https://doi.org/10.15407/cryo25.02.131
оригинальное исследование research article

УДК 547.42:537.226.1/.2

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Теплофизические свойства криопротекторов.
VIII. Диэлектрическая проницаемость ряда криопротекторов, их водных растворов и смесей

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Thermophysical Properties of Cryoprotectants.
VIII. Dielectric Permeability of Some Cryoprotectants, Their Aqueous Solutions and Mixtures

Реферат: Систематизированы литературные данные по статической диэлектрической проницаемости воды, чистых криопротекторов, их водных растворов и смесей. Построены эмпирические полиномиальные уравнения для расчета статической диэлектрической проницаемости воды и чистых криопротекторов в зависимости от температуры. Для водных растворов и смесей некоторых криопротекторов получены эмпирические полиномиальные уравнения в зависимости от температуры при фиксированных концентрациях или от концентрации при фиксированных температурах.

Ключевые слова: криопротектор, статическая диэлектрическая проницаемость, эмпирические полиномиальные уравнения.

Реферат: Систематизовано літературні дані зі статичної діелектричної проникності води, чистих кріопротекторів, їх водних розчинів і сумішей. Побудовано емпіричні поліноміальні рівняння для розрахунку статичної діелектричної проникності води і чистих кріопротекторів в залежності від температури. Для водних розчинів і сумішей деяких кріопротекторів отримано емпіричні поліноміальні рівняння в залежності від температури при фіксованих концентраціях або від концентрації при фіксованих температурах.

Ключові слова: кріопротектор, статична діелектрична проникність, емпіричні поліноміальні рівняння.

Abstract: There were summarised the reported data on static dielectric permeability for water, pure cryoprotectants, their aqueous solutions and mixtures. The empirical polynomial equations to calculate static dielectric permeability for water and pure cryoprotectants depending on temperature were derived. The empirical polynomial equations for aqueous solutions and mixtures of some cryoprotectants depending on either the temperature at fixed concentrations or the concentration at fixed temperatures were obtained.

Key words: cryoprotectant, static dielectric permeability, empirical polynomial equations.

Диэлектрическая проницаемость – физическая величина, которая характеризует свойства изолирующей (диэлектрической) среды и показывает зависимость электрической индукции от напряженности электрического поля. Она определяется эффектом поляризации диэлектриков под действием электрического поля и величиной диэлектрической восприимчивости среды.

Любая среда уменьшает напряженность электрического поля по сравнению с вакуумом. Диэлектрическая проницаемость показывает, во сколько раз электрическое поле в диэлектрике меньше электрического поля в вакууме, и дает возможность судить об интенсивности процессов

Dielectric permeability is the physical quantity, characterizing properties of isolating (dielectric) medium and demonstrating the dependency of dielectric flux density on electric field intensity. It is determined by the polarizaton effect of dielectrics under the impact of electric field and by characterizing this effect value of dielectric susceptibility of medium.

Any medium reduces the electric field intensity if compared to the vacuum. Dielectric permeability shows in which extent a electric field in a dielectrics is lower than in the vacuum and enables judging about the intensity of polarization processes and the quality of dielectric. The dielectric polarization is determined by the total effect of different polarization mechanisms.

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Поступила 16.09.2014
Принята в печать 02.10.2014

Received September, 16, 2014
Accepted October, 02, 2014

поляризации и качестве диэлектрика. Поляризация диэлектрика определяется суммарным действием различных механизмов поляризации. По температурной и частотной зависимости диэлектрической проницаемости можно получить информацию о механизмах поляризации и их относительном вкладе в поляризацию диэлектрика. Возрастание диэлектрической проницаемости приводит к росту электропроводности.

Цель работы – обобщение и систематизация литературных данных на основе построения эмпирических формул для расчета значений статической диэлектрической проницаемости чистых криопротекторов, их водных растворов и смесей в зависимости от массовой концентрации криопротектора и температуры.

Экспериментальные результаты по статической диэлектрической проницаемости криопротекторов, водных растворов и смесей, приведенные в литературе, были обработаны с помощью программы «Excel 2003» («Microsoft», США). Наряду с данными для криопротекторов были обработаны и экспериментальные литературные данные для воды, льда и ряда растворов веществ, которые важны как для жизнедеятельности человека, так и для криобиологии.

В таблицах концентрации приведены в массовых процентах для вещества, указанного первым.

В таблицах приняты следующие условные обозначения:

БД – бутандиол,
БСА – бычий сывороточный альбумин,
ДМАц – диметилацетамид,
ДМСО – диметилсульфоксид,
ДМФА – диметилформамид,
ДЭГ – диэтиленгликоль,
М – молярность,
МАц – метилацетамид,
МФА – метилформамид,
ПВП – поливинилпирролидон,
ПД – пропандиол,
ПЭГ – полиэтиленгликоль,
ТЭГ – триэтиленгликоль,
ФА – формамид,
ХФ – хлороформ,
ЭГ – этиленгликоль,
ж. ф. – жидкая фаза,
тв. ф. – твердая фаза.

Temperature and frequency dependencies of dielectric permeability contain information about polarization mechanisms and their relative contribution into dielectric polarization. The increase in dielectric permeability results in rise of electric conductivity.

The research aim was to summarize and systematize the reported data, using the derived empirical formulae to calculate the values of static dielectric permeability for pure cryoprotectants, their aqueous solutions and mixtures depending on cryoprotectant mass concentration and temperature.

Collected published experimental data on static dielectric permeability for cryoprotectants, aqueous solutions and mixtures were processed with Excel 2003 software (Microsoft, USA). Along with the data for cryoprotectants we also processed the published experimental findings for water, ice and some solutions of substances, important for both human vital activity and cryobiology.

The Tables show concentrations in mass percentage for the substance mentioned first.

The following abbreviations are assumed in the Tables:

BD – butanediol,
BSA – bovine serum albumin,
CF – chloroform,
DMAc – dimethylacetamide,
DMSO – dimethyl sulfoxide,
DMFA – dimethylformamide,
DEG – diethylene glycol,
EG – ethylene glycol,
FA – formamide,
MAc – methylacetamide,
MFA – methylformamide,
PVP – polyvinylpyrrolidone,
PD – propanediol,
PEG – polyethylene glycol,
TEG – triethylene glycol,
l. p. – liquid phase,
s. p. – solid phase.

Таблица 1. Уравнения для расчета статической диэлектрической проницаемости чистых веществ в зависимости от температуры; дисперсии аппроксимаций и диапазоны температур применения уравнений

Table 1. Equations to calculate static dielectric permeability for pure substances depending on temperature; dispersions of approximations and temperature ranges of equation application

