IJESRT: 8(11), November, 2019 ISSN: 2277-9655

# International Journal of Engineering Sciences &Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

Website: www.ijesrt.com Mail: editor@ijesrt.com

**IJESRT**

**INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY**

# ASSESSMENT OF HIGH CYCLE THERMAL FATIGUE ACCORDING TO HOT-COLD WATER MIXED FLOW IN NUCLEAR POWER PLANT PIPING SYSTEM

**Sun-Ki LEE**
Department of Energy Mechanical System, Dong-Shin University, Republic of Korea

**DOI**: 10.5281/zenodo.3559516

## ABSTRACT

In the case of nuclear power plants, there is a risk of thermal fatigue in equipment and piping affecting system soundness because the temperature change of the system accompanies in every operation and shutdown. Therefore, in order to prevent the excess of the fatigue limit during the lifetime of plants, in the designing stage, the fatigue limit of each piping material is determined. However, there are many cases where equipment or piping is locally subjected to thermal fatigue that is not considered in the design, resulting in damage to the equipment and piping, and failure of the operation. Currently, local thermal fatigue generation mechanisms that are not taken into account in nuclear power plant design are gradually being identified. In this paper, the effects of the fluid temperature fluctuations on the piping soundness due to the mixing of hot and cold water, one of the local thermal fatigue generating mechanisms, were evaluated.

**KEYWORDS**: High Cycle Thermal Fatigue, Hot-Cold Water Mixed Flow, Temperature Boundary Fluctuation, Residual Heat Removal System, Nuclear Power Plant.

## 1. INTRODUCTION

In May 1998, cracks and massive coolant leakage occurred in the heat exchanger outlet of the Civaux-1 residual heat removal (RHR) system in France. The crack site is an elbow portion where the low-temperature fluid passed through the RHR heat exchanger and the high-temperature fluid bypassed through the heat exchanger are combined. At the time of the crack occurrence, the system was in commissioning, and the hot and cold fluids were operated for about 1600 hours in the mixed state with the temperature difference of about 140℃.

The cause of the crack was found to be the high-cycle thermal fatigue due to the temperature change led by hot-cold water mixing. As a countermeasure for this, the Civaux-1 design was revised to move the hot-cold water mixture region as far away from the elbow position as possible.

For reference, Figure 1 shows the number of accidents that occurred in piping due to thermal fatigue by country and by types of reactor[1,2).]

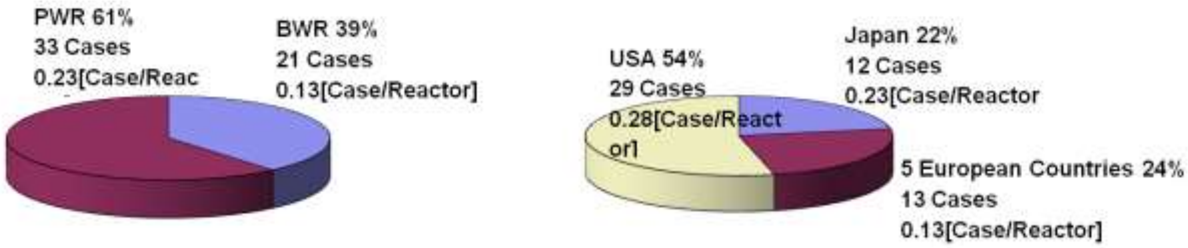

***Fig1.Number of accidents that occurred in piping due to thermal fatigue in nuclear power plants***

### *The mechanism analysis of nuclear power plant piping thermal fatigue occurrence*

As shown in Figure 1 above, the total number of damages caused by thermal fatigue in major countries is 54. When reviewing these 54 damage cases by mechanism, they are classified into the following seven cases.

(1) Case 1
The pressurizer surge line is a pipe connecting the pressurizer and the hot leg of the reactor coolant system, and in this pipe, the hot coolant on the pressurizer side and the coolant on the hot leg side, which is relatively low temperature, meet and the temperature difference always exists between the upper and lower pipe portions. This temperature difference caused abnormal deformation of the piping structure, contact with the support structure, breakage of the support, and the like.

(2) Case 2
The high-temperature fluid penetrated from the main pipe to the branch piping (turbulent penetration), creating a temperature boundary in the horizontal region of the branch piping, which caused thermal fatigue in conjunction with the fluctuations in the flow conditions (flow speed and flow rate) of the main piping.

