2150	5½	2.54	275	.65	2.38	220
VII	2050	6½	2.15	225	.45	1.91	254
VIII	1950	7½	1.87	175	.30	1.41	282
IX	1850	8½	1.65	125	.19	.94	297
X	1750	9½	1.47	75	.104	.47	271

LEAKAGE OF SODIUM INTO FURNACE

The expected rate of sodium leakage in the furnace for various postulated hole sizes for both pump on and pump off conditions has been calculated. The results are based on using a flow coefficient of 0.98 for the full pipe break and 0.61 for the small holes. At rated flow, the pump head available at the heater inlet is 89.1 psi. Static head available for causing leakage after pump shutoff is 32 feet.

<u>Hole Size</u>	<u>Leakage GPM</u>	
	<u>Pump on</u>	<u>Pump off</u>
One entire tube	341	120
1/2"	48	17
3/4"	11.8	4.3
1/8"	2.98	1.1
1/16"	0.74	0.27

The primary expansion tank is 60" in diameter. One inch change in level is equal to 12 1/4 gallons fluid. The minimum level change that can be detected using the instrumentation associated with the expansion tank is 0.6 inches which is equal to 7.4 gallons.

CONCLUSIONS

Draining the sodium heater of sodium in the event of a leak is not recommended if damage to the sodium heating coils is to be prevented. The rate of heat release by the refractory is limited by the thermal conductivity of the refractory brick. By leaving stagnant sodium in the coils, the maximum metal temperature will be limited to the boiling point of sodium ~ 1621°F. Operating the forced draft fan to supply 50,000 cfm of air (normal air requirement at full firing rate) will remove heat fast enough to prevent any significant amount of sodium vaporization in the tubes. Although sodium circulation through the heater increases heat removal capability, it is not worthwhile since the heat release is limited to a lower rate by the low conductivity of the firebrick. The best

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monitor for determining when the fan can be turned off is the tube wall temperature in the radiant section of the heater. The crude calculations made so far indicate that it will take 4 to 5 hours before all the fire-brick has no internal temperature above 1600°F.

The sodium from the heater can be dumped after the tube temperature is observed to start downward after reaching the expected maximum of ~ 1600°F. This should happen in less than one hour after cutting the fires.

The magnitude of the leak can best be determined by observing the change in sodium level in the primary expansion tank. In the event of a large leak, there will probably be so much sodium fire damage, that protecting the tubes from overheating will be insignificant by comparison. In such a case, merely isolating the heater, using the block valves, will be the only action required because a large leak will empty the total heater volume faster than it can be drained out from the unit.

REFERENCES

1. McAdams, W. H., "Heat Transmission".
2. Eckert, E.R.G., and R. M. Drake, "Heat and Mass Transfer".
3. Jakob, M., "Heat Transfer".
4. Marks, L. S., Mechanical Engineer's Handbook, 5th Edition