Вещество Substance	Уравнение Equation	R^2	Диапазон температур, °C Temperature range, °C	Источник	References
Вода, ж. ф. Water, l. p.	$\varepsilon = -9{,}712\times10^{-7}t^3 + 8{,}777\times10^{-4}t^2 - 0{,}4029t + 87{,}99$	0,9995	–40...370	[2, 10, 11, 15, 17, 23–25, 36, 37, 39, 40, 43, 54, 64 –66, 71, 78, 80, 96, 99, 103, 106]	[2, 3, 7, 9, 15–17, 28, 29, 31, 32, 35, 46, 58, 60, 61, 66, 75, 77, 93, 94, 97, 101, 104]
Вода, тв. ф. (лед) Water, s.p. (ice)	$\varepsilon = 2{,}8\times10^{-3}t^2 - 0{,}3076t + 93{,}8$	0,9945	–123...0	[14, 19, 36, 43, 54]	[4, 11, 28, 35, 46]
1,2-БД 1,2-BD	$\varepsilon = -0{,}1366t + 25{,}913$	0,9963	5...50	[2, 36]	[2, 28]
1,3-БД 1,3-BD	$\varepsilon = -1{,}317\times10^{-6}t^3 + 7{,}075\times10^{-4}t^2 - 0{,}1993t + 33{,}48$	0,9979	–28...150	[2, 4, 36]	[2, 28, 106]
1,4-БД 1,4-BD	$\varepsilon = 4{,}095\times10^{-4}t^2 - 0{,}1933t + 35{,}66$	0,9973	15...150	[2, 4, 9, 66]	[2, 61, 69, 106]
2,3-БД 2,3-BD	$\varepsilon = 2{,}351\times10^{-4}t^2 - 0{,}1144t + 23{,}69$	0,9992	10...150	[4, 103]	[101, 106]
1,2-ПД 1,2-PD	$\varepsilon = 2{,}159\times10^{-8}t^4 - 6{,}459\times10^{-6}t^3 + 9{,}836\times10^{-4}t^2 - 0{,}2017t + 34{,}0$	0,9965	–90...150	[2, 6, 16, 25, 26, 29, 34, 89, 92]	[2, 8, 17, 18, 21, 26, 53, 86, 89]
1,3-ПД 1,3-PD	$\varepsilon = 2{,}578\times10^{-6}t^3 + 2{,}844\times10^{-4}t^2 - 0{,}2024t + 39{,}18$	0,9978	–30...100	[36, 103]	[28, 101]
Ацетамид Acetamide	$\varepsilon = -2{,}249\times10^{-3}t^2 + 0{,}3312t + 55{,}97$	0,9994	91...175	[2, 36]	[2, 28]
Глицерин, ж. ф. Glycerol, l. p.	$\varepsilon = 5{,}134\times10^{-4}t^2 - 0{,}2663t + 48{,}61$	0,9933	–78...100	[2, 9, 25, 34, 35, 37, 61, 91, 93, 96, 103]	[2, 17, 26, 27, 29, 55, 69, 88, 90, 94, 101]
Глицерин, тв. ф. Glycerol, s. p.	$\varepsilon = 7{,}21\times10^{-4}t^3 + 0{,}1055t^2 + 5{,}207t + 91{,}58$	0,9997	–53...–13	[16]	[8]
	$\varepsilon = 1{,}183\times10^{-3}t^3 - 0{,}03185t^2 - 0{,}06638t + 47{,}12$	1,0	–13...17		
ДМАц DMAc	$\varepsilon = 6{,}584\times10^{-4}t^2 - 0{,}2495t + 44{,}3$	0,9912	–15...160	[2, 5, 36, 37, 53, 91, 103]	[2, 28, 29, 45, 47, 88, 101]
ДМСО DMSO	$\varepsilon = 2{,}966\times10^{-6}t^4 - 5{,}444\times10^{-4}t^3 + 3{,}527\times10^{-2}t^2 - 1{,}071t + 58{,}54$	0,993	10...70	[26, 35, 37, 93, 100, 103]	[18, 28, 29, 90, 98, 101]
ДМФА DMFA	$\varepsilon = -1{,}726\times10^{-6}t^3 + 8{,}004\times10^{-4}t^2 - 0{,}2114t + 42{,}12$	0,9953	–60...145	[2, 5, 9, 36, 103]	[2, 28, 47, 69, 101]
ДЭГ DEG	$\varepsilon = 1{,}09\times10^{-4}t^2 - 0{,}2042t + 36{,}04$	0,9942	–20...100	[2, 5, 36, 40, 70, 92]	[2, 28, 32, 47, 65, 89]
МАц MAc	$\varepsilon = -1{,}213\times10^{-5}t^3 + 7{,}393\times10^{-3}t^2 - 1{,}896t + 22{,}88$	0,9994	25...200	[2, 26, 36, 56]	[2, 18, 28, 49]
Метанол Methanol	$\varepsilon = -3{,}978\times10^{-6}t^3 + 1{,}045\times10^{-3}t^2 - 0{,}2309t + 37{,}39$	0,9946	–110...140	[2, 3, 5, 9, 23, 25, 27, 36, 38, 39, 49, 57, 66, 79, 80, 103]	[2, 15, 17, 19, 28, 30, 31, 41, 47, 50, 61, 69, 76, 77, 101, 105]
МФА MFA	$\varepsilon = 2{,}191\times10^{-6}t^3 + 7{,}628\times10^{-3}t^2 - 1{,}909t + 221{,}2$	0,991	–40...80	[2, 5, 36, 37, 103]	[2, 28, 29, 47, 101]
ПЭГ-1000 (тв. ф.) PEG-1000 (s. p.)	$\varepsilon = 6{,}429\times10^{-6}t^3 + 6{,}495\times10^{-4}t^2 + 0{,}04147t + 4{,}548$	0,9737	–70...30	[58]	[51]
ПЭГ-600 PEG-600	$\varepsilon = -6{,}3\times10^{-5}t^3 + 7{,}398\times10^{-3}t^2 - 0{,}2779t + 14{,}03$	0,9683	10...60	[58,86]	[51,83]

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Продолжение таблицы 1
Table 1. (Continued)

Вещество Substance	Уравнение Equation	R^2	Диапазон температур, °C Temperature range, °C	Источник	References
ПЭГ-400 PEG-400	$\varepsilon = 4{,}153\times10^{-4}t^2 - 0{,}1371t + 16{,}21$	0,9881	0...25	[86]	[83]
ПЭГ-300 PEG-300	$\varepsilon = 5{,}386\times10^{-4}t^2 - 0{,}132t + 17{,}5$	0,9817	0...25	[62, 86, 94]	[56, 83, 91]
ПЭГ-200 PEG-200	$\varepsilon = 5{,}524\times10^{-4}t^2 - 0{,}1639t + 23{,}79$	0,9749	4...25	[86, 94]	[83, 91]
ТЭГ TEG	$\varepsilon = 4{,}273\times10^{-4}t^2 - 0{,}1429t + 26{,}27$	0,9955	–20...60	[2, 5, 36]	[2, 28, 47]
Фенол Phenol	$\varepsilon = 2{,}656\times10^{-4}t^2 - 0{,}1034t + 15{,}38$	0,9954	4...160	[2, 36, 39]	[2, 28, 31]
Формамид Formamide	$\varepsilon = 7{,}988\times10^{-5}t^2 - 0{,}4343t + 119{,}4$	0,994	0...65	[2, 36, 103]	[2, 28, 101]
Хлороформ (тв. ф.) Chloroform (s. p.)	$\varepsilon = 5{,}78\times10^{-5}t^2 - 0{,}01432t + 3{,}318$	0,9689	–149...–70	[2, 79]	[2, 76]
Хлороформ Chloroform	$\varepsilon = 3{,}932\times10^{-5}t^2 - 0{,}01923t + 5{,}192$	0,9942	–70...180	[2, 25, 39, 66, 79]	[2, 17, 31, 61, 76]
Этанол Ethanol	$\varepsilon = 1{,}967\times10^{-8}t^4 - 4{,}341\times10^{-6}t^3 + 4{,}219\times10^{-4}t^2 - 0{,}1532t + 27{,}9$	0,9955	–143...160	[2, 5, 9, 24, 25, 36, 55, 57, 71, 79, 94, 103]	[2, 16, 17, 28, 47, 48, 50, 66, 69, 76, 91, 101]
ЭГ EG	$\varepsilon = 4{,}646\times10^{-4}t^2 - 0{,}2323t + 46{,}34$	0,9965	–20...150	[2, 25, 26, 36, 39, 40, 72, 80, 89, 93, 100]	[2, 17, 18, 28, 31, 32, 68, 77, 90, 98]

Таблица 2. Уравнения для расчета статической диэлектрической проницаемости растворов криопротекторов в зависимости от концентрации криопротекторов при фиксированной температуре; дисперсии аппроксимаций и диапазоны концентраций применения уравнений

Table 2. Equations to calculate static dielectric permeability for cryoprotective solutions depending on cryoprotectant concentration at a fixed temperature; dispersions of approximations and temperature ranges of equation application

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
1,2-ПД – вода 1,2-PD – water	25	$\varepsilon = -1{,}017\times10^{-3}C^2 - 0{,}3745C + 78{,}45$	0,9995	0...100	[26, 29, 103]	[18, 21, 101]
1,3-БД – вода 1,3-BD – water	25	$\varepsilon = -0{,}4971C + 78{,}45$	0,9999	0...100	[4, 6, 36, 76]	[28, 53, 73, 106]
$CaCl_2$-вода $CaCl_2$-water	25	$\varepsilon = -2{,}655\times10^{-3}C^3 + 0{,}168C^2 - 3{,}518C + 78{,}45$	0,9999	0...34	[1]	[1]
KCl-вода KCl-water	15	$\varepsilon = 0{,}7132C^2 - 3{,}6749C + 82{,}14$	0,99	0...2	[1]	[1]
	20	$\varepsilon = -1{,}6146C + 80{,}28$	0,9931	0...7	[47]	[39]
	25	$\varepsilon = -1{,}4552C + 78{,}45$	0,9901	0...14	[1, 51]	[1, 43]
	35	$\varepsilon = -1{,}7592C + 74{,}92$	0,9976	0...4	[1]	[1]
NaCl-вода NaCl-water	0	$\varepsilon = 6{,}723\times10^{-2}C^2 - 3{,}675C + 87{,}99$	0,9975	0...25	[1, 101]	[1, 99]
	1,5	$\varepsilon = 7{,}458\times10^{-2}C^2 - 3{,}398C + 87{,}39$	0,9939	0...25	[1, 51]	[1, 43]
	3	$\varepsilon = 6{,}957\times10^{-2}C^2 - 2{,}762C + 86{,}79$	0,991	0...5	[1]	[1]

