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# A simple model for the refractive index of sodium iodide aqueous solutions

**T. L. Narrow, M. Yoda, S. I. Abdel-Khalik**



**Abstract** A model for predicting the refractive index of sodium iodide (NaI) aqueous solution $n_{NaI}$ as a function of temperature $T$, NaI concentration $c$ and wavelength $\lambda$ was determined for moderate parameter variations. The equation accurately predicted the salt concentration required to match $n_{NaI}$ to the refractive index of Pyrex $n_P$.

## 1
## Introduction

Over the last two decades, nonintrusive optical diagnostic techniques for obtaining quantitative experimental flow data have become standard. These techniques require optical access to both illuminate and image the flow; all solid surfaces in the region of interest must therefore be refractive index-matched to the working fluid to obtain accurate, undistorted images. Budwig (1994) (among others) tabulates the refractive index of several transparent solids and liquids. A commonly used working fluid with adjustable refractive index is an aqueous solution of NaI. Kadambi et al. (1988) used an index-matched mixture of silica gel particles (refractive index 1.443) and 50% NaI solution to model coal–water slurries; by varying $c$ from 0–60% and $T$ from 20–40°C, they obtained $1.33 \leqslant n_{NaI} \leqslant 1.487$.

An aqueous NaI solution was used to study the flow in microchannels within a horizontal Pyrex seven-rod fuel bundle (rod diameters $D = 0.318$ cm spaced at a pitch-to-diameter ratio of 1.15 in a 1.064 cm ID circular housing) similar to those used in the Accelerator Production of Tritium design (Narrow 1998). Nonintrusive optical techniques were the only possibility for measuring velocity profiles in the narrow dimensions (hydraulic diameter $D_h \approx 1$ mm) of the microchannels.

For light passing through a circular rod of diameter $D$ and refractive index $n + \Delta n$ ($\Delta n \ll n$) immersed in a fluid with refractive index $n$, geometry and Snell's Law give that the angular deviation of the light ray $\delta$ is twice the difference between the angles of incidence $\theta_i$ and transmission $\theta_t$: $\delta = 2|\theta_t - \theta_i|$, where $\sin\theta_i = [1 + (\Delta n/n)] \sin\theta_t$. The maximum angular deviation per rod (note that a typical light ray passes through two or three rods in the seven-rod bundle) is 3° for $\Delta n/n = 0.005$ and $\theta_i = 70°$.

To ensure good optical access throughout the rod bundle, the indices of refraction of the working fluid and rod bundle were matched within the measurement error of 0.3%. Over several days of experiments, changes in $T$ due to ambient temperature fluctuations, variations in $c$ due to evaporation and changes in $\lambda$ from using different light sources (e.g. argon-ion lasers and white strobe lights), all changed the refractive index of the solution. A simple model to predict these changes, based partially upon the results of Kadambi et al. (1988), was therefore developed.

## 2
## Experimental results

The index of refraction of NaI solution, $n_{NaI}$, depends on ($T$, $c$, $\lambda$). An Abbe refractometer (Bellingham & Stanley Model 60/HR) was used to measure $n_{NaI}$ for $T = 20$–35°C, $c = 55$–58.5%, and $\lambda = 589.3$ nm (the sodium D line) and 632.8 nm (helium-neon laser wavelength). The solutions contained 0.1% (w/w) sodium thiosulfate ($Na_2S_2O_3$) to avoid discoloration due to $I_3^-$ formation.

$n_{NaI}$ varies linearly with $T$ over a moderate range of temperatures, and increases with $c$ (Kadambi et al. 1988). Based on these results and the Cauchy dispersion relation, which gives $\Delta n(\lambda) \propto \lambda^{-2}$ (Pedrotti and Pedrotti 1987), the experimental data, along with Kadambi's results, were curve-fit with linear regression to the following equation:

$$n_{NaI}(T, c, \lambda) = 1.252 - (2.91 \times 10^{-4}\,{}^\circ\mathrm{C}^{-1})\,T + (0.365)\,c + (5542\ \mathrm{nm}^2)\,\lambda^{-2}. \qquad (1)$$

Eq. (1) fits all the data with a standard error of $8 \times 10^{-4}$ and a regression coefficient $R^2 = 0.996$.

