Euramet Electrochemical Analysis WG

Comparison Euramet 898

Electrolytic conductivity at pure water level

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[1]PTB (D), [2]DFM (DK), [3]SP (SE)

Field:
Amount of substance

Subject:
Electrolytic conductivity at pure water level

Organising body:
Euramet – former Euromet

Rationale:

Electrolytic conductivity in aqueous solutions is one of the most used electrochemical measurement techniques in industry – it is relatively simple, cheap, and robust and is performing with a low measurement uncertainty compared with most other analytical techniques.
Since electrolytic conductivity is a sensitive measure of amount of ions dissolved in the solution a limit value for conductivity is a clear and simple quality specification for purity of water in general but also for high purity water. The relevant measuring range is below 1 mS/m (0.06 to 10 µS/cm at 25 °C). The European Pharmacopoeia as well as the Japanese and United States have indeed specified the demand for purified water, highly purified water and water for injection for the pharmaceutical industry based on conductivity. Sectors that also use conductivity limits for water purity are electrical power production, food industry, electronic industry and analytical laboratories.

At these low levels it is not feasible to circulate water samples due to contamination. The main contamination is coming from carbon dioxide in ambient air. Therefore this comparison will be based on using a transfer standard calibrated at each laboratory in the appropriate conductivity and temperature range using closed flow systems. The transfer standard will be a commercial instrument with appropriate cells for this conductivity levels.
The intercomparison is opened for both laboratories using primary and secondary calibration methods.

Participants:

Acronym	**Participant**	**Country**
DFM	Danish Fundamental Metrology	Denmark
PTB	Physikalisch-Technische Bundesanstalt	Germany
SP	Swedish National Testing and Research Institute	Sweden

Timetable:

October 2006: Protocol

November-December 2006: PTB measurements reported 2007-01-16. Transfer instrument send to SP

January 2007: SP reported 2007-01-10. Transfer instrument send to DFM

January 2007 DFM measurements – not possible due to instrument problems. Transfer instrument sent to PTB.

February-March 2007: PTB measurements – check on stability on transfer standard – reported 2007-04-12.

March 2007 – Comparison stalled waiting for DFM

January 2010 – Comparison finished and results from PTB and SP reported

Pilot laboratory and contact person:

Bertil Magnusson

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Results were sent to project secretary Eskil Sahlin - eskil.sahlin@sp.se

Preparation of the transfer standard:

PTB provided a transfer standard, a Thornton 200 CR meter and two cells (0.01 cm-1 and one 0.1 cm-1) from Millipore. The cells are the same as normally used inside Milli-Q systems. The transfer standard was first used at PTB and then at SP and then again at PTB.

Description of measurement object:

SP and PTB made measurements on ultrapure water produced in the laboratory. At the level around 1 µS/cm only SP made measurements.

Measurement conditions:

Participants were requested to measure within one month after receipt of transfer standard. The nominal values of the cell constant should be used.
Measurements were carried out at 25 °C and at 37 °C for the two conductivity cells.

Measurement results

Table 1 Measurement results for Electrolytic conductivity at pure water level project Euromet 898. Results in yellow is given for information only – not used in the calculations

	Nominal conductivity (µS/cm)	Date Measured[1)]	Transfer standard Cell (cm^{-1})	Temp. °C	Result (µS/cm)	Stand. Dev, (µS/cm)	Difference (µS/cm)
PTB1	0.05500	27–28 Nov	0.0101	25	0.05366	0.00002	-0.00134
SP	0.06050	4–5 Jan	0.0101	25	0.05950	0.00070	-0.00100
PTB2	0.05499	18 Feb	0.0101	25	0.05366	0.00004	-0.00133
PTB1	0.05499	14-15 Nov	0.1133	25	0.05366	0.00003	-0.00133
SP	0.05950	4–5 Jan	0.1133	25	0.05850	0.00070	-0.00100
PTB2	0.05499	21 Feb	0.1133	25	0.05368	0.00004	-0.00131
PTB1	0.09900	2-3 Dec	0.0101	37	0.09448	0.00010	-0.00452
SP	0.11250	4–5 Jan	0.0101	37	0.1115	0.0007	-0.00100
PTB2	0.09850	25 Mar	0.0101	37	0.09713	0.00004	-0.00137
PTB1	Measurements not made on this cell						
SP	0.11300	4–5 Jan	0.1133	37	0.10750	0.00070	-0.00550
PTB2	0.09850	21 Feb	0.1133	37	0.09131	0.00011	-0.00719

For measurement at 25 °C the differences SP – (PTB1+PTB2)/2 were calculated and for measurements at 37 °C the differences SP- PTB2 were calculated – see Table 2.

