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Design of Heat Tracing Capacity for a Sodium Experimental Installation

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1. Introduction

A sodium experimental installation requires a pipe heat tracing system such as a N_2 gas heating system and/or an electrical trace heating system. STELLA-1 (Sodium Integral Effect Test Loop for Safety Simulation and Assessment) [1] adopts an electrical trace heating system since it is easy to operation for the frequent use for sodium filling and draining.

In this paper, the pipe heating system capacity including pipe preheating, heat adsorption of the insulation material and heat loss into the environment was estimated after the determination of the pipe thermal insulation thickness.

2. Method and Results

2.1 Insulation Thickness and Natural Convection Heat Loss

Determination factors for insulation thickness are insulation material properties, the operation temperature of the pipe, the insulation surface temperature maintaining below 60℃, and environmental temperatures from -20℃ to 35℃.

A determination of the insulation thickness [2] was discussed using a steady state heat balance equation, the requirements of the experimental conditions and convection heat loss from the insulation surfaces. Figure 1 shows the calculation procedure of the insulation thickness and convection heat loss.

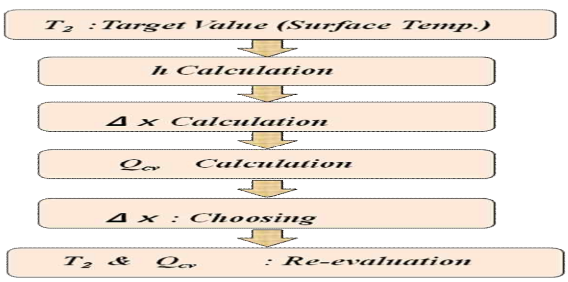

Figure 1. Calculation procedure of Δx and Q_{cd}

Table 1. Insulation thickness of pipe for operating conditions

Pipe type	Diameter ID/OD(mm)	Operation T_1(℃)	Calculated Δx (mm)	Selected Δx (mm)
10SCH40	254.5/273.0	340	107.04	125
4SCH40	102.3/114.3	500	127.67	130
4SCH40	102.3/114.3	300	77.32	90
2SCH40	52.5/60.3	500	108.51	115
2SCH40	52.5/60.3	300	60.61	80

At the same pipe temperature and insulation thickness, the temperature of the insulation surface of the vertical pipe is lower than that of horizontal pipe because of a larger heat transfer coefficient. The insulation surface temperature depends on the ambient air temperature. The higher ambient temperature condition has a higher insulation surface temperature. Thus, the insulation surface limiting condition of the surface temperature of 60℃ requires a greater insulation thickness at the ambient temperature of 35℃. The selected insulation thickness is shown in Table 1.

Heat loss from the insulation surface by convection can be estimated from the heat balance equations using the physical properties of materials shown in Table 2.

Table 2. Physical properties of pipe and insulation materials

Material	Density(ρ) (g/㎤)	Specific heat(C_p) (J/kg·℃)	Thermal conductivity(k) (W/m·K)
Pipe(SS304)	7.98	494	15.91
Insulation*	0.21	700	0.05

*Thermal Ceramics

Heat loss from the insulation surface in Table 3 was estimated with the operation conditions of Table 1, and a heating condition temperature of 250℃. Pipe heat tracing capacity should compensate the maximum heat loss occurring at operational conditions of ambient temperature of -20℃.

Table 3. Pipe heat loss Q_{cv} by natural convection

Pipe type (Δx mm)	Operation Condition (Watt)		Heating Condition (Watt)	
	35℃	-20℃	35℃	-20℃
10S(125)	137.21	162.88	96.77	121.69
4S(130)	116.67	131.17	53.98	68.15
4S(90)	81.01	98.60	65.75	83.22
2S(115)	88.29	99.23	40.85	51.55
2S(80)	59.39	72.23	48.19	60.96

2.2 Radiation Heat Loss from Insulation Surface

Heat loss from the insulation surface by radiation was determined from the simplified model giving the conservative values. The emissive power, e, of a nonblack surface at a Kelvin temperature T_k, is given by

$$e = \varepsilon e_b = \varepsilon \sigma T_k^4 \quad (1)$$

where e_b is the emissive power of a blackbody at the same temperature T_k.

