Water refractive index in dependence on temperature and wavelength: A simple approximation

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ABSTRACT

Water is the most important biological liquid. On the basis of literature data we present a simple approximation of water refractive index in dependence on temperature and wavelength in the spectral range from 200 to 1000 nm. The approximation is important for different applications in biomedical optics and optics of tissues.

Keywords: water refractive index, wavelength dependence, temperature dependence

1. INTRODUCTION

Water is the most important liquid of human organism. It is the main component of interstitial fluid, plasma of blood, intercellular fluid, etc. Knowledge of optical properties of water is very important for solution of problems of biomedical optics. In particular, wavelength dependence of the refractive index determines spectral dependence of refractive index of tissue interstitial fluid that in its turn defines the wavelength dependence of scattering properties of tissues. Furthermore, water refractive index depends on temperature.

The wavelength dependence of the water refractive index is presented in literature[1,2]. Wavelength dependence of water in visible and near-infrared spectral ranges has been presented as an Eq. 1[1], where λ is wavelength, nm. In near-UV, visible and near-infrared spectral ranges wavelength dependence of water refractive index can be described by Eq. 2[2]. Unfortunately, these dependencies have been obtained for temperature 20 ^{0}C. At the same time, temperature of interstitial fluid is about 37 ^{0}C.

$$n(\lambda) = 1.3199 + \frac{6878}{\lambda^2} - \frac{1.132 \cdot 10^9}{\lambda^4} + \frac{1.11 \cdot 10^{14}}{\lambda^6}, \tag{1}$$

$$n(\lambda) = 1.31848 + \frac{6.662}{\lambda[nm] - 129.2}. \tag{2}$$

Taking into account the temperature dependence of water refractive index is very important for biomedical optics. Therefore, the goal of this study is obtaining the water refractive index in dependence on temperature and wavelength.

2. MATERIALS AND METHODS

As initial data for the construction of approximation dependencies we have used data presented in Ref. 3 (see Table 1). These data show that water refractive index decreases with increase both wavelength and temperature.

For approximation of the presented data, we have used Cauchy formula with temperature-dependent coefficients (see Eq. 3). Approximation procedure has been performed with a curve fitting system for Windows (CurveExpert, Ver. 1.34, Copyright by Daniel Hyams, 1995-1997). The Cauchy coefficients have been approximated by polynomial dependence 3-rd degree. They are presented below (see Eqs. 4-7).

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$$n(\lambda,t)=A(t)+\frac{B(t)}{\lambda^2}+\frac{C(t)}{\lambda^4}+\frac{D(t)}{\lambda^6}, \quad (3)$$

where λ is wavelength, nm; and $A(t)$, $B(t)$, $C(t)$, $D(t)$ are the Cauchy coefficients presented as a function of temperature; t is temperature, ^{0}C.

Table 1. The water refractive index in dependence on temperature and wavelength[3].

Temperature, ^0C	***Wavelength***					
	226.5 *nm*	**361.05 *nm***	**404.41 *nm***	**589 *nm***	**632.8 *nm***	**1013.98 *nm***
0	1.3945	1.34896	1.34415	1.33432	1.33306	1.32612
10	1.39422	1.3487	1.34389	1.33408	1.33282	1.32591
20	1.39336	1.34795	1.34315	1.33336	1.33211	1.32524
30	1.39208	1.34682	1.34205	1.3323	1.33105	1.32424
40	1.39046	1.3454	1.34065	1.33095	1.32972	1.32296
50	1.38854	1.34373	1.33901	1.32937	1.32814	1.32145
60	1.38636	1.34184	1.33714	1.32757	1.32636	1.31974
70	1.38395	1.33974	1.33508	1.32559	1.32438	1.31784
80	1.38132	1.33746	1.33284	1.32342	1.32223	1.31576
90	1.37849	1.33501	1.33042	1.32109	1.31991	1.31353
100	1.37547	1.33239	1.32784	1.31861	1.31744	1.31114

Relative error has been obtained from following relationship: $\varepsilon=\frac{|n_{table}-n_{calc}|}{n_{table}}$, where n_{table} is water refractive index presented in Table 1, and n_{calc} is water refractive index calculated with our approximation.

3. RESULTS AND DISCUSSION

Using the data presented in Table 1 we have approximated spectral dependence of water refractive index by the Cauchy formula for each temperature. Obtained coefficients are presented in Table 2.

Table 2. The Cauchy coefficients obtained from calculations.

Temperature, ^0C	***A***	***B***	$C\times10^8$	***D***	***Mean relative error*** $\times10^{-4}$
0	1.32074	5207.924	-2.55522	9.35006	7.5467
10	1.32051	5200.71	-2.55787	9.37275	7.46308
20	1.31984	5190.553	-2.56169	9.39388	7.45798
30	1.31885	5173.8657	-2.56817	9.43261	7.37812
40	1.3176	5154.7658	-2.5756	9.47474	7.50379
50	1.31609	5134.0393	-2.58372	9.51384	7.3477
60	1.31438	5109.635	-2.59321	9.56139	7.27287
70	1.31249	5083.2735	-2.60364	9.61276	7.12462
80	1.31044	5057.2226	-2.61394	9.65879	7.2006
90	1.30821	5028.0151	-2.62537	9.71071	7.0504
100	1.30587	4997.0391	-2.63769	9.76828	7.17674

Using coefficients presented in Table 2 we have obtained temperature dependence of each coefficient (see Eq. 4-7).

$$A(t) = 1.3208 - 1.2325 \cdot 10^{-5} t - 1.8674 \cdot 10^{-6} t^2 + 5.0233 \cdot 10^{-9} t^3 \quad (4)$$

$$B(t) = 5208.2413 - 0.5179t - 2.284 \cdot 10^{-2} t^2 + 6.9608 \cdot 10^{-5} t^3 \quad (5)$$

$$C(t) = -2.5551 \cdot 10^8 - 18341.336t - 917.2319t^2 + 2.7729t^3 \quad (6)$$

$$D(t) = 9.3495 + 1.7855 \cdot 10^{-3} t + 3.6733 \cdot 10^{-5} t^2 - 1.2932 \cdot 10^{-7} t^3 \quad (7)$$

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