(3) Case 3
The high-cycle thermal fatigue occurred in the piping due to the variation of the temperature boundary generated when the low-temperature fluid which passed through the heat exchanger and the bypassed high-temperature fluid met.

(4) Case 4
Since the low-temperature water leaked into the main pipe from the isolation valve of the rear end of the branch pipe connected to the main pipe, a large temperature boundary was generated in the branch piping, and the change of this boundary caused thermal fatigue.

(5) Case 5
Although similar to case 4, out leakage occurred periodically from the RCS side to the branch piping, and thus thermal fatigue occurred due to the periodic variation of the temperature boundary.

(6) Case 6
When the low-temperature water flowed into the steam generator at low speed, the hot-water stagnated in the piping horizontal region, and because the low-temperature water flowed from the lower part of the pipe, a temperature boundary occurred, and this boundary changed together with the change of the flow conditions resulting in the thermal fatigue.

(7) Case 7
This is the case that first happened in Japan, and it caused the leakage of coolant due to the damage of the outlet pipe of the regenerative heat exchanger. The problematic regenerative heat exchanger is a heat exchanger of special shape with a cylinder inside, and thermal fatigue occurred due to the following mechanism.

First, the gap between the inner cylinder and the housing was designed to be small at the bottom, so that the by-pass flow was low at the lower side. Due to this reason, the fluid flowing in the lower part of the heat exchanger was cooled more than the by-pass fluid at the upper part, causing a temperature difference in both parts of the heat exchanger and the deformation of it as well. If this deformation exceeds a certain limit, the flow area becomes narrower in the upper part of the heat exchanger and wider in the lower part of it, and the flow shows the opposite phenomenon resulting in the heat exchanger returns to the initial state. Accordingly, the fluid temperature of the heat exchanger outlet pipe also changed periodically so that thermal fatigue occurred.

According to the result of the reviewing above cases and mechanisms, the piping failure caused by thermal fatigue was led by local temperature change not considered in the design.

In this paper, the soundness assessment on the Korea nuclear power plant K-3 and K-4 RHR systems was conducted according to Case 3 above, which covers cases that the temperature change caused by mixing of the high-temperature fluid and the low-temperature fluid causes the thermal stress variation.

## 2. THE THERMAL FATIGUE ASSESSMENT METHOD FOR THE PIPING OF THE HIGH AND LOW TEMPERATURE FLUIDS MIXING

### Method

In the United States and Korea, no systematic research and quantitative assessment criteria for high-cycle thermal fatigue have been established. Therefore, as needed, local evaluations are attempted with excessive assumptions and some experimental approaches.

On the other hand, in Japan, a standardization committee was recently established to evaluate the high-cycle thermal fatigue occurring in piping, and an assessment guideline was set up in December of 2003 after integrating the research results of the long term. In this paper, the assessment was conducted per the Japanese Society of Mechanical Engineers (JSME) criterion "Assessment Guidelines for High-Cycle Thermal Fatigue of Piping (JSME S 017-2003)"[3)]

### Procedure

The overview of the assessment procedure is shown in Figure 2.