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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
NaCl-вода NaCl-water	5	$\varepsilon = 3{,}152 \times 10^{-2}C^2 - 2{,}689C + 86{,}0$	0,9997	0...24	[48]	[40]
	10	$\varepsilon = 5{,}206 \times 10^{-2}C^2 - 3{,}399C + 84{,}05$	0,9984	0...16	[1]	[1]
	20	$\varepsilon = 3{,}156 \times 10^{-2}C^2 - 2{,}33C + 80{,}28$	0,9975	0...24	[48, 59]	[40, 52]
	25	$\varepsilon = 3{,}1 \times 10^{-2}C^2 - 2{,}273C + 78{,}45$	0,9952	0...25	[1, 32, 33, 48, 101]	[1, 24, 25, 40, 99]
	30	$\varepsilon = 3{,}941 \times 10^{-2}C^2 - 2{,}584C + 76{,}67$	0,9931	0...25	[1, 51, 101]	[1, 43, 99]
	35	$\varepsilon = 4{,}005 \times 10^{-2}C^2 - 2{,}222C + 74{,}92$	0,9985	0...24	[48]	[40]
	40	$\varepsilon = 3{,}705 \times 10^{-2}C^2 - 2{,}862C + 73{,}22$	0,9998	0...16	[1, 21]	[1, 13]
	50	$\varepsilon = 8{,}034 \times 10^{-2}C^2 - 3{,}057C + 69{,}92$	0,9955	0...11	[101]	[99]
NaCl-глицерин NaCl-glycerol	-35,5	$\varepsilon = -1{,}249 \times 10^{-3}C^3 - 0{,}06069C^2 - 1{,}181C + 58{,}71$	0,9855	0...29	[1]	[1]
Аланин-вода Alanine-water	25	$\varepsilon = 0{,}1123C^3 - 1{,}592C^2 + 8{,}226C + 78{,}45$	1,0	0...9	[28]	[20]
	30	$\varepsilon = 2{,}815 \times 10^{-2}C^3 - 0{,}3331C^2 + 3{,}654C + 76{,}67$	0,9974	0...9		
	35	$\varepsilon = 2{,}184 \times 10^{-2}C^3 - 0{,}3042C^2 + 3{,}843C + 74{,}92$	0,9949	0...9		
	40	$\varepsilon = 6{,}793 \times 10^{-2}C^3 - 1{,}018C^2 + 5{,}871C + 73{,}22$	0,9878	0...9		
БСА-вода BSA-water	25	$\varepsilon = -4{,}507 \times 10^{-2}C^4 + 0{,}432C^3 - 1{,}5C^2 + 1{,}362C + 78{,}45$	0,9959	0...5	[12]	[4]
Галактоза-вода Galactose-water	5	$\varepsilon = -1{,}867 \times 10^{-3}C^2 - 0{,}1623C + 86{,}0$	0,997	0...18	[1, 31]	[1, 23]
	10	$\varepsilon = -1{,}958 \times 10^{-3}C^2 - 0{,}1536C + 84{,}05$	0,9949	0...18		
	15	$\varepsilon = -2{,}907 \times 10^{-3}C^2 - 0{,}1379C + 82{,}14$	0,992	0...18		
	20	$\varepsilon = -3{,}91 \times 10^{-3}C^2 - 0{,}1277C + 80{,}28$	0,9918	0...18		
	25	$\varepsilon = 5{,}812 \times 10^{-4}C^2 - 0{,}193C + 78{,}45$	0,9944	0...60		
	30	$\varepsilon = 4{,}679 \times 10^{-4}C^2 - 0{,}2057C + 76{,}67$	0,9966	0...60		
	35	$\varepsilon = -3{,}431 \times 10^{-3}C^2 - 0{,}1432C + 74{,}92$	0,9972	0...18		
	40	$\varepsilon = 4{,}121 \times 10^{-4}C^2 - 0{,}1988C + 73{,}22$	0,9964	0...60		
	50	$\varepsilon = -1{,}404 \times 10^{-3}C^2 - 0{,}08834C + 69{,}92$	0,9976	0...60		
Глицерин-ДМАц Glycerol-DMAc	15	$\varepsilon = -7{,}24 \times 10^{-6}C^3 + 2{,}832 \times 10^{-4}C^2 + 0{,}08025C + 40{,}71$	0,9958	0...100	[91]	[88]
	30	$\varepsilon = -2{,}808 \times 10^{-6}C^3 - 5{,}335 \times 10^{-4}C^2 + 0{,}1192C + 37{,}41$	0,9978	0...100		
	45	$\varepsilon = 6{,}325 \times 10^{-7}C^3 - 1{,}146 \times 10^{-3}C^2 + 0{,}1542C + 34{,}41$	0,9955	0...100		
	60	$\varepsilon = -2{,}325 \times 10^{-6}C^3 - 1{,}483 \times 10^{-3}C^2 + 0{,}1727C + 31{,}7$	0,9969	0...100		
Глицерин-ДМФА Glycerol-DMFA	15	$\varepsilon = -1{,}102 \times 10^{-5}C^3 - 1{,}375 \times 10^{-4}C^2 + 0{,}1727C + 39{,}12$	0,9913	0...100	[91]	[88]
	30	$\varepsilon = -2{,}359 \times 10^{-6}C^3 - 1{,}445 \times 10^{-3}C^2 + 0{,}2192C + 36{,}45$	0,9939			

Продолжение на следующей странице
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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
Глицерин-ДМФА Glycerol-DMFA	45	$\varepsilon = 1{,}673\times10^{-6}C^3 - 1{,}913\times10^{-3}C^2 + 0{,}2242C + 34{,}07$	0,996	0...100	[91]	[88]
	60	$\varepsilon = -8{,}459\times10^{-7}C^3 - 1{,}398\times10^{-3}C^2 + 0{,}1932C + 31{,}94$	0,9947			
Глицерин-вода Glycerol-water	-19,5	$\varepsilon = -5{,}161\times10^{-3}C^2 + 0{,}1737C + 87{,}75$	0,9987	85...100	[69]	[64]
	-15,3	$\varepsilon = 1{,}042\times10^{-2}C^2 - 2{,}624C + 210{,}9$	0,9953	85...100		
	-7,5	$\varepsilon = 2{,}971\times10^{-3}C^2 - 1{,}242C + 145{,}5$	0,9976	85...100		
	20	$\varepsilon = -1{,}996\times10^{-3}C^2 - 0{,}1873C + 80{,}28$	0,9966	0...100	[7, 35, 78]	[27, 59, 75]
	25	$\varepsilon = -1{,}95\times10^{-3}C^2 - 0{,}1812C + 78{,}45$	0,9944		[78, 84, 85, 96]	[75, 81, 82, 94]
	30	$\varepsilon = -1{,}154\times10^{-3}C^2 - 0{,}2404C + 76{,}67$	0,9989		[37, 41, 103]	[29, 33, 101]
	35	$\varepsilon = -1{,}299\times10^{-3}C^2 - 0{,}2269C + 74{,}92$	0,9994		[41, 85]	[33, 82]
	37	$\varepsilon = -8{,}162\times10^{-4}C^2 - 0{,}2866C + 74{,}24$	0,9991		[22]	[14]
	40	$\varepsilon = -1{,}397\times10^{-3}C^2 - 0{,}2177C + 73{,}22$	0,9992		[78, 96]	[75, 94]
	45	$\varepsilon = -1{,}489\times10^{-3}C^2 - 0{,}2028C + 71{,}55$	0,9976		[41, 85, 91]	[33, 82, 88]
	60	$\varepsilon = -1{,}112\times10^{-3}C^2 - 0{,}2169C + 66{,}77$	0,9996		[78]	[75]
	70	$\varepsilon = -4{,}304\times10^{-4}C^2 - 0{,}2732C + 63{,}75$	0,9985		[2, 22]	[2, 14]
	80	$\varepsilon = -9{,}825\times10^{-4}C^2 - 0{,}2038C + 60{,}88$	0,9994		[78]	[75]
	100	$\varepsilon = -8{,}945\times10^{-4}C^2 - 0{,}1874C + 55{,}51$	0,9998		[78]	[75]
Глицерин-трегалоза Glycerol-trehalose	-23	$\varepsilon = 3{,}051\times10^{-6}C^5 - 3{,}06\times10^{-4}C^4 + 0{,}01126C^3 - 0{,}1852C^2 + 1{,}534C + 6{,}8$	0,9953	0...47	[13]	[5]
	0	$\varepsilon = 1{,}963\times10^{-6}C^5 - 2{,}017\times10^{-4}C^4 + 7{,}807\times10^{-3}C^3 - 0{,}138C^2 + 1{,}306C + 7{,}426$	0,9953	0...47		
	24	$\varepsilon = 1{,}105\times10^{-6}C^5 - 1{,}254\times10^{-4}C^4 + 5{,}553\times10^{-3}C^3 - 0{,}1131C^2 + 1{,}264C + 7{,}51$	0,9942	0...47		
Глицерин-этанол Glycerol-ethanol	20	$\varepsilon = 5{,}628\times10^{-4}C^2 + 0{,}1126C + 24{,}97$	0,9945	0...100	[7, 35]	[27, 59]
	25	$\varepsilon = 1{,}202\times10^{-3}C^2 + 0{,}0615C + 24{,}27$	0,9989		[88, 103]	[85, 101]
Глицин – 2,84 % NaCl Glycine -– 2.84% NaCl	25	$\varepsilon = 3{,}2196C + 77{,}293$	0,9996	0...20	[33]	[25]
Глицин – 5,6 % NaCl Glycine – 5.6% NaCl	25	$\varepsilon = 3{,}1613C + 76{,}767$	0,9999	0...20	[33]	[25]
Глицин -–10,85 % NaCl Glycine –10.85% NaCl	25	$\varepsilon = 3{,}2053C + 74{,}893$	0,9996	0...20	[33]	[25]
Глицин-вода Glycine-water	18	$\varepsilon = 3{,}1983C + 81{,}02$	0,9994	0...18	[1]	[1]
	20	$\varepsilon = 3{,}117C + 80{,}28$	1,0	0...8		

