A Study on the Steam Dryer Performance of Shin-Kori Units 3 and 4

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1. Introduction

The steam generator is a heat exchanger component in the nuclear power plant, which transfers thermal energy from the reactor to steam turbine. The steam-water mixture produced at the upper part of U-tube bundle in a steam generator, are removed initially in the moisture separator and the remaining fine water droplets are removed in the steam dryer. The moisture amount beyond the steam dryer is a very crucial parameter which decides the turbine performance and soundness.

The purpose of this study is to investigate the moisture removal efficiency of the steam dryer at the operating condition of the nuclear power plant units of Shin-Kori 3 and 4 conservatively using experimental results and computationally calculated results.

2. Analytical Methods and Results

2.1 Geometric and Physical Conditions

The flow channels of the steam dryer used in the analysis are shown in Fig. 1, which is formed by two neighboring vanes spaced at given distance. Each vane has double-hooked pockets at every curved stage to catch more droplets. Most of droplets will follow the curved steam stream lines in the waved-flow channel by inertia force and adhere to the vane wall. But, some fine droplets will pass through the waved flow channels without adhering the wall. The steam mass flux and steam quality at the separator inlet region was calculated by ATHOS3 code [1]. ATHOS3 is a three-dimensional, two-phase steady state and transient computer program for the thermal-hydraulics analysis of recirculating U-tube steam generators. The steam quality beyond the separator is assumed to be about 90 % based on the operation experience. The maximum steam velocity was chosen for the calculation with maldistribution of 1.64.

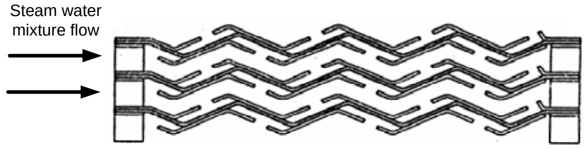

Figure 1 Flow channel of the steam dryer

2.2 Droplet Mean Diameter and Distribution

The mean diameter of the droplet was estimated by using Ueda's experimental correlation using vane spacing distance for nozzle diameter at the maximum steam velocity condition [3]. Also, Weber number criterion was used for comparative result. For dispersed flow, Weber number of 1.5 was used in the calculation [2].

$$We = \rho_g (\upsilon_g - \upsilon_f)^2 \frac{d_{MAX}}{\sigma} \tag{1}$$

The mean diameter of the droplets was decided to be 131 μm. The droplet distribution was expressed approximately by a gamma distribution [3].

$$\frac{\Delta n}{N} = \frac{\lambda^m}{\Gamma(m)} t^{m-1} \exp(-\lambda t)\Delta t \tag{2}$$

The standard deviation of the measured droplet's distribution was affected by the surface tension. The calculated standard deviation was 0.44. The calculated droplet's normalized distribution is shown in Fig. 2.

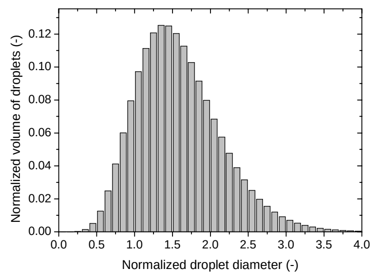

Figure 2 Normalized droplet distribution

2.3 Droplet Removal Performance

Droplet removal efficiency was calculated using Fluent 6.3. In order to model the turbulent fluctuation, RNG k-ε turbulence model was used. For the analysis of particle flow, Lagrangian approach was adopted. The trap boundary condition was applied as a wall boundary condition [4]. The prediction correlation of droplet removal efficiency of the dryer vane was developed for dimensionless droplet diameter ($d^*=d/d_{\mathrm{mean}}$) and steam velocity ($u_g^*=u_g/u_{g.avg}$).

$$E_{rmv} = \left(\left(\frac{-0.003 + 0.010 \cdot u_g^*}{d^*} \right) + (0.013 - 0.025 \cdot u_g^*) + 1 \right)^{-1} \tag{3}$$

The predicting correlation was considered to be conservatively lower than calculated value with coefficient of correlation of 0.939. The comparison of the correlation with calculated result is shown in Fig. 3.

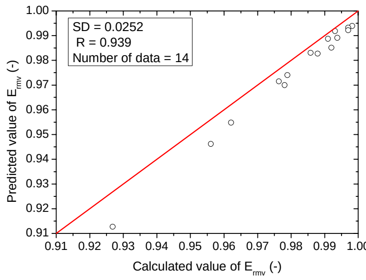

Figure 3 Comparison of correlation with calculation

The normalized volume of carry-overed droplets are shown in Fig. 4 according to the droplet diameter at the maximum steam flow rate condition. In the analysis, breakup of the droplets was not considered as the Weber number was too small to breakup phenomena [5]. The calculated result was validated with Unit Cell Test [6]. Most of droplets were removed which has larger diameter than 60 μm. The performance of the steam dryer is decided by the amount of the fine droplet distribution.

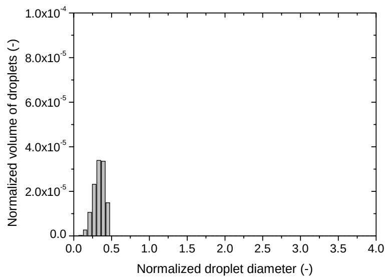

Figure 4 Normalized volume of moisture after the dryer vane

The overall moisture carry over rate was calculated with the water droplet distribution and removal efficiency of the steam dryer as less than 0.004%.

3. Conclusions

This study has been performed to investigate the flow behaviors and evaluate moisture removal efficiency in a steam dryer using CFD analysis. The major results are summarized as follows:

1) The velocity profile and steam quality was calculated using ATHOS3 code to evaluate maldistribution of the steam-droplet mixture..

2) The mean diameter and distribution of the produced droplets were calculated using Weber number criterion and Ueda's experimental correlation.

3) The trajectories of the droplets and removal efficiency of the dryer vane were calculated using CFD analysis.

4) The prediction correlation of the droplet removal efficiency of the dryer vane was suggested conservatively at the maximum steam velocity condition

5) The MCO of the steam dryer was predicted less than 0.004 %.

Moisture removal efficiency of the steam generator for Shin-Kori Units 3 and 4 is expected to be outstanding. The calculated steam quality of it at the steam nozzle is higher than 99.996 %, and this value is much higher than that of design requirement, 99.9 %. More precise analysis of the steam dryer performance considering localized quality and secondary generating droplets in the waved flow path of the dryer vane will be presented later.

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