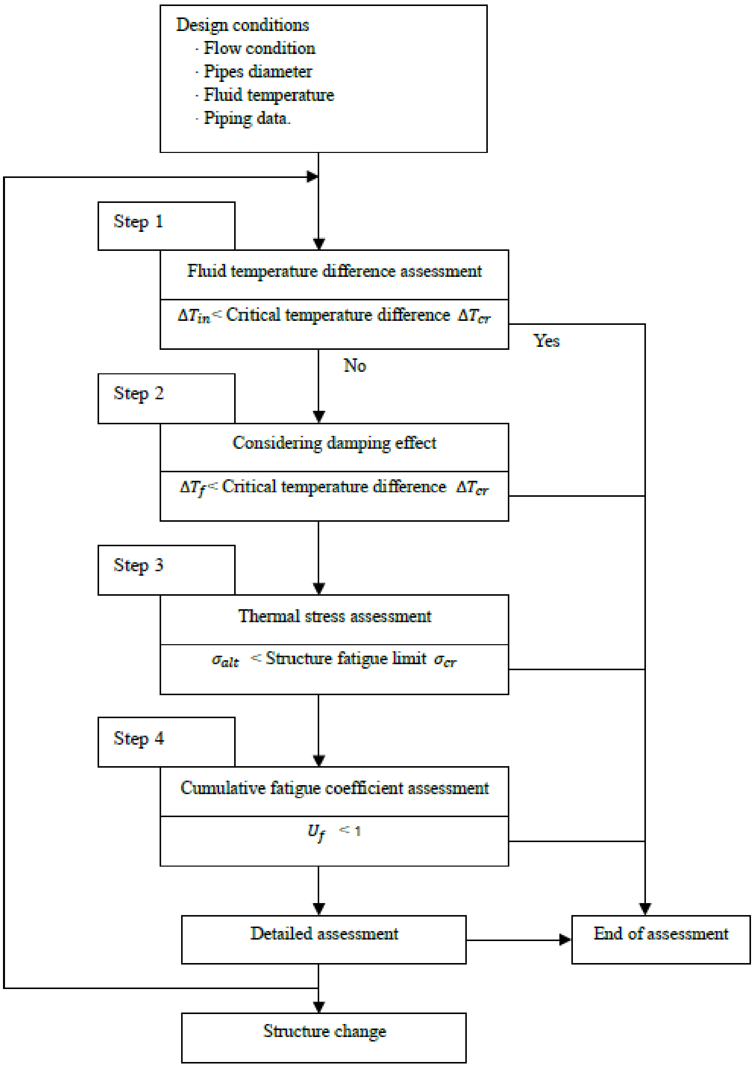

*Fig. 2 Thermal fatigue assessment procedure of the high & low-temperature fluid mixing piping*

1) Step 1: Assessment considering critical temperature difference related to structure soundness
Evaluation under the assumption that the fluid temperature difference before mixing is the same as the temperature occurring in the structure. The temperature difference at this moment has to be less than the temperature difference (critical temperature difference) corresponding to the fatigue limit of the structure.
2) Step 2: Assessment considering the damping effect of the temperature fluctuation range (considering the fluid temperature difference damping effect)
Assessment considering the damping effect of temperature fluctuation range due to the mixing, etc. The temperature difference at this moment has to be less than the critical temperature.
3) Step 3: Assessment considering thermal stress
In this step, the thermal stress amplitude generated in the structure due to temperature fluctuation is obtained from the heat transfer rate between the fluid and the surface of the structure calculated using the actual measurement data. This value has to be no more than the fatigue limit.
4) Step 4: Assessment considering cumulative fatigue coefficient
The cumulative fatigue coefficient of the assessment part is calculated from the fatigue assessment considering the damping of the temperature fluctuations. This value has to meet the limit.

## 3. ASSESSMENT OF THE KOREA NUCLEAR POWER PLANT K-3 AND K-4 RHR SYSTEM

**RHR system**
Figure 3 shows an overview of the K-3 and K-4 RHR system. This system is connected in parallel to the reactor coolant system at a certain point (RCS temperature = 177℃, RCS pressure = 30kg/cm$^2$) of the time while the plant was cooled down to remove decay heat during the reactor shutdown. The reactor coolant is taken from the reactor's hot leg and circulated to the cold leg.

The design criteria for this system are as follows: The operation starts at 177℃ and pressure 30kg/cm$^2$, 4 hours after the reactor shutdown, and it takes 16 hours to cool down the coolant temperature from 177℃ to 60℃ which is the fuel reload start temperature.

The problematic part in the figure is where the pipe passing through the heat exchanger and the by-pass pipe join. In this part, a temperature boundary is created when the low-temperature fluid passed through the heat exchanger and the high-temperature fluid in the by-pass pipe meet and mix. The change in this temperature boundary causes piping thermal stress (the bold circled part in the figure). At this moment, the flow rate range of the coolant passed through the heat exchanger is 680~518(m$^3$/hr), and the flow rate of the by-passed coolant is 0~162(m$^3$/hr).