Продолжение на следующей странице
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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
Глицин-вода Glycine-water	25	$\varepsilon = 3{,}158C + 78{,}45$	0,9988	0...20	[1,33]	[1,25]
	30	$\varepsilon = 3{,}0653C + 76{,}67$	1,0	0...8	[1]	[1]
	40	$\varepsilon = 2{,}9908C + 73{,}22$	0,9999	0...8		
	50	$\varepsilon = 2{,}9553C + 69{,}92$	0,9999	0...8		
Глюкоза-вода Glucose-water	5	$\varepsilon = -6{,}815\times10^{-4}C^2 - 0{,}2608C + 86{,}0$	0,9988	0...18	[31]	[23]
	10	$\varepsilon = -8{,}703\times10^{-4}C^2 - 0{,}2493C + 84{,}05$	0,9994	0...18		
	15	$\varepsilon = -1{,}808\times10^{-3}C^2 - 0{,}2273C + 82{,}14$	0,9992	0...18		
	20	$\varepsilon = -1{,}159\times10^{-4}C^3 + 8{,}757\times10^{-3}C^2 - 0{,}3739C + 80{,}28$	0,995	0...90	[1, 31, 105]	[1, 23, 103]
	25	$\varepsilon = -1{,}688\times10^{-3}C^2 - 0{,}2165C + 78{,}45$	0,9999	0...50	[1, 31]	[1, 23]
	30	$\varepsilon = -3{,}884\times10^{-5}C^3 + 1{,}782\times10^{-3}C^2 - 0{,}2711C + 76{,}67$	0,9964	0...90	[1]	[1]
	35	$\varepsilon = -2{,}194\times10^{-3}C^2 - 0{,}2012C + 74{,}92$	0,9986	0...18	[31]	[23]
	40	$\varepsilon = -5{,}604\times10^{-5}C^3 + 3{,}217\times10^{-3}C^2 - 0{,}2155C + 73{,}22$	0,9941	0...90	[1]	[1]
	50	$\varepsilon = -4{,}582\times10^{-5}C^3 + 2{,}491\times10^{-3}C^2 - 0{,}1979C + 69{,}92$	0,9948	0...90		
	60	$\varepsilon = -3{,}842\times10^{-5}C^3 + 1{,}942\times10^{-3}C^2 - 0{,}1791C + 66{,}77$	0,9976	0...90		
	70	$\varepsilon = -4{,}394\times10^{-5}C^3 + 2{,}991\times10^{-3}C^2 - 0{,}2173C + 63{,}75$	0,9956	0...95		
	80	$\varepsilon = -4{,}363\times10^{-5}C^3 + 3{,}489\times10^{-3}C^2 - 0{,}2416C + 60{,}88$	0,9951	0...95		
	90	$\varepsilon = -4{,}163\times10^{-5}C^3 + 3{,}818\times10^{-3}C^2 - 0{,}2656C + 58{,}13$	0,9935	0...95		
ДМАц-вода DMAc-water	25	$\varepsilon = -2{,}05\times10^{-3}C^2 - 0{,}2448C + 78{,}45$	0,9996	0...100	[5, 37, 103]	[29, 47, 101]
ДМСО-вода DMSO-water	10	$\varepsilon = -7{,}548\times10^{-5}C^3 + 6{,}396\times10^{-3}C^2 - 0{,}2148C + 84{,}05$	0,9982	0...100	[17, 100]	[9, 98]
	20	$\varepsilon = -5{,}583\times10^{-5}C^3 + 3{,}231\times10^{-3}C^2 - 0{,}09819C + 80{,}28$	0,9992		[17, 18, 35]	[9, 10, 27]
	25	$\varepsilon = -5{,}78\times10^{-5}C^3 + 3{,}824\times10^{-3}C^2 - 0{,}1025C + 78{,}45$	0,9972		[37, 45, 60, 74, 87, 97]	[29, 37, 54, 71, 84, 95]
	30	$\varepsilon = -5{,}101\times10^{-5}C^3 + 3{,}22\times10^{-3}C^2 - 0{,}1124C + 76{,}67$	0,9983		[17, 60, 103]	[9, 54, 101]
	35	$\varepsilon = -5{,}871\times10^{-5}C^3 + 4{,}961\times10^{-3}C^2 - 0{,}1977C + 74{,}92$	0,9975		[18, 60, 103]	[10, 54, 101]
	40	$\varepsilon = -4{,}769\times10^{-5}C^3 + 3{,}249\times10^{-3}C^2 - 0{,}1236C + 73{,}22$	0,9965		[17, 60, 103]	[9, 54, 101]
	45	$\varepsilon = -4{,}855\times10^{-5}C^3 + 3{,}754\times10^{-3}C^2 - 0{,}1484C + 71{,}55$	0,9982		[60, 103]	[54, 101]
ДМСО-ЭГ DMSO-EG	10	$\varepsilon = -5{,}816\times10^{-7}C^4 + 8{,}718\times10^{-5}C^3 - 5{,}598\times10^{-3}C^2 + 0{,}3368C + 44{,}06$	0,9945	0...100	[100, 103]	[98, 101]

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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
ДМСО-ЭГ DMSO-EG	20	$\varepsilon = -8{,}862\times10^{-7}C^4 + 1{,}454\times10^{-4}C^3 - 9{,}183\times10^{-3}C^2 + 0{,}4166C + 41{,}88$	0,9938	0...100	[100, 103]	[98, 101]
	25	$\varepsilon = -1{,}036\times10^{-6}C^4 + 1{,}861\times10^{-4}C^3 - 1{,}273\times10^{-2}C^2 + 0{,}5288C + 40{,}82$	0,992	0...100		
	30	$\varepsilon = -1{,}389\times10^{-6}C^4 + 2{,}403\times10^{-4}C^3 - 1{,}487\times10^{-2}C^2 + 0{,}5435C + 39{,}79$	0,9958	0...100		
	40	$\varepsilon = -1{,}29\times10^{-6}C^4 + 2{,}225\times10^{-4}C^3 - 1{,}422\times10^{-2}C^2 + 0{,}5673C + 37{,}79$	0,9972	0...100		
ДМФА-вода DMFA-water	25	$\varepsilon = 1{,}605\times10^{-6}C^3 - 3{,}092\times10^{-3}C^2 - 0{,}1193C + 78{,}45$	0,9992	0...100	[1, 37, 103]	[1, 29, 101]
	30	$\varepsilon = 1{,}803\times10^{-6}C^3 - 2{,}525\times10^{-3}C^2 - 0{,}1645C + 76{,}67$	0,999	0...100	[93, 103]	[90, 101]
ДМФА-глицерин DMFA-glycerol	30	$\varepsilon = 6{,}273\times10^{-6}C^3 - 2{,}606\times10^{-3}C^2 + 0{,}1548C + 41{,}08$	0,998	0...100	[93,103]	[90,101]
ДМФА-ДМСО DMFA-DMSO	30	$\varepsilon = -4{,}021\times10^{-4}C^2 - 0{,}05143C + 45{,}86$	0,9971	0...100	[93,103]	[90,101]
ДМФА-метанол DMFA-methanol	10	$\varepsilon = -1{,}065\times10^{-3}C^2 + 0{,}1592C + 35{,}18$	0,996	0...100	[1]	[1]
	25	$\varepsilon = 3{,}002\times10^{-4}C^2 + 0{,}03135C + 32{,}21$	0,994		[2, 49, 103]	[2, 41, 101]
	30	$\varepsilon = 3{,}066\times10^{-4}C^2 + 0{,}03049C + 31{,}3$	0,9933			
	35	$\varepsilon = 3{,}943\times10^{-4}C^2 + 0{,}01649C + 30{,}42$	0,9976			
	40	$\varepsilon = 5{,}479\times10^{-4}C^2 - 3{,}879\mathrm{x}10^{-3}C + 29{,}57$	0,9953			
	55	$\varepsilon = -1{,}024\times10^{-3}C^2 + 0{,}1583C + 27{,}19$	0,9962		[1]	[1]
ДМФА-ЭГ DMFA-EG	30	$\varepsilon = 2{,}032\times10^{-6}C^3 - 1{,}469\times10^{-3}C^2 + 0{,}09594C + 39{,}79$	0,9987	0...100	[93, 103]	[90, 101]
ДМФА-этанол DMFA-ethanol	30	$\varepsilon = 2{,}327\times10^{-4}C^2 + 0{,}1064C + 23{,}58$	0,9987	0...100	[93, 103]	[90, 101]
ДЭГ-вода DEG-water	15	$\varepsilon = -2{,}113\times10^{-3}C^2 - 0{,}2804C + 82{,}14$	0,9996	0...100	[1, 36]	[1, 28]
	25	$\varepsilon = -1{,}997\times10^{-3}C^2 - 0{,}275C + 78{,}45$	0,9991	0...100	[1, 40, 94]	[1, 32, 91]
	35	$\varepsilon = -1{,}765\times10^{-3}C^2 - 0{,}2778C + 74{,}92$	0,9997	0...100	[1, 2]	[1, 2]
ДЭГ-этанол DEG-ethanol	25	$\varepsilon = 4{,}69\times10^{-5}C^2 + 0{,}06224C + 24{,}27$	0,9965	0...100	[94,103]	[91,101]
Ксилоза-вода Xylose-water	5	$\varepsilon = -0{,}307C + 86{,}0$	0,9984	0...16	[31]	[23]
	10	$\varepsilon = -0{,}3028C + 84{,}05$	0,9992			
	15	$\varepsilon = -0{,}3006C + 82{,}14$	0,9991			
	20	$\varepsilon = -0{,}3056C + 80{,}28$	0,9957			
	25	$\varepsilon = -0{,}3C + 78{,}45$	0,9959			
	30	$\varepsilon = -0{,}3068C + 76{,}67$	0,9941			
	35	$\varepsilon = -0{,}3123C + 74{,}92$	0,9918			
	40	$\varepsilon = -0{,}3206C + 73{,}22$	0,9894			
Мальтоза-вода Maltose-water	5	$\varepsilon = -2{,}126\times10^{-3}C^2 - 0{,}2596C + 86{,}0$	0,9987	0...50	[68]	[63]

