Development of the SCS Performance Analysis and Capacity Evaluation Code

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1. Introduction

The Shutdown Cooling System (SCS) removes core decay heat during the planned plant shutdown or after the accident. A computer code such as DESCENT used by Combustion Engineering or RHRCOOL used by Westinghouse, is utilized to analyze the capacity and performance of the SCS for the system design of new plant and the replacement/repair of SCS heat exchanger of the operating reactors. These codes include approximated correlations for heat exchangers for the tube side flow ratio, total heat transfer coefficient, and the balance of the resistance constant calculated by the heat exchanger design codes, such as HTRI or HTFS. HTRI or HTFS does not have the capability to simulate the transient conditions of SCS. In this study, the SCS performance analysis and capacity evaluation (SPACE) code is developed to evaluate the total heat transfer coefficient for the heat exchanger as well as to analyze the SCS cooldown performance.

2. Analytical Model

2.1 Description of SCS Operation

The SCS consists of two trains and each train has a heat exchanger of one shell pass and two tube pass type. The basic purpose of shutdown cooling process is to transfer the decay heat from the primary loop (reactor coolant) to the secondary loop (component cooling water).

When the reactor coolant system (RCS) temperature and pressure are decreased to 350 °F and 410 psia by the initial phase of heat rejection to secondary side of the steam generators, the shutdown cooling is initiated and the RCS temperature and pressure are reduced until the refueling condition is reached. At the initiation of shutdown cooling, normal full SCS pump flow through the shutdown cooling heat exchanger could result in a cooldown rate exceeding administratively controlled limit. To avoid this, a portion of the shutdown cooling flow is diverted through the heat exchanger bypass line. As the cooldown continues and the RCS temperature decreases, the tube side flow must be increased to maintain the constant cooldown rate. Throughout the entire shutdown cooling process, the shell side (component cooling water) flow remains constant.

2.2 Modeling of Heat Transfer within Shutdown Cooling Heat Exchanger

The tube side film heat transfer coefficient (h_i) as a function of Reynolds number is calculated by using Siedler and Tate's correlation[1] as follows:

For 2,100 ≤Re≤1,000,000,

$$h_i = 0.025\frac{k}{D_i}(\mathrm{Re})^{0.79}(\mathrm{Pr})^{0.42}\left(\frac{\mu}{\mu_w}\right)^{0.14} \quad (1)$$

where $D_i(ft)$ is the tube inside diameter, k (Btu/hr-ft-°F) the tube side fluid thermal conductivity, Re the Reynolds number, Pr the Prandtl number, μ the tube side bulk viscosity, and μ_w the tube side wall viscosity. A properly designed correlation is required for the shell side heat transfer evaluation because the cross flow against tube bundle is affected by baffle cut, baffle configuration, baffle space, tube outside diameter, and overall arrangement. McAdams's correlation[2] is used in this modeling. The shell side film heat transfer coefficient (h_o) is calculated as follows: For 2,000≤Re≤1,000,000,

$$h_o = 0.36\left(\frac{k}{D_e}\right)(\mathrm{Re})^{0.55}(\mathrm{Pr})^{\frac{1}{3}}\left(\frac{\mu}{\mu_w}\right)^{0.14}(\eta_a)(\eta_b) \quad (2)$$

where $D_e(ft)$ is the shell side equivalent diameter, k (Btu/hr-ft-°F) the shell side fluid conductivity, μ the tube side bulk viscosity, μ_w the tube side wall viscosity, η_a the efficiency due to shell side flow direction, and η_b the baffle efficiency.

3. Results and Conclusions

The total heat transfer coefficients (THTC) of shutdown cooling heat exchangers calculated by the SPACE code are compared with those by the HTRI and DESCENT codes for KSNP and APR1400 at various conditions. As shown in Table 1, the results of the SPACE code agree well to those of the HTRI code. The DESCENT code underestimates THTC as compared to the SPACE code. The SCS cooldown performance calculated by the SPACE code is almost the same as that calculated by the DESCENT code as shown in Fig. 1. The heat transfer coefficient predicted by the SPACE code agrees to that by the HTRI code better than that by the DESCENT code as shown in Fig. 2.

In this study, it is concluded that the SPACE code has the capability to evaluate the shutdown cooling heat exchanger size and to analyze the SCS cooldown performance

REFERENCES

[1] Siedler, E. N., and Tate, G. E., Ind. Eng. Chem., Vol. 28, p1429-36, 1936.
[2] McAdams, W. H., Heat Transmission, 3rd Ed., McGraw-Hill, New York, 1954.

Table 1. Total Heat Transfer Coefficients calculated by the HTRI, DESCENT and SPACE codes

Parameter / Type	Area (FT^2)	Tube Side			Shell Side		HTRI	SPACE	HTRI Input/ DESCENT
		Pitch(in) India(in) Outdia(in)	Inlet Temp.(F)	Flow (1000 lbm/hr)	Inlet Temp.(F)	Flow (1000 lbm/hr)	THTC (BTU/F-HR- FT^2)	THTC (BTU/F-HR- FT^2)	THTC (BTU/F-HR- FT^2)
KSNP (1000 MWe)	7563	1.25	125	2370	95	3980	316	301	316
		1.0	350	506	110	3970	212	211	181
		0.902	270	2240	110	3970	327	338	316
APR1400 (1400 MWe)	8362	1.0	120	2380	95	5480	384	377	384
		0.75	350	656	110	5460	262	293	261
		0.68	290	2240	110	5460	386	429	384

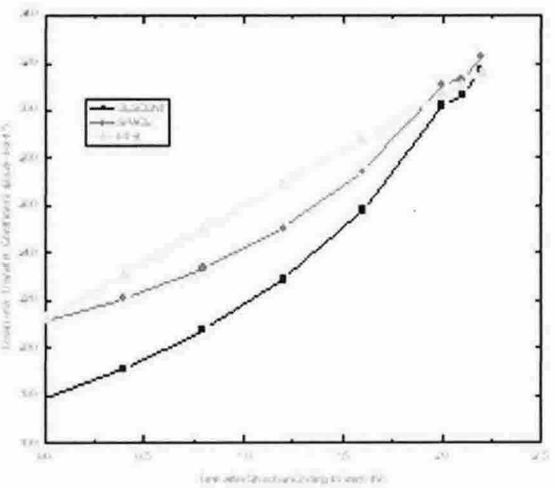

Fig. 1. Shutdown cooling performance simulated by the DESCENT and SPACE codes

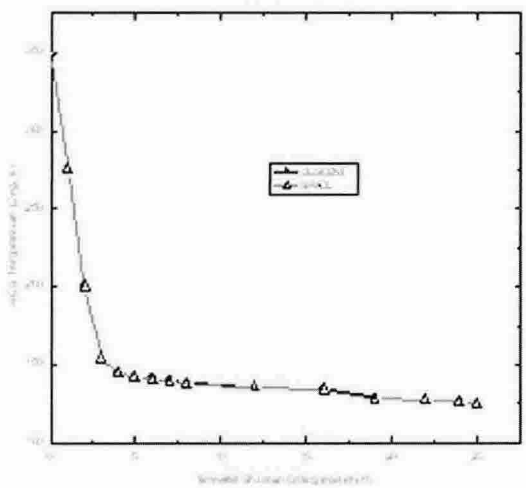

Fig. 2. Total Heat Transfer Coefficients calculated by the HTRI, DESCENT and SPACE codes during cooldown