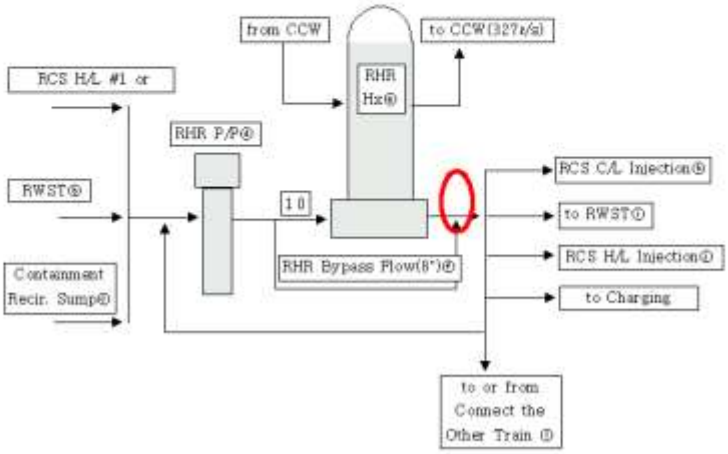

*Fig. 3 The schematic diagram of the RHR system*

***Internal thermal flow analysis***

To analyze the thermal flow inside the pipe during hot-cool fluid mixing, as shown in Figure 4, the modeling of the target pipe was conducted. This model's boundary condition is as follows: the low-temperature fluid with a flow speed of 4.5m/s and temperature of 60°C passed through the heat exchanger and the bypassed high-temperature fluid with a flow speed of 1.0m/s and temperature of 177°C are mixed and flow downstream.

Figure 5 shows the temperature distribution obtained from the internal thermal flow analysis of the target pipe. As can be seen in the figure, joining of the high-temperature fluid and the relatively low-temperature fluid forms a temperature boundary, and getting more active this mixing as downstream, more mitigating the temperature difference in this temperature boundary.

The problem is the area where the temperature boundary forms due to the joining of hot and cold fluids in a confined narrow space of the piping. Thermal fatigue occurs because the temperature boundary changes with the instability of the fluids themselves and the changes in the system operating conditions. Also in the analysis results, it can be confirmed that the temperature boundary changes with time.