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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °С Temperature, °С	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
Мальтоза-вода Maltose-water	15	$\varepsilon = -1{,}622\times10^{-3}C^2 - 0{,}2652C + 82{,}14$	0,9982	0…50	[68]	[63]
	25	$\varepsilon = -1{,}427\times10^{-3}C^2 - 0{,}2625C + 78{,}45$	0,9993			
	35	$\varepsilon = -1{,}124\times10^{-3}C^2 - 0{,}2656C + 74{,}92$	0,9991			
Маннит-вода Mannitol-water	20	$\varepsilon = -1{,}632\times10^{-3}C^2 - 0{,}1237C + 80{,}28$	0,9988	0…15	[1]	[1]
	25	$\varepsilon = -8{,}461\times10^{-3}C^2 - 6{,}887\times10^{-3}C + 78{,}45$	0,9982	0…50	[1, 92]	[1, 89]
	30	$\varepsilon = -9{,}355\times10^{-4}C^2 - 0{,}1331C + 76{,}67$	0,9982	0…20	[1]	[1]
	40	$\varepsilon = 6{,}645\times10^{-4}C^2 - 0{,}1687C + 73{,}22$	0,9997	0…20		
	50	$\varepsilon = -2{,}258\times10^{-4}C^2 - 0{,}1543C + 69{,}92$	0,9998	0…20		
	60	$\varepsilon = 1{,}194\times10^{-3}C^2 - 0{,}1806C + 66{,}77$	0,9991	0…20		
МАц-вода MAc-water	5	$\varepsilon = 1{,}38\times10^{-4}C^3 - 9{,}82\times10^{-3}C^2 + 0{,}393C + 86{,}0$	0,9993	0…80	[26]	[18]
	10	$\varepsilon = 1{,}556\times10^{-4}C^3 - 1{,}278\times10^{-2}C^2 + 0{,}4797C + 84{,}5$	0,9991	0…80		
	15	$\varepsilon = 1{,}673\times10^{-4}C^3 - 1{,}523\times10^{-2}C^2 + 0{,}5828C + 82{,}14$	0,9996	0…80		
	20	$\varepsilon = 1{,}844\times10^{-4}C^3 - 1{,}791\times10^{-2}C^2 + 0{,}6667C + 80{,}28$	0,9996	0…80		
	25	$\varepsilon = -4{,}259\times10^{-6}C^4 + 8{,}945\times10^{-4}C^3 - 5{,}616\times10^{-2}C^2 + 1{,}342C + 78{,}45$	0,9956	0…100		
	30	$\varepsilon = -2{,}852\times10^{-6}C^4 + 6{,}423\times10^{-4}C^3 - 4{,}233\times10^{-2}C^2 + 1{,}111C + 76{,}67$	0,9985	0…100		
	35	$\varepsilon = -3{,}002\times10^{-6}C^4 + 7{,}283\times10^{-4}C^3 - 5{,}184\times10^{-2}C^2 + 1{,}386C + 74{,}92$	0,9999	0…100		
	40	$\varepsilon = -2{,}916\times10^{-6}C^4 + 7{,}722\times10^{-4}C^3 - 5{,}961\times10^{-2}C^2 + 1{,}671C + 73{,}22$	0,9995	0…100		
	45	$\varepsilon = -3{,}011\times10^{-6}C^4 + 8{,}446\times10^{-4}C^3 - 6{,}806\times10^{-2}C^2 + 1{,}92C + 71{,}55$	0,9968	0…100		
Метанол-вода Methanol-water	–90	$\varepsilon = 8{,}921\times10^{-3}C^2 - 2{,}163C + 193{,}9$	0,9858	54…100	[1]	[1]
	–80	$\varepsilon = 7{,}836\times10^{-3}C^2 - 1{,}959C + 179{,}8$	0,987			
	–70	$\varepsilon = 6{,}708\times10^{-3}C^2 - 1{,}757C + 166{,}9$	0,9893			
	–60	$\varepsilon = 2{,}865\times10^{-3}C^2 - 1{,}11C + 136{,}6$	0,9919	44…100		
	–50	$\varepsilon = 2{,}881\times10^{-3}C^2 - 1{,}08C + 130{,}5$	0,9918			
	–40	$\varepsilon = -1{,}177\times10^{-3}C^2 - 0{,}4614C + 105{,}57$	0,9968	0…100		
	–30	$\varepsilon = -9{,}911\times10^{-4}C^2 - 0{,}4614C + 100{,}89$	0,998			
	–20	$\varepsilon = -7{,}725\times10^{-4}C^2 - 0{,}4668C + 96{,}41$	0,9926			
	–10	$\varepsilon = -6{,}287\times10^{-4}C^2 - 0{,}4477C + 92{,}11$	0,9945		[1, 3]	[1, 105]
	0	$\varepsilon = -4{,}905\times10^{-4}C^2 - 0{,}4513C + 87{,}99$	0,9996			
	5	$\varepsilon = -6{,}698\times10^{-4}C^2 - 0{,}4239C + 86{,}0$	0,9998		[23,57,74]	[15,50,71]
	10	$\varepsilon = -3{,}032\times10^{-4}C^2 - 0{,}455C + 84{,}05$	0,9992		[1]	[1]

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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
Метанол-вода Methanol-water	15	$\varepsilon = -4{,}734\times10^{-4}C^2 - 0{,}4255C + 82{,}14$	0,9999	0...100	[1, 23, 42, 103]	[1, 15, 34, 101]
	17	$\varepsilon = -1{,}87\times10^{-4}C^2 - 0{,}4639C + 81{,}39$	0,9997		[1]	[1]
	20	$\varepsilon = -2{,}023\times10^{-4}C2 - 0{,}4481C + 80{,}28$	0,9974		[1, 42, 71, 103]	[1, 34, 66, 101]
	25	$\varepsilon = -1{,}501\times10^{-4}C^2 - 0{,}4414C + 78{,}45$	0,999		[1, 23, 41, 42, 52, 87, 102, 103]	[1, 15, 33, 34, 44, 84, 100, 101]
	30	$\varepsilon = -2{,}118\times10^{-4}C^2 - 0{,}4267C + 76{,}67$	0,9983		[1, 41, 42, 98, 103]	[1, 33, 34, 96, 101]
	35	$\varepsilon = -2{,}631\times10^{-4}C^2 - 0{,}4137C + 74{,}92$	0,9985		[1, 23, 41, 42, 103]	[1, 15, 33, 34, 101]
	40	$\varepsilon = -8{,}251\times10^{-5}C^2 - 0{,}4253C + 73{,}22$	0,9993		[1, 41, 103]	[1, 33, 101]
	45	$\varepsilon = -1{,}092\times10^{-4}C^2 - 0{,}4157C + 71{,}55$	0,9995		[23, 41, 103]	[15, 33, 101]
	50	$\varepsilon = -1{,}017\times10^{-3}C^2 - 0{,}3775C + 69{,}92$	0,9973		[1, 30, 103]	[1, 22, 101]
	55	$\varepsilon = 9{,}783\times10^{-5}C^2 - 0{,}4193C + 68{,}32$	1,0		[23, 103]	[15, 101]
	60	$\varepsilon = 4{,}72\times10^{-4}C^2 - 0{,}4525C + 66{,}77$	0,9994		[1, 2, 103]	[1, 2, 101]
Метанол-ДМСО Methanol-DMSO	20	$\varepsilon = 2{,}01\times10^{-5}C^3 - 3{,}858\times10^{-3}C^2 + 0{,}04268C + 47{,}35$	0,9992	0...100	[8]	[67]
Мочевина-вода Urea-water	18	$\varepsilon = -3{,}588\times10^{-2}C^2 + 0{,}2269C + 81{,}01$	0,9969	1,6...9,5	[1]	[1]
	20	$\varepsilon = 1{,}872\times10^{-3}C^2 + 0{,}5109C + 80{,}28$	0,9996	0...48	[1, 67]	[1, 62]
	25	$\varepsilon = 1{,}153\times10^{-3}C^2 + 0{,}5321C + 78{,}45$	1,0	0...28	[1, 46]	[1, 38]
МФА-вода MFA-water	25	$\varepsilon = 2{,}498\times10^{-6}C^4 - 3{,}086\times10^{-4}C^3 + 1{,}404\times10^{-2}C^2 + 0{,}1484C + 78{,}45$	0,9996	0...100	[37]	[29]
ПЭГ-200 – вода PEG-200 – water	25	$\varepsilon = -2{,}627\times10^{-3}C^2 - 0{,}316C + 78{,}45$	0,9989	0...100	[53,92,94]	[45,89,91]
ПЭГ-300 – вода PEG-300 – water	25	$\varepsilon = -2{,}792\times10^{-3}C^2 - 0{,}3287C + 78{,}45$	0,9962	0...100	[53,62,94]	[45,56,91]
ПЭГ-400 – вода PEG-400 – water	25	$\varepsilon = -2{,}784\times10^{-3}C^2 - 0{,}3641C + 78{,}45$	0,9969	0...100	[62,94]	[56,91]
ПЭГ-600 – вода PEG-600 – water	25	$\varepsilon = -1{,}933\times10^{-3}C^2 - 0{,}4586C + 78{,}45$	0,9981	0...100	[53,62,94]	[45,56,91]
ПЭГ-200 – этанол PEG-200 – ethanol	25	$\varepsilon = -2{,}617\times10^{-4}C^2 - 0{,}01805C + 24{,}27$	0,9939	0...100	[94]	[91]
ПЭГ-300 – этанол PEG-300 – ethanol	25	$\varepsilon = -3{,}042\times10^{-4}C^2 - 0{,}04003C + 24{,}27$	0,9962	0...100	[94]	[91]
ПЭГ-400 – этанол PEG-400 – ethanol	25	$\varepsilon = -3{,}525\times10^{-4}C^2 - 0{,}0576C + 24{,}27$	0,9908	0...100	[88]	[85]
ПЭГ-600 – этанол PEG-600 – ethanol	25	$\varepsilon = -4{,}406\times10^{-4}C^2 - 0{,}06083C + 24{,}27$	0,9966	0...100	[94]	[91]
Рибоза-вода Ribose-water	5	$\varepsilon = -6{,}204\times10^{-3}C^2 - 0{,}1941C + 86{,}0$	0,9969	0...16	[31]	[23]
	10	$\varepsilon = -7{,}789\times10^{-3}C^2 - 0{,}1854C + 84{,}05$	0,9967			
	15	$\varepsilon = -1{,}017\times10^{-2}C^2 - 0{,}1832C + 82{,}14$	0,9962			