Figure 1 shows $n_{NaI}(T)$: experimental data (points) and model predictions from Eq. (1) (lines) at $c = 57\%$ for $\lambda = 589.3$ and 632.8 nm are presented along with the Kadambi's data at $c = 47\%$, 51%, and 55% for $\lambda = 589.3$ nm. Figure 2 shows $n_{NaI}(c)$; data (points) and predictions (lines) are shown at $T = 20$°C for $\lambda = 589.3$ and 632.8 nm and at $T = 25$°C, 30°C and 35°C for $\lambda = 589.3$ nm (Ka88). The experimental data presented here are averages over several measurements and have a standard deviation of about $5 \times 10^{-3}$.

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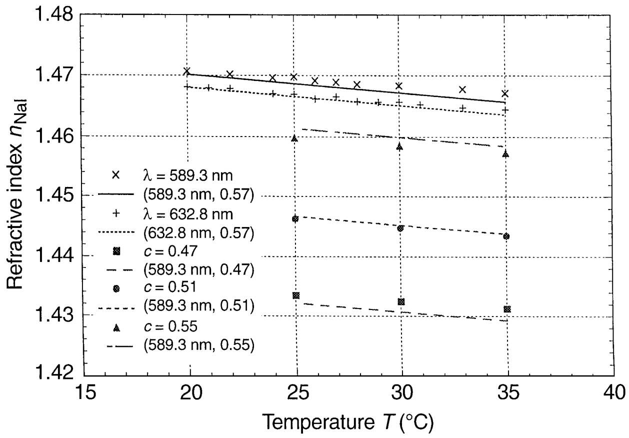


**Fig. 1.** Plot of $n_{\mathrm{NaI}}$ vs. $T$. Our experimental data for $c = 0.57$ are denoted by the symbols ( ×, + ). The Kadambi et al. (1988) data at $\lambda = 589.3$ nm are denoted by filled symbols (■, ●, ▲). The model predictions from Eq. 1 are plotted as lines; the legend gives the ($\lambda$, $c$) values for each line

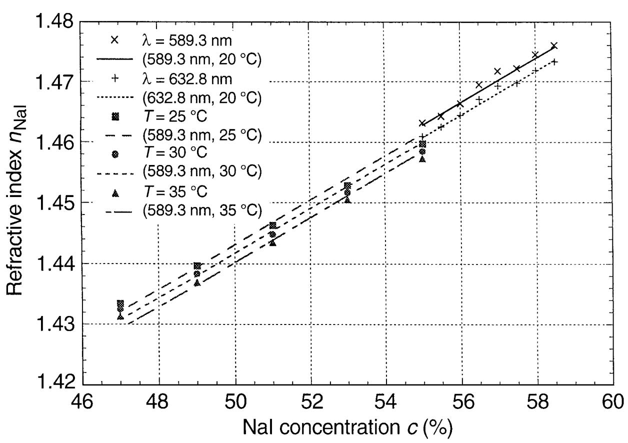


**Fig. 2.** Plot of $n_{\mathrm{NaI}}$ vs. $c$. Our experimental data at $T = 20°$C are denoted by the symbols ( ×, + ). The Kadambi data at $\lambda = 589.3$ nm are denoted by filled symbols (■, ●, ▲). The model predictions from Eq. 1 are plotted as lines; the legend gives the ($\lambda$, $T$) values for each line

This model was used to determine the concentration required to match $n_{\mathrm{NaI}}$ to $n_{\mathrm{P}}$ within a horizontal seven-rod micro-bundle. Using the same Abbe refractometer, $n_{\mathrm{P}}$ was found to be 1.47 over our $T$ and $\lambda$ ranges. Eq. (2) at the experimental conditions – the desired $n_{\mathrm{NaI}}$ value of 1.47 ($= n_{\mathrm{P}}$), $T = 21°$C, and $\lambda = 514$ nm – gave a $c$ of 54.5%. For $c = 0.545$, the solution index-matched the Pyrex rod bundle within the measurement error of 0.005 or a refractive index mismatch of 0.3%, even at a $\lambda$ significantly less than those used to calibrate the model.

## 3
## Conclusions

A simple model has been developed from experimental measurements for predicting $n_{\mathrm{NaI}}(T, c, \lambda)$ over parameter ranges typical of ambient conditions. The model was used to predict the concentration required to match the refractive index of solid Pyrex; the 54.5% NaI solution given by the model matched $n_{\mathrm{P}}$ to within $5 \times 10^{-3}$. This model gives us the capability to "tune" (by adjusting $c$, for example) $n_{\mathrm{NaI}}$ to match several transparent plastics and glasses over a commonly used range of temperatures and wavelengths.

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