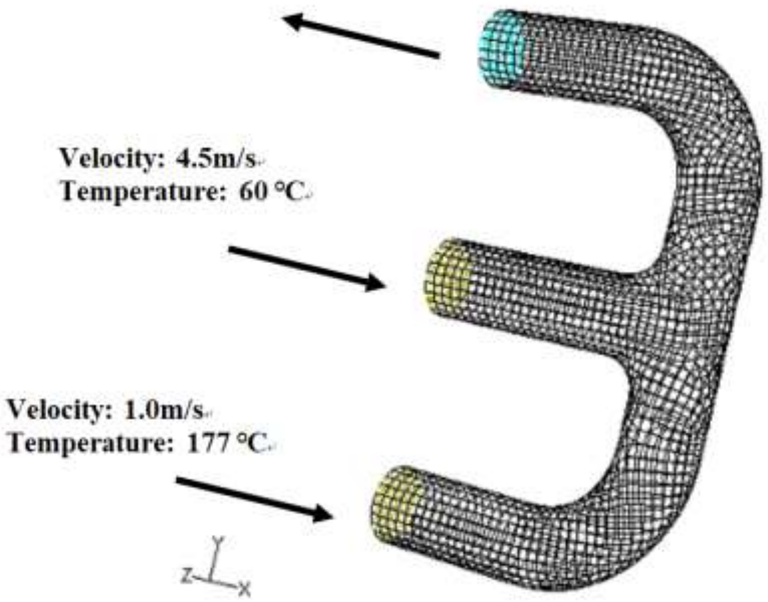

***Fig. 4 Modeling of the thermal flow analysis for the target pipe***

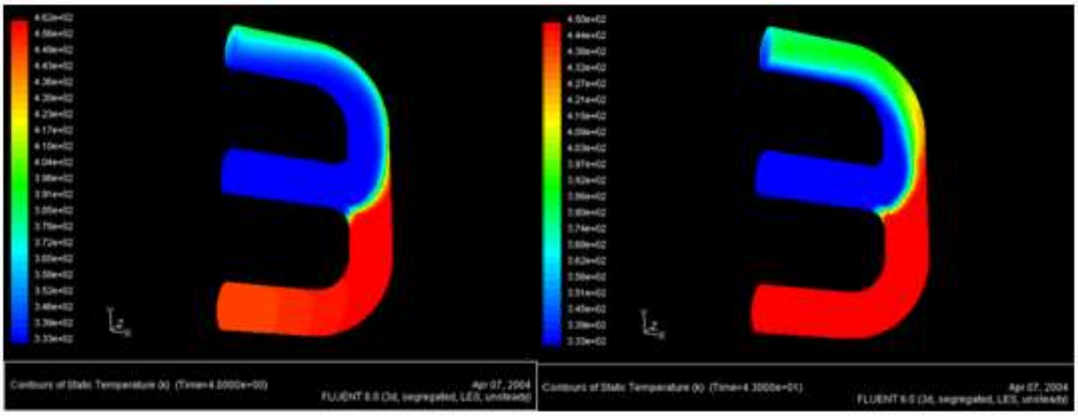

*Fig. 5 Results of thermal flow analysis*

***Soundness assessment***

In this paper, the assessment was conducted per the Japanese Society of Mechanical Engineers (JSME) criterion "Assessment Guidelines for High-Cycle Thermal Fatigue of Piping (JSME S 017-2003)" written above, and the basic input data, required for the assessment, are summarized in Table 1.

*Table 1 Assessment conditions of target pipe*

| | External diameter [inch] | Internal diameter [inch] | Thickness [inch] | Fluid temperature[°C] | Flow velocity [m/s] | Material |
|---|---|---|---|---|---|---|
| Main piping | 10.75 | 9.75 | 0.5 | 60 | 4.5 | SUS304 SCH60 |
| Branch piping | 8.625 | 7.813 | 0.406 | 177 | 1.0 | SUS304 SCH60 |

(1) Step 1: Assessment according to structure soundness evaluation critical temperature difference

The temperature fluctuations of the fluid in the piping due to the mixing of the high & low-temperature fluid are transmitted to the pipe by heat transfer. Thermal stress in the piping accumulates as fatigue due to repeated action with temperature fluctuations. In this step, the critical temperature difference$\Delta T_{cr}$is introduced to judge the necessity of considering the thermal stress from the comparison between the thermal stress and the fatigue limit generated in the piping. The critical temperature difference $\Delta T_{cr}$ defines the maximum temperature difference$\Delta T_{max}$at which the stress range$\Delta\sigma(T)$falls below the fatigue limit of the material as$\Delta T_{cr}$, and is represented by the following equation.

$$\Delta\sigma(T) = \frac{E\alpha\Delta T_{cr}}{1-\upsilon} < \text{Fatigue limit} \qquad \text{(i)}$$

The critical temperature difference $\Delta T_{cr}$ is determined according to the material. In addition, in the guideline, the coefficient of A, B, C is given for each material so that if only the target material is known, $\Delta T_{cr}$ can easily be found with the following equation.

$$\Delta T_{cr} = A \times T_h^2 + B \times T_h + C \qquad \text{(ii)}$$

For piping material SUS304,
Use $A = 4.62 \times 10^{-5},\ B = -4.27 \times 10^{-2},\ C = 4.50 \times 10^{1}$
When calculating $\Delta T_{cr}$ from the formula above, $\Delta T_{cr}$= 41°C.
In this case, hot-cold fluids temperature difference is $\Delta T_{in}$= 177 - 60 = 117°C.
"Fluid temperature difference $\Delta T_{in}$<critical temperature difference$\Delta T_{cr}$"is not valid so that perform Step 2 assessment.

(2) Step 2: Assessment considering the damping effect of the temperature fluctuation range

The temperature difference between the main and branch piping before joining decreases after the joining. In the calculation of the temperature fluctuation reduction, the damping coefficient β for the fluid temperature difference $\Delta T_{in}$ before joining is introduced using the parameters such as the diameter ratio of the branch pipe and the main pipe, the main pipe flow speed, and the flow speed ratio between the main pipe and the branch pipe. $\beta_{max}$=0.9 is applied to this case.

The temperature fluctuation range $\Delta T_f$ after joining is calculated with the formula below.

$$\Delta T_f = \Delta T_{in} \times \beta_{max} \qquad \text{(iii)}$$

"$\Delta T_f$=105.3°C" is obtained from the formula above.

"$\Delta T_f < \Delta T_{cr}$"is not valid so that perform Step 3 assessment.