Продолжение на следующей странице
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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °С Temperature, °С	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
Рибоза-вода Ribose-water	20	$\varepsilon = -1{,}159 \times 10^{-2}C^2 - 0{,}2004C + 80{,}28$	0,9966	0...16	[31]	[23]
	25	$\varepsilon = -1{,}225 \times 10^{-2}C^2 - 0{,}2285C + 78{,}45$	0,9944			
	30	$\varepsilon = -1{,}31 \times 10^{-2}C^2 - 0{,}2884C + 76{,}67$	0,9954			
	35	$\varepsilon = -1{,}069 \times 10^{-2}C^2 - 0{,}4227C + 74{,}92$	0,9968			
	40	$\varepsilon = -5{,}65 \times 10^{-3}C^2 - 0{,}6354C + 73{,}22$	0,9896			
Сахароза-вода Sucrose-water	10	$\varepsilon = -9{,}134 \times 10^{-4}C^2 - 0{,}2447C + 84{,}05$	1,0	0...40	[1]	[1]
	20	$\varepsilon = -7{,}683 \times 10^{-5}C^3 + 4{,}314 \times 10^{-3}C^2 - 0{,}3083C + 80{,}28$	0,9976	0...80	[1, 12, 63]	[1, 4, 57]
	22	$\varepsilon = -1{,}239 \times 10^{-2}C^2 - 0{,}129C + 79{,}54$	0,9969	0...14	[73]	[70]
	25	$\varepsilon = -1{,}466 \times 10^{-3}C^2 - 0{,}214C + 78{,}45$	0,9974	0...60	[1, 12, 63]	[1, 4, 57]
	30	$\varepsilon = -2{,}311 \times 10^{-3}C^2 - 0{,}1758C + 76{,}67$	0,9967	0...70		
	35	$\varepsilon = -2{,}592 \times 10^{-3}C^2 - 0{,}2083C + 74{,}92$	0,9916	0...25	[11]	[3]
	40	$\varepsilon = -2{,}656 \times 10^{-3}C^2 - 0{,}1504C + 73{,}22$	0,9948	0...80	[1]	[1]
	45	$\varepsilon = -4{,}704 \times 10^{-3}C^2 - 0{,}1498C + 71{,}55$	0,9969	0...25	[11]	[3]
	50	$\varepsilon = -2{,}027 \times 10^{-3}C^2 - 0{,}1724C + 69{,}92$	0,997	0...80	[1]	[1]
	60	$\varepsilon = -3{,}374 \times 10^{-5}C^3 + 1{,}684 \times 10^{-3}C^2 - 0{,}2531C + 66{,}77$	0,995	0...90		
	70	$\varepsilon = -1{,}816 \times 10^{-5}C^3 + 5{,}138 \times 10^{-4}C^2 - 0{,}2392C + 63{,}75$	0,9959	0...90		
	80	$\varepsilon = -1{,}908 \times 10^{-5}C^3 + 1{,}361 \times 10^{-3}C^2 - 0{,}2815C + 60{,}88$	0,9953	0...90		
	90	$\varepsilon = -3{,}256 \times 10^{-5}C^3 + 3{,}096 \times 10^{-3}C^2 - 0{,}3102\,C + 58{,}13$	0,9956	0...90		
	95	$\varepsilon = -1{,}699 \times 10^{-3}C^2 - 0{,}1324C + 56{,}8$	0,9997	0...90		
	100	$\varepsilon = -4{,}09 \times 10^{-4}C^2 - 0{,}2539C + 55{,}51$	0,9997	0...70		
Сорбит-вода Sorbitol-water	0	$\varepsilon = 1{,}231 \times 10^{-3}C^2 - 0{,}4114C + 87{,}99$	0,9871	0...70	[95]	[92]
	5	$\varepsilon = 1{,}7 \times 10^{-3}C^2 - 0{,}4467C + 86{,}0$	0,9877	0...70		
	10	$\varepsilon = 4{,}435 \times 10^{-3}C^2 - 0{,}6147C + 84{,}05$	0,9942	0...70		
	15	$\varepsilon = -3{,}269 \times 10^{-4}C^3 + 3{,}702 \times 10^{-2}C^2 - 1{,}394C + 82{,}14$	0,9987	0...60		
	20	$\varepsilon = -3{,}102 \times 10^{-4}C^3 + 3{,}375 \times 10^{-2}C^2 - 1{,}253\,C + 80{,}28$	0,9961	0...60		
	25	$\varepsilon = -4{,}007 \times 10^{-4}C^3 + 4{,}092 \times 10^{-2}C^2 - 1{,}394C + 78{,}45$	0,9954	0...50		
Трегалоза-вода Trehalose-water	5	$\varepsilon = -1{,}811 \times 10^{-3}C^2 - 0{,}2206C + 86{,}0$	0,9989	0...50	[68]	[63]
	15	$\varepsilon = -1{,}377 \times 10^{-3}C^2 - 0{,}2141C + 82{,}14$	0,9993	0...50		
	25	$\varepsilon = -9{,}856 \times 10^{-4}C^2 - 0{,}2252C + 78{,}45$	0,9961	0...50		
	35	$\varepsilon = -7{,}602 \times 10^{-4}C^2 - 0{,}2316C + 74{,}92$	0,9957	0...50		

