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Viability analysis of employing Ultrasound Technique for boric acid concentration measurement in liquid medium

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Abstract

SMRs (Small Modular Reactors) are pressurized nuclear water-cooled reactors still under development. They may use boric acid solution as an auxiliary control for the core reactivity, demanding the need to characterize boric acid concentrations in reactor vessels noninvasively. The contribution of this work is to analyze the viability of using ultrasound technique to characterize the concentration of boric acid in liquid medium noninvasively. Ultrasonic tests were performed relating different boric acid concentrations with the path time of the ultrasound wave. Factors able to mask the characterization of these concentrations by ultrasound technique were also evaluated. The results showed that this technique allows the characterization of boric acid concentrations in liquid medium under very simple conditions, requiring further studies in complex conditions.

1. Introduction

SMRs (Small Modular Reactors) are designed by using modular technology to minimize outgoings on series production and to allow the construction in a short period of time. Such projects comprise a range of know-how and most of them are variations of the Generation III systems. SMR designs vary in power output, physical dimensions, fuel type, refueling frequency, sitting options and status of development [1]. Some SMRs have a group of principles like the setting of primary system components inside a single vessel (increasing the primary reactor vessel), the providence of a more effective heat removal and the redistribution of components in the vessel, thus favoring core cooling by natural convection. These features use passive safety systems, ensuring the optimization of the installations' safety and the overall economic aspects [2]. Usually, the pressurizer is located at the reactor vessel top in an SMR. This configuration demands variations on the construction of a larger system without any additional costs [3]. Coolant mixing inside nuclear reactor is one of the most important inherent safety mechanisms against power peaks or overcooling transients [4]. Thus, it is indispensable to analyze boron mixing in the pressurizer as a function of flow mechanisms, which are being considered in the development of an integral modular nuclear reactor.

The purpose of this study is to analyze the viability of employing an ultrasound technique to characterize boric acid concentration in liquid medium under the simplest conditions (stationary liquid for a small range of pressure and temperature) and to verify if such technique is sensitive enough to characterize accurately different concentrations of boric acid solutions. This analysis is a pioneer application of ultrasound technique to characterize boric acid concentrations in nuclear reactor vessels at real time, with low cost and in a noninvasively way, sparing on-site manipulation.

2. Methodology

In this chapter, all processes accomplished in the laboratory are presented to analyze the feasibility of measuring boric acid concentration in a stationary liquid according to the following steps: Equipment calibration; Time interval records over varying condition; Ultrasound wave path time in distilled water with temperature variation inside the acrylic box; Ultrasound wave path time in boric acid solution with varying concentrations inside the acrylic box; Ultrasound wave path time in distilled water and saturated boric acid solution in a stainless steel tube with temperature variation; Ultrasound wave path time in boric acid solution with concentrations of 600 ppm and 650 ppm in a stainless-steel tube with temperature variation.

3. Results and Discussion

3.1. Equipment calibration

For the calibration procedure, pulse speed was used instead of path time since the reference speed in distilled water is found in the literature. The other experiments were based on the path time due to the advantage of being unnecessary to know the distance between the transducers, since the difference in concentrations depends on path times. If there is no interference in transducers displacement when liquids are substituted, time differences are the characterization parameters of each concentration for the boric acid solutions, decreasing error propagation.

3.2. Boric acid measurements

The procedure adopted for the saturated boric acid (H3BO3) solution considers only the difference of path times (or speeds) for the two liquids, because the distance separating the transducers and the whole configuration did not change. Boric acid solution, initially at 25°C, was subjected to an identical procedure for distilled water at (20.8$\pm$ 0.1)°C, providing a path time equal to 4.9683×10^{-6}s. A comparison for the average path times is shown in Table 1.

Table 1 – Comparison of path times for distilled water and boric acid

Solution	**Average path time (s)**	**Standard deviation (s)**
Distilled water	5.0124×10^{-6}	1.2396×10^{-9}
Saturated boric acid solution	4.9683×10^{-6}	3.3506×10^{-10}

From Table 1, it can be noticed that there is almost no difference for the path times. Such a short difference may be explained based on physical grounds: when the liquid density increases (saturated solution), the path time decreases due to the shortest distance between the molecules. According to Figure 1, it may be concluded that both liquids present well defined statistical characterization.

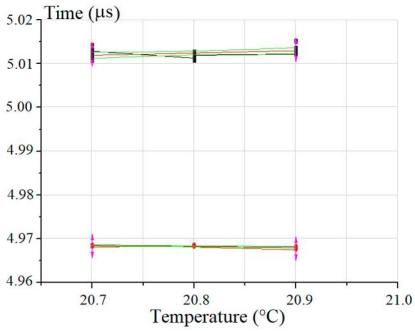

Figure 1 – Comparison of path times as a function of temperature

The results shown in Figure 1 and the statistical analyses accomplished with the *Origin Pro* software indicate, for a 95% confidence interval, well characterized plots for both liquids. Therefore, distilled water and saturated boric acid solution can be differentiated by the ultrasound technique even at the same temperature.