(3) Step 3: Assessment considering the thermal stress

In order to assess the effect of the temperature cycle of the fluid on the stress change of the structure, Bi No. $B_i$ and the maximum dimensionless stress range $\Delta\sigma^*_{max}$ are introduced. In this step, the maximum dimensionless stress range $\Delta\sigma^*_{max}$ is the ratio at which the temperature change of the fluid is transferred to the stress and is a function of Bi No. $B_i$.

The mixed fluid thermal equilibrium temperature $T_{mix}$ after the mixing of the fluids of the main pipe and the branch pipe is as follows.

$$T_{mix} = \frac{170\times1.0\times(7.813/9.75)^2+60\times45}{1.0\times(7.813/9.75)^2+4.5} = 74.6℃$$

The thermal conductivity $\lambda_f$ of the fluid corresponding to this temperature is 0.671(W/m/K), the kinematic viscosity $v_f$ = 0.366E-6(m$^2$/s), and Prandtl number $P_r$ = 0.23.

Nusselt number $N_u$ is calculated with the following formula.

$$N_u = 0.023{R_e}^{0.8}{P_r}^{0.4} = 3540 \qquad \text{(iv)}$$

Normal heat transfer rate $h_s$ is

$$h_s = \frac{N_u \times \lambda_f}{D_{mix}} = 9591 \qquad \text{(W/m}^2\text{/K)} \qquad \text{(v)}$$

Heat transfer coefficient $F_P$ becomes 5.9, abnormal heat transfer rate $h_u$ is 56589(W/m$^2$/K) from $h_u = F_P \times h_s$.
When obtaining Bi No.$B_i$from the pipe thickness $t_s$=0.0127m and the pipe heat conductivity $\lambda_s$=50(W/m/K),

$$B_i = \frac{h_u \times t_s}{\lambda_s} = 14.37 \qquad \text{(vi)}$$

The guideline gives the relationship between Bi No. $B_i$and the maximum dimensionless stress range $\Delta\sigma^*_{max}$, whereby the maximum dimensionless stress range $\Delta\sigma^*_{max}$ can be obtained by $\Delta\sigma^*_{max}$ = 0.65.

The thermal stress amplitude $\sigma_{alt}$ generated in the structure due to the temperature fluctuations caused by hot-cold fluid mixing is obtained by the following equation.

$$\sigma_{alt} = (1/2) \times K_t \times \frac{E\alpha\Delta T_f}{1-\upsilon_s} \times \Delta\sigma^*_{max} = 118.3\text{(MPa)} \qquad \text{(vii)}$$

In this equation, $K_t$ is the stress magnification factor, $E$ is the module of direct elasticity of structure, α is the thermal expansion coefficient, $\nu_s$ is Poisson's ratio.

On the other hand, the fatigue limit $\sigma_{cr}$ corresponding to this pipe material is 94 (MPa) and it does not satisfy

"$\sigma_{alt} < \sigma_{cr}$" so that Step 4 assessment is performed.

(4) Step 4: Assessment considering the fatigue damage
Temperature fluctuation range ($\Delta T_k^*$) and frequency of occurrence ($N_{sk}^*$) in hot-cold fluid mixing are presented after non-dimensional in the guideline by flow speed ratio, main pipe flow speed, and location of the assessment target. The dimensionless temperature fluctuation range and the frequency of occurrence shall be presented in a table.

a. Conversion to actual units
After conversion to actual units, the temperature fluctuation range $\Delta T_{pk}$ is obtained by the following equation.

$$\Delta T_{pk} = \Delta T_k^* \times \Delta T_{in} \qquad (k = 1,2,3 \cdots, n) \qquad \text{(viii)}$$

For example, if the dimensionless temperature fluctuation range $\Delta T_k^*$=84(k=42) is dimensionalized,
$\Delta T_{pk} = 0.84 \times 117 = 98.3$℃

On the other hand, if the dimensionless frequency of occurrence ($N_{sk}^*$) is dimensionalized using the following equation,

$$N_{sk} = \frac{N_{sk}{}^* \times U_{mix}}{D_{mix}}, \qquad (k = 1,2,3, \cdots, n) \qquad \text{(ix)}$$

$$=7.87\times 10^{-3}\times 5/0.24765=15.9\times 10^{-2}(s^{-1})$$

In this equation $N_{sk}$ is the occurrence number per unit time.

