Development of Boron on-line monitoring system in reactor coolant system (RCS)

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1. Introduction

In the pressurized water reactor (PWR), boron is injected to control the reactor power. The boron concentration in the coolant gradually decreases from about 3,800 ppm before the start-up to about 2,000 ppm in the reactor coolant system, and boron is finally contained about 10 ppm at the end of life (EOL). Analysis of boron concentration in RCS is a very important factor to control nuclear fission. Currently, the conventional on-line measurement using neutron and manual analysis using NaOH titration are performed concurrently. So data is obtained once a day.

Because the conventional analysis method using neutrons usually has an error of about 30 to 50 ppm, it is difficult to apply it as reliable data when the boron concentration in the RCS is low at the end life. Therefore, it is used only for the trend analysis. In case of the boron analysis of NaOH titration, there is always an analysis error dependent on the skill of the analyzer. Besides, it takes a lot of time because the analysis should be performed at intervals of 30 min at the time of the core physics test performed every cycle. So, the analyzers have the intense anxiety of the radiation exposure because it is taken directly into the radiation-controlled area. Actually, in some nuclear power plants, it is often the case that the core physics retest is carried out due to the analytical error during its period.

This study was performed for the boron concentration monitoring technique of the reactor coolant system by using on-line ultraviolet-visible (UV-Vis) spectrometer. The sample taken in the line of RCS enters the sample injection port of the monitoring system and, boron ion is converted into a complex compound by reacting boron ion with color reagent in a controlled pH state. The boron concentration can be monitored by the measured absorbance in an online method within 20 min.

2. Methods and Results

In this part, includes the absorbance measurement by complex of between boron ion and improved-azomethine H acid as a color reagent. And, the direct test without dilution at 0~200 ppm B are also described.

2.1 Reaction of Boron and Improved-azomethine H

The absorbance of boron is measured by yellow complex compound, which is passed through the light source to measure the inherent absorbance of boron in the wavelength range of 400 to 650 nm, resulted from boron and improved-azomethine H acid reagent.

Azomethine H was first suggested in 1961 by Capelle as a reagent for boron determination. Although this reagent has a high selectivity, the range of analysis is so narrow 0~8 ppm. On the other hand, the developed color reagent can extensively analyze the boron from 0 to 3,000 ppm, and the molecule structure of improved-azomethine used in this study is shown in Fig. 1.

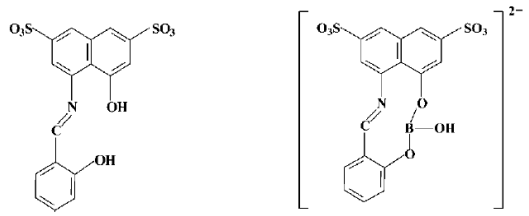

Fig. 1. Complex between boron and improved-azomethine

2.2 Analysis Method

The experiment was performed with multi-wavelengths in the range of 200 to 700 nm, which is UV-Vis spectrometer, and used 2 mm cell. The sample volume contained boron was 2.5 ㎖, color reagent of improved-azomethine was 3 ㎖ of 0.2 g/100 ㎖, and ammonium acetate as a buffer solution used 3 ㎖. The sample contained boron ion, buffer solution, and color reagent are transported to a heating mixer by a digital syringe pump with multi-port valves. After complexion stage in the mixer during 2 min, the absorbance of boron was finally measured at the detector.

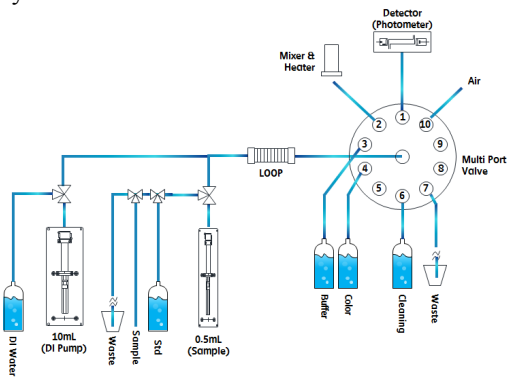

Fig. 2. Flow diagram of the boron analysis using the digital syringe pump

2.3 Linearity Test of 0~200 ppm B

The linearity of absorbance is directly related to the analytic range of boron concentration. Compared to the previously method, the developed color reagent can be determined from 0 to 200 ppm(Fig. 3). The correlation coefficient with single wavelength 376 nm was 0.9990, and multi-wavelengths 378, 416 nm were 0.9994. Based on this result, it was possible to analyze the broad 0~3,000 ppm within the error of ±10 ppm using the precision dilution system together.

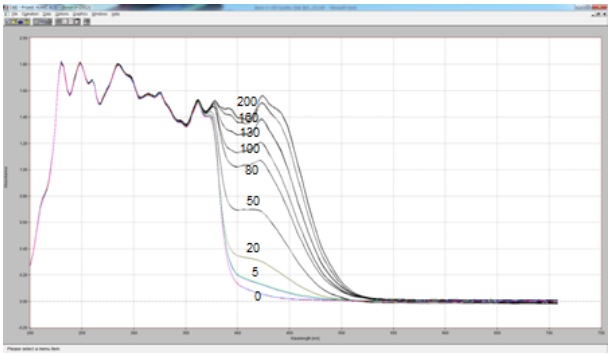

Fig. 3. Spectrum of the boron absorbance at 0~200 ppm

2.4 Precision Dilution System

In order to enhance the field application feasibility, developed monitoring system can be easily maintained with operational convenience for analyzer. In addition, a high precision dilution system, which is based on the extended linearity, must be needed to analyze the wide range. The precision dilution is applied by 0.5 ㎖ and 10 ㎖ precision syringe (Accuracy: Lower than ± 5 ㎕@ 10 ㎖ Full Stroke) It is possible to analyze the boron concentration over a wide range through automatic dilution of the standard solution at regular time intervals, and it is possible to obtain excellent accuracy and repeatability over the wide range measurement range (0~3,000 ppm).

3. Conclusions

The correlation coefficient from 0 to 100 ppm B in the range of 400~430 nm is above 0.9990 by UV-Vis spectrometer. It is expected that the photometer can be applied to this wavelength range as a single wavelength. This will be needed the additional experiments in terms of economics. In the range of 0~200 ppm B, the correlation coefficient showed up to 0.9994 by using spectrometer which is a multi-wavelength. And, a functional equation was a quadratic function.

Since analysis of boron concentration in PWR is directly related to control of the reactor power, the analysis method of extensive concentration of this study is expected to be effective technique in terms of stability of operation and maintenance convenience. In order to have a reliability of development technology based on UV-Vis spectrometer, it is required to carry out repeated experiments in the range of 0~3,000 ppm through the precision dilution system developed.

ACKNOWLEDGMENTS

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