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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
ТЭГ-вода TEG-water	15	$\varepsilon = -2{,}481\times10^{-3}C^2 - 0{,}3227C + 82{,}14$	0,999	0...100	[1]	[1]
	25	$\varepsilon = -2{,}539\times10^{-3}C^2 - 0{,}2927C + 78{,}45$	0,9995	0...100	[1, 40]	[1, 32]
	35	$\varepsilon = -2{,}323\times10^{-3}C^2 - 0{,}2925C + 74{,}92$	0,9992	0...100	[1, 2]	[1, 2]
Фенол-вода Phenol-water	70	$\varepsilon = -1{,}543\times10^{-3}C^2 - 0{,}09431C + 33{,}87$	0,9991	40...100		
ФА – 1,2-ПД FA – 1,2-PD	30	$\varepsilon = 0{,}7806C + 28{,}68$	0,9997	0...100	[92]	[89]
ФА-вода FA-water	25	$\varepsilon = -4{,}097\times10^{-5}C^3 + 3{,}555\times10^{-3}C^2 + 0{,}3663C + 78{,}45$	0,9966	0...100	[1,37,52]	[1,29,44]
	30	$\varepsilon = -5{,}644\times10^{-5}C^3 + 5{,}358\times10^{-3}C^2 + 0{,}3315C + 76{,}67$	0,9987	0...100	[92]	[89]
ФА-глицерин FA-glycerol	30	$\varepsilon = -2{,}528\times10^{-3}C^2 + 0{,}9119C + 41{,}08$	0,9993	0...100		
ФА-ДЭГ FA-DEG	30	$\varepsilon = -1{,}997\times10^{-3}C^2 + 0{,}8699C + 39{,}99$	0,9994	0...100		
ФА-ДМСО FA-DMSO	30	$\varepsilon = 1{,}127\times10^{-3}C^2 + 0{,}4993C + 45{,}86$	0,9996	0...100		
ФА-ДМФА FA-DMFA	30	$\varepsilon = 1{,}87\times10^{-3}C^2 + 0{,}5171C + 36{,}45$	0,9997	0...100	[90,92]	[87,89]
ФА-метанол FA-methanol	30	$\varepsilon = 1{,}905\times10^{-3}C^2 + 0{,}5719C + 31{,}3$	0,9995	0...100	[92]	[89]
ФА – ПЭГ-200 FA – PEG-200	30	$\varepsilon = 0{,}8717C + 19{,}37$	0,9995	0...100		
ФА – ПЭГ-300 FA – PEG-300	30	$\varepsilon = 0{,}9187C + 14{,}02$	0,999	0...100		
ФА – ПЭГ-400 FA – PEG-400	30	$\varepsilon = 8{,}159\times10^{-4}C^2 + 0{,}8548C + 12{,}47$	0,9991	0...100		
ФА – ПЭГ-600 FA – PEG-600	30	$\varepsilon = 7{,}358\times10^{-4}C^2 + 0{,}8803C + 10{,}65$	0,9993	0...100		
ФА-этанол FA-ethanol	30	$\varepsilon = 4{,}864\times10^{-3}C^2 + 0{,}3494C + 23{,}58$	0,9998	0...100		
ФА-ЭГ FA-EG	30	$\varepsilon = -1{,}728\times10^{-3}C^2 + 0{,}8454C + 39{,}79$	0,9997	0...100		
Фруктоза-вода Fructose-water	5	$\varepsilon = -1{,}047\times10^{-3}C^2 - 0{,}2451C + 86{,}0$	0,9997	0...18	[31]	[23]
	10	$\varepsilon = -1{,}282\times10^{-3}C^2 - 0{,}2268C + 84{,}05$	0,9998	0...18		
	15	$\varepsilon = -1{,}495\times10^{-3}C^2 - 0{,}2176C + 82{,}14$	0,9996	0...18		
	20	$\varepsilon = -1{,}005\times10^{-3}C^2 - 0{,}2192C + 80{,}28$	0,9988	0...18		
	25	$\varepsilon = -1{,}249\times10^{-3}C^2 - 0{,}2069C + 78{,}45$	0,9992	0...18		
	30	$\varepsilon = -1{,}565\times10^{-3}C^2 - 0{,}1996C + 76{,}67$	0,9997	0...18		
	35	$\varepsilon = -1{,}655\times10^{-3}C^2 - 0{,}188C + 74{,}92$	0,9991	0...18		
	40	$\varepsilon = -1{,}762\times10^{-3}C^2 - 0{,}1847C + 73{,}22$	0,9951	0...20	[12, 31]	[4, 23]
ХФ-метанол CF-methanol	20	$\varepsilon = -1{,}916\times10^{-3}C^2 - 0{,}09204C + 33{,}16$	0,9996	0...100	[1]	[1]

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Продолжение таблицы 2
Table 2. (Continued)

Раствор Solution	Температура, °C Temperature, °C	Уравнение Equation	R^2	Диапазон концентраций, масс. % Concentration range, % w/w	Источник	References
ХФ-этанол CF-ethanol	18	$\varepsilon = -1{,}096\times10^{-3}C^2 - 0{,}09585C + 25{,}26$	0,9975	0...100	[1]	[1]
	25	$\varepsilon = -1{,}079\times10^{-3}C^2 - 0{,}08791C + 24{,}27$	0,998			
Этанол-вода Ethanol-water	-5	$\varepsilon = 1{,}703\times10^{-4}C^2 - 0{,}6328C + 90{,}03$	0,9975			
	0	$\varepsilon = 2{,}313\times10^{-4}C^2 - 0{,}6284C + 87{,}99$	0,9981		[1, 11, 103]	[1, 3, 101]
	5	$\varepsilon = -3{,}514\times10^{-4}C^2 - 0{,}6131C + 86{,}0$	0,9988		[24]	[16]
	10	$\varepsilon = 7{,}248\times10^{-4}C^2 - 0{,}6494C + 84{,}05$	0,9942		[1, 11, 103]	[1, 3, 101]
	15	$\varepsilon = 2{,}165\times10^{-4}C^2 - 0{,}6073C + 82{,}14$	0,9953		[11, 24, 103]	[3, 16, 101]
	20	$\varepsilon = 6{,}742\times10^{-4}C^2 - 0{,}623C + 80{,}28$	0,9965		[1, 7, 42, 55, 71, 103]	[1, 34, 48, 59, 66, 101]
	22	$\varepsilon = 4{,}974\times10^{-4}C^2 - 0{,}6052C + 79{,}56$	0,9999		[73]	[70]
	25	$\varepsilon = 7{,}513\times10^{-4}C^2 - 0{,}6207C + 78{,}45$	0,9982		[1, 11, 24, 42, 44, 52, 87, 88, 104, 103]	[1, 3, 16, 34, 36, 44, 84, 85, 101, 102]
	30	$\varepsilon = 7{,}52\times10^{-4}C^2 - 0{,}6106C + 76{,}67$	0,999		[1, 98, 103]	[1, 96, 101]
	32	$\varepsilon = 5{,}385\times10^{-4}C^2 - 0{,}5772C + 75{,}96$	0,9998		[55, 103]	[48, 101]
	35	$\varepsilon = 7{,}22\times10^{-4}C^2 - 0{,}6015C + 74{,}92$	0,997		[1, 11, 24, 103]	[1, 3, 16, 101]
	40	$\varepsilon = 8{,}497\times10^{-4}C^2 - 0{,}6016C + 73{,}22$	0,9983		[1, 11, 42, 103]	[1, 3, 34, 101]
	45	$\varepsilon = 9{,}567\times10^{-4}C^2 - 0{,}6092C + 71{,}55$	0,9927		[1, 11, 103]	[1, 3, 101]
	50	$\varepsilon = 9{,}68\times10^{-4}C^2 - 0{,}5955C + 69{,}92$	0,9982		[1, 24, 30, 103]	[1, 16, 22, 101]
	55	$\varepsilon = 1{,}053\times10^{-3}C^2 - 0{,}5913C + 68{,}32$	0,9992		[1, 103]	[1, 101]
	60	$\varepsilon = 9{,}703\times10^{-4}C^2 - 0{,}5725C + 66{,}77$	0,9991			
	75	$\varepsilon = 1{,}02\times10^{-3}C^2 - 0{,}5519C + 62{,}3$	0,9993			
	80	$\varepsilon = 8{,}857\times10^{-4}C^2 - 0{,}536C + 60{,}88$	0,9995		[1, 101, 103]	[1, 99, 101]
ЭГ-вода EG-water	15	$\varepsilon = -1{,}975\times10^{-3}C^2 - 0{,}1885C + 82{,}14$	0,9973		[1, 40]	[1, 32]
	20	$\varepsilon = -1{,}894\times10^{-3}C^2 - 0{,}2224C + 80{,}28$	0,9955		[70, 77, 101, 106]	[65, 74, 99, 104]
	25	$\varepsilon = -1{,}819\times10^{-3}C^2 - 0{,}205C + 78{,}45$	0,9935		[1, 20, 40, 72, 80, 94, 106]	[1, 12, 32, 68, 77, 91, 104]
	30	$\varepsilon = -1{,}707\times10^{-3}C^2 - 0{,}2216C + 76{,}67$	0,9975		[80]	[77]
	35	$\varepsilon = -1{,}442\times10^{-3}C^2 - 0{,}2174C + 74{,}92$	0,9946		[1, 40, 80]	[1, 32, 77]
	40	$\varepsilon = -1{,}622\times10^{-3}C^2 - 0{,}2219C + 73{,}22$	0,9971		[70, 77, 80, 106]	[65, 74, 77, 104]
	45	$\varepsilon = -1{,}406\times10^{-3}C^2 - 0{,}2307C + 71{,}55$	0,9999		[80]	[77]
	50	$\varepsilon = -7{,}672\times10^{-4}C^2 - 0{,}2722C + 69{,}92$	0,9962		[30]	[22]
	60	$\varepsilon = -1{,}112\times10^{-3}C^2 - 0{,}2387C + 66{,}77$	0,9988		[70, 77, 101, 106]	[65, 74, 99, 104]
	80	$\varepsilon = -7{,}978\times10^{-4}C^2 - 0{,}2419C + 60{,}88$	0,9995		[70, 77, 106]	[65, 74, 104]
	100	$\varepsilon = -5{,}427\times10^{-4}C^2 - 0{,}2435C + 55{,}51$	0,9995		[70, 77, 101, 106]	[65, 74, 99, 104]
ЭГ-этанол EG-ethanol	25	$\varepsilon = 7{,}618\times10^{-4}C^2 + 0{,}09216C + 24{,}27$	0,9979		[94]	[91]

Таблица 3. Уравнения для расчета статической диэлектрической проницаемости растворов криопротекторов в зависимости от температуры при фиксированной концентрации; дисперсии аппроксимаций и диапазоны концентраций применения уравнений

Table 3. Equations to calculate static dielectric permeability for cryoprotective solutions depending on temperature at a fixed concentration; dispersions of approximations and temperature ranges of equation application