b. Conversion to the thermal stress amplitude of the temperature fluctuation range (double amplitude)
The conversion to the thermal stress amplitude $\sigma_{altk}$ corresponding to the above temperature fluctuation range $\Delta T_{pk}$ is calculated by the following equation.

$$\sigma_{altk} = (1/2)\times K_t \times \frac{E\alpha\Delta T_{pk}}{1-\nu_s} \times \Delta\sigma_{max}{}^*, \qquad (k = 1,2,3, \cdots n) \qquad \text{(x)}$$

$$= (1/2) \times 1.0 \times \frac{1.95\times10^{11}\times1.32\times10^{-6}\times98.3}{1-0.3} \times 0.6 = 117.5(MPa)$$

c. Calculation of the cumulative fatigue coefficient per unit time
If the allowable repetition number $N_k$ corresponding to the above thermal stress amplitude $\sigma_{altk}$ = 117.5 (MPa) is obtained from the fatigue curve, the result is $8.0 \times 10^6$.

If the cumulative fatigue coefficient per unit time is calculated with the following equation,

$$U_{fk} = \frac{N_{sk}}{N_k} \qquad (k = 1,2,3, \cdots, n) = 1.99 \times 10^{-8}\ (s^{-1}) \qquad \text{(xi)}$$

The result of the calculation performed from a to c above for k = 1~n is described in Table 2.
Total cumulative fatigue coefficient per unit time $\sum U_{fk}$ is $1.46\times10^{-7}$.

d. Assessment of the cumulative fatigue coefficient
If the operation is 40 cycles under the condition that the high-temperature fluid (177°C) and the low-temperature fluid (60°C) are mixed for 16 hours during power plant cooling,

$$U_f = 1.46 \times 10^{-7} \times 3600 \times 16 \times 40 = 0.34$$

In other words, the above results indicate that the cumulative fatigue coefficient is 0.34 during the 40-cycle operation of the power plant, and this means the piping is sound under the condition of high-cycle thermal fatigue due to the hot-cold fluid mixing.

***Table 2 Result of the fatigue coefficient calculation according to the dimensionless temperature fluctuation range ($\Delta T^*{}_k$)and the frequency of occurrence ($N^*_{sk}$)***