Radiant heat loss from surface 1 enclosed by surface 2 can be estimated by a simple relationship,

$$\frac{Q_1}{A_1} = \frac{e_{b1} - e_{b2}}{(1/\varepsilon_1) + (A_1/A_2)[(1/\varepsilon_2) - 1]} \quad \text{.................... (2)}$$

If A_2 is much larger than A_1, the ratio *(A1/A2)* approaches zero, and the rate of heat transfer from surface 1 is

$$q_1 = A_1 \varepsilon_1 (e_{b1} - e_{b2}) \quad \text{.......................(3)}$$

Eq.(3) holds if surface 2 is black, and/or if the area of surface 2 is much greater than the area of surface 1. The total emissivity of aluminum of a commercial sheet surrounding the insulation surface is 0.09 at 100℃, and that of heavily oxidized aluminum is 0.20-0.33 at 100-550℃ in reference 3.

Table 4. Radiation heat loss from the insulation surface with ε=0.09

Pipe type (△X mm)	Operation Condition(Watts)		Heating Condition(Watts)	
	35℃	-20℃	35℃	-20℃
10S(125)	22.83	14.25	15.52	11.00
4S(130)	19.31	11.11	8.28	5.30
4S(90)	12.89	8.11	10.21	6.67
2S(115)	14.21	8.18	6.11	3.92
2S(80)	9.13	5.76	7.25	4.74

2.3 Pipe heat-up capability

A heat tracing heater has a capability to heat-up the pipe capability to 250℃ for sodium experimental installation before sodium filling at the operation requirement rate of 25 ℃/hr. The heat-up power for pipe and insulation materials is given by

$$Q_h(W) = M(kg) \cdot C_p(J/kg\cdot^{\circ}C) \cdot \Delta T(^{\circ}C/\text{sec}) \quad \text{.............(4)}$$

Physical properties of the pipe and insulation materials in Table 2 were used with the selected insulation thickness.

Table 5. Total pipe heat tracing capacity (Watts)

Pipe type (△x mm)	Heat-up		Heat Loss	Total (Heat-up& Heat loss)
	Pipe	Insulat.	Total	
10S (125)	209.8	159.6	132.7	502.1
4S(130)	55. 8	101.9	73.5	231.2
4S(90)	55.9	59.0	89.9	204.8
2S(115)	18.9	64.7	55.5	139.1
2S(80)	18.9	36.0	65.7	120.6

2.4 Results and Discussions

The required total pipe heat tracing capacities are shown in Table 5. In the STELLA-1 installation, heater capacity requiring pipe and insulation material heat-up are larger than the heat loss at various operating conditions.

The portion of radiation heat loss to convection heat loss reaches 15-17% at an ambient temperature of 35℃, and 7-9% at an ambient temperature of -20℃, respectively under both operating and heating conditions.

The power consumption portion of a smaller pipe stands in order of heat losses, adsorption heat of the insulation materials, and pipe heat-up, while the dominant power consumption portion of a larger pipe is the heat-up power. The heat tracing capacity of the heat-up condition can accommodate the total maximum heat loss during operating conditions in a larger diameter pipe.

3. Conclusion

The designing of the heat tracing capacity of a sodium experimental installation such as STELLA-1 should consider the adsorption heat of the insulation materials as well as pipe heat-up itself. During the determination of the insulation thickness, a higher ambient temperature of 35℃ is recommended for a conservative calculation of the insulation thicknesses, while the lower ambient temperature of -20℃ for a conservative calculation of heat losses. The radiation heat loss for the design of the heat tracing capacity cannot be neglected. The design margin of the heat tracing capacity may be required for other reasons such as the electrical control ability and calculation uncertainties coming from the material properties and correlation of the heat transfer coefficient.

Nomenclature

A Surface area
D diameter of pipe
C_p Specific heat
T_1 pipe surface temperature
T_2 surface temperature of insulating material
T_k temperature in Kelvin degree
Q_{cv} heat transferred by convection
Q_{loss} heat loss from the insulating material surface
k_{ins} thermal conductivity of insulation material
h heat transfer coefficient outside the insulator
Δx insulation thickness
e_b emissive power of a blackbody at the same
ε emissivity of the surface (ranges from zero to unity)
σ Stefan-Boltzmann constant

Acknowledgements

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