Раствор Solution	Концентрация, масс. % Concentration, % w/w	Уравнение Equation	R^2	Диапазон температур, °C Temperature range, °C	Источник	References
NaCl-вода NaCl-water	0,5	$\varepsilon = -4{,}19\times10^{-3}t^2 - 0{,}03055t + 79{,}98$	0,9966	10...60	[83]	[80]
	1	$\varepsilon = -5{,}05\times10^{-3}t^2 - 0{,}03674t + 77{,}36$	0,9975	10...60		
	1,5	$\varepsilon = -4{,}785\times10^{-3}t^2 - 7{,}846\text{x}10^{-3}t + 76{,}66$	0,994	10...60		
	2	$\varepsilon = -1{,}372\times10^{-3}t^2 - 0{,}1563t + 76{,}78$	0,9982	10...50		
	2,84	$\varepsilon = -5{,}143\times10^{-4}t^2 - 0{,}3114t + 79{,}57$	0,9966	0...60	[1]	[1]
	3,73	$\varepsilon = -1{,}357\times10^{-3}t^2 - 0{,}3567t + 79{,}19$	0,9956	0...40	[51]	[43]
NaCl – агар-гель (1%) NaCl – agar gel (1%)	0	$\varepsilon = 3{,}709\times10^{-4}t^2 - 0{,}2419t + 79{,}54$	0,9973	10...60	[83]	[80]
	0,5	$\varepsilon = -1{,}481\times10^{-3}t^2 - 0{,}1366t + 77{,}43$	0,9956	10...60		
	1	$\varepsilon = 6{,}893\times10^{-4}t^2 - 0{,}2563t + 76{,}45$	0,9973	10...60		
	1,5	$\varepsilon = 7{,}719\times10^{-4}t^2 - 0{,}249t + 75{,}44$	0,9913	10...60		
	2	$\varepsilon = 1{,}384\times10^{-3}t^2 - 0{,}2738t + 73{,}98$	0,9993	10...60		
NaCl-глицерин NaCl-glycerol	4,55	$\varepsilon = 1{,}029\times10^{-2}t^2 + 0{,}501t + 58{,}5$	1,0	–49...–27	[1]	[1]
	21,15	$\varepsilon = 6{,}363\times10^{-3}t^2 - 0{,}2968t + 49{,}39$	0,9968	–50...–22		
NaCl – глициновый буфер (0,2 M) NaCl – glycine buffer (0.2 M)	0	$\varepsilon = 1{,}818\times10^{-5}t^4 - 3{,}824\text{x}10^{-3}t^3 + 0{,}2931t^2 - 10{,}13t + 195{,}7$	0,9976	20...70	[75]	[72]
	0,5	$\varepsilon = 2{,}333\times10^{-3}t^3 - 0{,}24t^2 + 6{,}221t + 34{,}73$	1,0	20...50	[75]	[72]
NaCl – фосфатный буфер (0,05 M) NaCl – phosphate buffer (0.05 M)	0	$\varepsilon = -6{,}378\times10^{-4}t^2 - 0{,}1867C + 83{,}71$	0,9929	7...65	[81]	[78]
	0,5	$\varepsilon = -1{,}002\times10^{-3}t^2 - 0{,}1343C + 81{,}09$	0,9931	7...65		
	0,75	$\varepsilon = -1{,}049\times10^{-3}t^2 - 0{,}1601C + 81{,}51$	0,9919	7...65		
	1	$\varepsilon = -1{,}121\times10^{-3}t^2 - 0{,}1562C + 81{,}15$	0,9922	7...65		
Галактоза-вода Galactose-water	3,48	$\varepsilon = -0{,}3636t + 87{,}243$	0,9998	5...40	[31]	[23]
	6,72	$\varepsilon = -0{,}366t + 86{,}571$	0,9998	5...40		
	9,75	$\varepsilon = -0{,}3702t + 86{,}093$	0,9998	5...40		
	12,6	$\varepsilon = -0{,}3667t + 85{,}425$	0,9999	5...40		
	15,27	$\varepsilon = -0{,}3902t + 84{,}993$	0,9999	5...40		
	17,78	$\varepsilon = -0{,}379t + 84{,}529$	0,9999	5...40		
Глицин-вода Glycine-water	7,33	$\varepsilon = -9{,}647\times10^{-4}t^2 - 0{,}3216\,t + 109{,}8$	0,998	0...50	[1]	[1]
Глюкоза-вода Glucose-water	3,48	$\varepsilon = -0{,}3605t + 86{,}836$	0,9999	5...40	[31]	[23]
	6,72	$\varepsilon = -0{,}3536t + 85{,}843$	0,9997			
	9,75	$\varepsilon = -0{,}3517t + 85{,}0$	0,9999			
	12,6	$\varepsilon = -0{,}3536t + 84{,}343$	0,9997			
	15,27	$\varepsilon = -0{,}35t + 83{,}575$	0,9997			

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Продолжение таблицы 3
Table 3. (Continued)

Раствор Solution	Концентрация, масс. % Concentration, % w/w	Уравнение Equation	R^2	Диапазон температур, °С Temperature range, °C	Источник	References
Глюкоза-вода Glucose-water	17,78	$\varepsilon = -0{,}3429t + 82{,}689$	0,9995	5...40	[31]	[23]
ДМСО-вода DMSO-water	40	$\varepsilon = -0{,}3845t + 83{,}633$	0,9997	5...35	[74]	[71]
ДМФА-вода DMFA-water	29,55	$\varepsilon = -0{,}29t + 70{,}56$	0,9997	20...40	[18]	[10]
МАц-вода MAc-water	41,73	$\varepsilon = 8{,}615\times10^{-4}t^2 - 0{,}3387t + 97{,}46$	0,9915	5...45	[26]	[18]
	57,49	$\varepsilon = 3{,}9\times10^{-3}t^2 - 0{,}582t + 104{,}6$	0,999			
	80,23	$\varepsilon = 3{,}801\times10^{-3}t^2 - 0{,}8614t + 129{,}5$	0,9998			
Метанол-вода Methanol-water	34	$\varepsilon = 2{,}485\times10^{-3}t^2 - 0{,}3293t + 67{,}02$	0,9886	–22...18	[20]	[12]
	50	$\varepsilon = 5{,}788\times10^{-4}t^2 - 0{,}3564t + 64{,}81$	0,9903	5...35	[1, 41, 74]	[1, 33, 71]
Сахароза – агар-гель (1%) Sucrose – agar gel (1%)	10	$\varepsilon = 2{,}202\times10^{-5}t^3 - 3{,}254\times10^{-3}t^2 + 1{,}696\times10^{-2}t + 71{,}14$	0,9939	10...60	[83]	[80]
	20	$\varepsilon = 2{,}293\times10^{-4}t^3 - 2{,}468\times10^{-2}t^2 + 0{,}7437t + 54{,}57$	0,9703			
	30	$\varepsilon = -1{,}442\times10^{-4}t^3 + 1{,}002\times10^{-2}t^2 - 2{,}922\times10^{-2}t + 53{,}81$	0,9678			
	40	$\varepsilon = 1{,}998\times10^{-4}t^3 - 2{,}197\times10^{-2}t^2 + 0{,}904t + 25{,}42$	0,9966			
Сахароза-вода Sucrose-water	5	$\varepsilon = 9{,}781\times10^{-4}t^2 - 0{,}4222t + 86{,}51$	0,9998	0...100	[1, 83]	[1, 80]
	10	$\varepsilon = 7{,}889\times10^{-4}t^2 - 0{,}4059t + 85{,}38$	0,9989			
	20	$\varepsilon = 6{,}833\times10^{-4}t^2 - 0{,}3911t + 82{,}45$	0,9966			
	30	$\varepsilon = 5{,}113\times10^{-4}t^2 - 0{,}3684t + 79{,}32$	0,9971	–2...100		
	40	$\varepsilon = 5{,}351\times10^{-4}t^2 - 0{,}3652t + 76{,}45$	0,9991	–3...100		
ФА-вода FA-water	33,41	$\varepsilon = -0{,}378t + 103{,}8$	0,9997	20...40	[18]	[10]
Этанол-вода Ethanol-water	95	$\varepsilon = 2{,}998\times10^{-3}t^2 + 0{,}04805t + 38{,}4$	0,9998	–156...–110	[50]	[42]
	99	$\varepsilon = 5{,}455\times10^{-3}t^2 + 0{,}7786t + 84{,}34$	0,9973	–162...–119		
ЭГ-вода EG-water	20	$\varepsilon = 9{,}493\times10^{-4}t^2 - 0{,}4203t + 82{,}93$	0,9991	–10...100	[70, 80, 82, 106]	[65, 77, 79, 104]
	30	$\varepsilon = 9{,}181\times10^{-4}t^2 - 0{,}4116t + 79{,}7$	0,9994	–10...100		
	40	$\varepsilon = 6{,}727\times10^{-4}t^2 - 0{,}3394t + 74{,}32$	0,9986	–20...100	[80, 106]	[77, 104]
	50	$\varepsilon = 1{,}052\times10^{-3}t^2 - 0{,}4116t + 72{,}9$	0,9996	–20...100	[70, 77, 80, 82, 106]	[65, 74, 77, 79, 104]
	60	$\varepsilon = 9{,}555\times10^{-4}t^2 - 0{,}3787t + 68{,}0$	0,9979	–40...100	[80, 106]	[77, 104]
	80	$\varepsilon = 1{,}23\times10^{-3}t^2 - 0{,}3012t + 55{,}46$	0,9953	–15...100		

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