| $k$ | $\Delta T^*_k$ | $N^*_{sk}$ | $\Delta T_{pk}$ | $N_{sk}$ | $\sigma_{altk}$ | $N_k$ | $U_{fk}$ |
|---|---|---|---|---|---|---|---|
| 1 | 0.02 | 9.90E-02 | 2.34 | 1.998789 | 2.7965 | | 0 |
| 2 | 0.04 | 6.64E-02 | 4.68 | 1.340602 | 5.5929 | | |
| 3 | 0.06 | 4.89E-02 | 7.02 | 0.98728 | 8.3894 | | |
| 4 | 0.08 | 3.37E-02 | 9.36 | 0.680396 | 11.1859 | | |
| 5 | 0.10 | 3.26E-02 | 11.7 | 0.658187 | 13.9823 | | |
| 6 | 0.12 | 2.81E-02 | 14.04 | 0.567333 | 16.7788 | | |
| 7 | 0.14 | 1.91E-02 | 16.38 | 0.385625 | 19.5753 | | |
| 8 | 0.16 | 1.46E-02 | 18.72 | 0.294771 | 22.3717 | | |
| 9 | 0.18 | 1.46E-02 | 21.06 | 0.294771 | 25.1682 | | |
| 15 | 0.30 | 1.12E-02 | 35.1 | 0.226126 | 41.9470 | | |
| 16 | 0.32 | 1.01E-02 | 37.44 | 0.203917 | 44.7435 | | |
| 18 | 0.38 | 5.62E-03 | 44.46 | 0.113467 | 53.1329 | | |
| 20 | 0.40 | 1.01E-02 | 46.8 | 0.203917 | 55.9293 | | |
| 21 | 0.42 | 6.75E-03 | 49.14 | 0.136281 | 58.7258 | | |
| 22 | 0.44 | 9.56E-03 | 51.48 | 0.193014 | 61.5223 | | |
| 25 | 0.50 | 5.62E-03 | 58.5 | 0.113467 | 69.9117 | | |
| 26 | 0.52 | 2.25E-03 | 60.84 | 0.045427 | 72.7081 | | |
| 27 | 0.54 | 2.25E-03 | 63.18 | 0.045427 | 75.5046 | | |
| 28 | 0.56 | 7.87E-03 | 65.52 | 0.158894 | 78.3011 | | |
| 29 | 0.58 | 2.81E-03 | 67.86 | 0.056733 | 81.0975 | | |
| 30 | 0.60 | 5.62E-03 | 70.2 | 0.113467 | 83.8940 | | |
| 31 | 0.62 | 1.12E-03 | 72.54 | 0.022613 | 86.6905 | | |
| 32 | 0.64 | | 74.88 | 0 | 89.4869 | | |
| 33 | 0.66 | 2.25E-03 | 77.22 | 0.045427 | 92.2834 | | |
| 34 | 0.68 | 2.25E-03 | 79.56 | 0.045427 | 95.0799 | 1.00E+09 | 4.54E-11 |
| 35 | 0.70 | 3.37E-03 | 81.9 | 0.06804 | 97.8764 | 6.00E+07 | 1.13E-09 |
| 36 | 0.72 | 2.25E-03 | 84.24 | 0.045427 | 100.6728 | 3.00E+07 | 1.51E-09 |
| 37 | 0.74 | 2.25E-03 | 86.58 | 0.045427 | 103.4693 | 2.00E+07 | 2.27E-09 |
| 38 | 0.76 | 6.75E-03 | 88.92 | 0.136281 | 106.2658 | 1.50E+07 | 9.09E-09 |
| 39 | 0.78 | 2.25E-03 | 91.26 | 0.045427 | 109.0622 | 1.30E+07 | 3.49E-09 |
| 40 | 0.80 | 2.25E-03 | 93.6 | 0.045427 | 111.8587 | 1.00E+07 | 4.54E-09 |
| 41 | 0.82 | 1.12E-03 | 95.94 | 0.022613 | 114.6552 | 9.00E+06 | 2.51E-09 |
| 42 | 0.84 | 7.87E-03 | 98.28 | 0.158894 | 117.4516 | 8.00E+06 | 1.99E-08 |
| 43 | 0.86 | 4.50E-03 | 100.62 | 0.090854 | 120.2481 | 7.00E+06 | 1.30E-08 |
| 44 | 0.88 | 7.87E-03 | 102.96 | 0.158894 | 123.0446 | 6.00E+06 | 2.65E-08 |
| 45 | 0.90 | 4.50E-03 | 105.3 | 0.090854 | 125.8410 | 5.00E+06 | 1.82E-08 |
| 46 | 0.92 | 2.25E-03 | 107.64 | 0.045427 | 128.6375 | 4.50E+06 | 1.01E-08 |
| 47 | 0.94 | 3.37E-03 | 109.98 | 0.06804 | 131.4340 | 4.20E+06 | 1.62E-08 |
| 48 | 0.96 | 2.25E-03 | 112.32 | 0.045427 | 134.2304 | 4.00E+06 | 1.14E-08 |
| 49 | 0.98 | 1.12E-03 | 114.66 | 0.022613 | 137.0269 | 3.50E+06 | 6.46E-09 |
| 50 | 1.00 | | 117 | 0 | 139.8234 | 2.00E+05 | 0.00E+00 |
| | | | | | | $\sum U_{fk}$ | 1.46E-07 |

## 4. CONCLUSION

In this paper, the effects of fluctuations in the internal pipe temperature due to the mixing of hot and cold water, one of the local thermal fatigue generating mechanisms, on the piping soundness were assessed for the outlet pipes of the Korea nuclear power plant K-3 and K-4 RHR heat exchangers.

As a result, the cumulative fatigue coefficient was 0.34 during the 40-cycle operation of the power plants, indicating that the piping is sound under the condition of the high-cycle thermal fatigue due to hot-cold fluid mixing.

## 5. ACKNOWLEDGEMENTS

This work was supported by the Korea Institute of Energy Technology Evaluation and Planning.

## REFERENCES

[1] EPRI, “Thermal Stratification, Cycling and Striping(TASCS)” TR-103581, 1994
[2] EPRI, “Interim Thermal Fatigue Management Guideline(MRP-24)” TR-1000701, 2001
[3] JSME, “Assessment Guidelines for High-Cycle Thermal Fatigue of Piping” JSME S 017, 2003