# Study for Ejected Tube Plugs in Loss of Condenser Vacuum Event

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## 1. Introduction

In August 2014, the power plant of Kori-2 was shut down due to heavy rain, which caused the pressure and temperature of the condenser to rise, resulting in the ejection of a rubber material plug from the tube. If the power plant is restarted with the tube damaged and the plug ejected due to the increase in the internal temperature and pressure of the condenser, seawater will flow into the secondary water system and then increase the concentration of impurities. In the long term, it will accelerate the corrosion rate of steam generator tubes and adversely affect the life span of the plant.

Fig 1. Kori 2 plant Condenser

Fig 2. Ejected Rubber Tube Plug

Therefore, this study is to investigate the possibility of damage of the condenser tube and the release mechanism of the rubber plug under the relevant experiential conditions.

## 2. Analysis Methods & Results

After the circulating water pump was stopped, condenser dump was not occurred and the operation parameters of the condenser were checked. As a result, the maximum pressure was 1064.2 mbar and the maximum temperature rose to 99.89 ° C(see Fig 3).

Based on this condition, we discussed 1. Analysis of stress behavior due to expansion of the tube, 2. Analysis of expansion of the tube by the internal temperature and pressure rise, and 3. The plug release mechanism through the analysis result.

| | POINT ID | DESCRIPTION | VALUE | UNIT | Y MIN | Y MAX |
|---|---|---|---|---|---|---|
| 🟥 | T4042A | LP1 EXHAUST STM TEMP FRONT TEMP | 97.67 | DEG C | 0.000 | 150.000 |
| 🟦 | T4043A | LP1 EXHAUST STM TEMP REAR TEMP | 97.44 | DEG C | 0.000 | 150.000 |
| 🟩 | P2502A | CONDENSER A VACUUM(ABSOLUTE) | 1022.0 | MBARA | 20.000 | 1400.000 |
| 🟦 | P2503A | CONDENSER B VACUUM(ABSOLUTE) | 1022.1 | MBARA | 20.000 | 1400.000 |
| 🟧 | P2400A | CW PUMPS OUTLET HEADER P | 0.13 | KG/CM2 | 0.000 | 4.000 |
| ⬜ | QC340A | GROSS ELECTRIC POWER (WATT) | LL 7.20 | MW | 0.000 | 1143.000 |

Send Message To Server GRPMNGR.
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Fig 3. Condenser Pressure and Temperature Trend

### *2.1 Analysis of stress behavior of the condenser tube*

As the temperature rises with plugged on both side of the tube, the internal pressure increases and the diameter becomes larger.

The shape of the tube is 25.4 mm in outer diameter and 0.71 mm in thickness. Tube material is titanium (SB-338 Gr.2). Coefficient of the thermal expansion of titanium ( $\alpha$ ) is 8.50 x 10-6 mm/mm/° C from 20° C to 100° C, and Poisson's ratio ( $\upsilon$ ) is 0.32.

When the tube is subjected by a plug, the air inside the tube is assumed to follow an ideal gas behavior. The stress caused by the internal pressure rise was 30.83 MPa by applying Boyle Charles laws, which confirmed that the ASME Sec II Part D behaved within the elastic limit at a temperature of 100 ° C, which was lower than the value of the yield stress of 213 MPa at 100 ° C.

### *2.2 Tube deformation due to temperature and pressure*

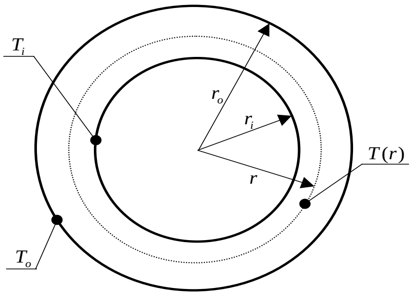

Fig 4. Condenser's tube section

a. radial deformation of tube due to temperature

$$u_{th}(r)=\frac{1+\upsilon}{1-\upsilon}\frac{\alpha}{r}\int_{r_i}^{r_0}T(r)rdr+\frac{(1+\nu)(1-2\nu)}{1-\nu}\frac{\alpha r}{r_0^{\,2}-r_i^{\,2}}\int_{r_i}^{r_0}T(r)rdr$$
$$+\frac{1+\upsilon}{1-\upsilon}\frac{\alpha}{r}\frac{r_i^{\,2}}{r_0^{\,2}-r_i^{\,2}}\int_{r_i}^{r_0}T(r)rdr \qquad (1)$$

In the above displacement equation of the cylinder [1], it was confirmed that the outer displacement increase 0.00942 mm and inner displacement increase 0.00955 mm when the temperature condition (T (r) = 99.89 ° C) and the outer radius of the tube was 12.7 mm, the inner radius was 12.345 mm. In addition, the hole change of the tube support plate is 0.0179 mm. The tube support plate's displacement increases more than the diameter of the tube increases when the temperature rises. This shows that the tube plate does not interfere with the displacement of the tube.

b. radial deformation of tube due to pressure

The radial and axial stresses of the tube receiving both internal pressure ( $p_i$ ) and external pressure ( $p_o$ ) are as follows [2][3].

$$\sigma_r(r) = \frac{r_i^2 r_o^2 (p_o - p_i)}{r_o^2 - r_i^2}\frac{1}{r^2} + \frac{(p_i r_i^2 - p_o r_o^2)}{r_o^2 - r_i^2} \qquad (2)$$

$$\sigma_\theta(r) = -\frac{r_i^2 r_o^2 (p_o - p_i)}{r_o^2 - r_i^2}\frac{1}{r^2} + \frac{(p_i r_i^2 - p_o r_o^2)}{r_o^2 - r_i^2} \qquad (3)$$

In the above $\sigma_r(r)$ and $\sigma_\theta(r)$ can be obtained by applying a tube shape with a pressure condition of 1064.2 mbar. $\sigma_r(r)$ is -0.126Mpa(-1.248atm) and $\sigma_\theta(r)$ is 0.784Mpa(7.74atm).
Applying this value to the following radial displacement equation of the cylinder,

$$u_p = \frac{(1-\nu^2)}{E} r(\sigma_\theta - \frac{\nu}{1-\nu}\sigma_r) \qquad (4)$$

The plain strain of the tube was very small value 6.885 x $10^{-8}$ mm, but the diameter of the heat transfer tube was increased.

### 2.3 Mechanism of Plug Disengagement

Normally, the tube plug is forcedly fitted into the tube so that the surface of the plug is pressed onto the tube inner wall, so that the tube plug does not come out by due to the friction force.
The plug of the rubber material detached from KORI 2 condenser was subjected to the plastic deformation, and the condenser internal pressure and temperature rose due to circulation water pump cut off. As a result, the inner diameter of the tube is increased and such a mechanism is considered that the plug is ejected due to the force of pushing the plug out by the internal pressure rising.

## 3. Conclusions

It was confirmed that the condenser tubes were changed within the yield stress value under the condition that the internal temperature and pressure were increased due to the stoppage of the circulating water system during the normal operation of the KORI 2 condenser due to the heavy rain. And it was found to expand in the radial direction.

As a result, the plug of the rubber material would have disappeared as the inner diameter of the tube increased and the pressure increased. If a similar case occurs, a visual inspection of the plug and a tube ECT should be performed to confirm the condition of the tube.

## REFERENCES

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