3.3. Path time in boric acid solution with concentrations of 600 ppm and 650 ppm in a stainless-steel tube with temperature variation

This item aims to analyze the measurement sensitivity by using two boric acid concentrations with the same temperature variation. As can be seen from Figure 2, obtained with a 95% confidence interval to estimate the data linearity, there are different plots, implying a characterization as function of concentration. The linear regression data are shown in Table 2.

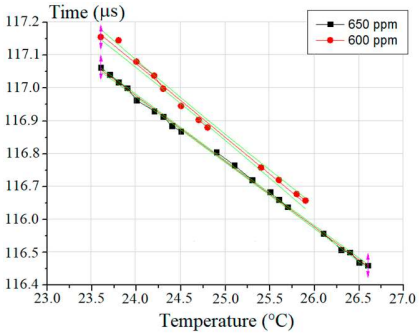

Figure 2 – Time dependence for varying temperature in distilled water and saturated boric acid solution.

Table 2 – Statistical results of linear regression and adjusted angular and linear coefficients

Equation	y = a + bx		
Boric acid concentrations	**Value**	**Standard deviation**	**Adj. R-Square**
650 ppm	a 1.22×10^{-4} (s)	3.87×10^{-8} (s)	0.999
	b -1.99×10^{-9} (s/°C)	1.55×10^{-9} (s/°C)	
600 ppm	a 1.22×10^{-4} (s)	1.27×10^{-7} (s)	0.994
	b -2.23×10^{-7} (s/°C)	5.014×10^{-9} (s/°C)	

The results demonstrate that both temperature and distance traveled by the signal interfere significantly in the ultrasonic pulse path time and, therefore, in the characterization of the analyzed liquid concentrations, in a perfect agreement with surveys carried out by [5] when studying hydrochloric acid, sulfuric acid and a sodium chloride solution.

4. Conclusions

Distilled water and saturated boric acid solution can be characterized by the ultrasound technique if the same operational conditions are maintained. Small temperature variations about 20°C exhibit a linear behavior for the concentration curves in boric acid solutions.

When the temperature was kept constant, it was possible to distinguish by ultrasound technique distilled water from boric acid solutions with concentrations of 100 ppm, 400 ppm and 1,000 ppm. However, results indicate that the increase in concentrations does not vary linearly with path time.

Boric acid solutions may be characterized for different concentrations with a reading limit of 50 ppm among concentrations and a 95% confidence interval. The hypothesis of more accurate readings is not discarded, since it has been observed that the greater the distance traveled by the ultrasonic pulse, the better is the sensitivity to differentiate the curves of concentrations.

Crossing through the metallic wall has just attenuated the pulse energy, originating a signal with less amplitude, but it did not interfere the path time for characterizing solutions with different concentrations, since the distance traveled, temperature and impurity control were maintained unchanged during the whole process, and for the case of temperature variation, the same interval was maintained for different concentrations.

The aim of analyzing the viability of employing the ultrasound technique to characterize boric acid was achieved, and even for especial conditions, it was demonstrated that it is possible to define the concentration of boric acid within a metallic tube by using a noninvasive technique, with an accuracy of 50 ppm and a 95% confidence interval.

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References

[1] Carelli, M.D., Garrone, P., Locatelli, G., Mancini, M., Mycoff, C., Trucco, P., Ricotti, M.P., 2010. Economic features of integral, modular, small-to-medium size reactors. Prog. Nuc. Energy J. 52, 403-414.

[2] Ferri, R., Achilli, A., Cattadori, G., Bianchi, F., Luce, A., Monti, S., Meloni, P., Ricotti. M.E., 2012. SPES-3: the integral facility for safety on small and medium sized reactors. In: European National Conference, Manchester, United Kingdom, 9-12, December 2012.

[3] Barroso, A.C.O., Baptista, B.D., Arone, F.I.D., Macedo, L.A., Sampaio, P.A.B., Moraes, M., 2003. IRIS pressurizer design. In: Proceedings of the International Congress on Advances in Nuclear Power Plants ICAPP'03, Cordoba, Spain, 4–7 May 2003.

[4] Rohde, U., Höhne, T., Kliem, S., Hemström, B., Scheuerer, M., Toppila, T., Aszodi. A., Boros, I., Farkas, I., Mühlbauer, P., Vyscocil, L., Klepac, J., Remis, J., Dury, T. 2007. Fluid mixing and flow distribution in a primary circuit of a nuclear pressurized water reactor – validation of CFD codes. Nucl. Eng. Des. 237, 1639-1655.

[5] Weerstra, D. D. On line rolling oil and picking acid concentration measurement using ultrasonics, R & D Chemist – Mesa Laboratories, Inc., NuSonics Division, 2003.