Table 2 Difference SP- PTB calculated from measurement using the transfer standards.

Nominal conductivity (µS/cm)	Transfer standard Cell (cm^{-1})	Temp. °C	Difference SP-PTB (µS/cm)	Expanded uncertainty of difference[1] (µS/cm)	Relative difference
≈ 0.06050	0.0101	25	0.0003	0.0020	0.55%
≈ 0.05950	0.1133	25	0.0003	0.0020	0.55%
≈ 0.11250	0.0101	37	0.0004	0.0020	1.73%
≈ 0.11300	0.1133	37	0.0017	0.0020	1.50%

[1] The main contribution for expanded uncertainty of the difference SP-PTB is the uncertainty given by SP – see appendix B.

Discussion

Direct comparison of electric conductivity for pure water by sending round samples is not possible. The results obtained with measurement using a transfer standard sent round to the laboratories is one possibility. The differences obtained for the electric conductivity between SP and PTB measurements using this transfer standard for ultra pure water are well within the expanded uncertainties given. No results for comparison in the range 1 – 10 µS/cm were possible to obtain since these level were measured only at one laboratory

Conclusions

Further comparisons will be needed to compare PTB. DFM and SP at pure water level. One possibility is perform measurement using absolute cells from PTB and DFM at SP in line with the SP cell and to use the SP system to create conductivity levels in the range 1 – 10 *µS/cm.*

Appendix A Measurement Reports PTB

Laboratory: *Physikalisch Technische Bundesanstalt (PTB)*
AG 3.13 Electrochemistry
Bundesallee 100
38116 Braunschweig. Germany
Contact: Petra Spitzer petra.spitzer@ptb.de

	Date Received	Date Sent
Transfer standard	15 Oct 2006	8 Dec 2006

Measurement results PTB1:

Ultrapure water

Nominal conductivity *(µS/cm)*	Date Measured	Cell	Temp-erature °C	Result *(µS/cm)*	Standard Deviation *(µS/cm)*	Number of Measurements	Ambient pressure *(mbar)*
0.055	27 – 28 Nov	0.0101	25	0.05366	0.00002	3x 50	1000-1020
0.055	14 – 15 Nov	0.1133	25	0.05366	0.00003	3x 50	1000-1020
0.099	2 – 3 Dec	0.0101	37	0.09448	0.0001	3x 50	1000-1020
0.042	25 – 26 Oct	0.1133	20	0.04095	0.00002	4x 50	1000-1020

For information only

Results:

Ultrapure water

Nominal conductivity *(µS/cm)*	Cell	Temp-erature °C	Difference in cell constant (result – nominal) (cm-1)	Standard uncert. of the difference *(µS/cm)*	Coverage factor	Expanded Uncertainty *(µS/cm)*
0.055	0.0101	25	-0.00017	0.000001	2	0.000002
0.055	0.1133	25	-0.0051	0.00003	2	0.00005
0.099	0.0101	37	-0.00010	0.000005	2	0.000001
0.042	0.1133	20	-0.0056	0.00003	2	0.00006

Transfer Standard with two conductivity cells, 0.1133 and 0.0101

	Date Received	Date Sent
Transfer standard	8 Feb 07	27 March 07

Measurement results PTB2:

Ultrapure water

Nominal conductivity *(µS/cm)*	Date Measured	Cell	Temp-erature °C	Result *(µS/cm)*	Expanded Uncertainty k=2 *(µS/cm)*	Number of Measurements
0.02313	4. Feb	0.0101	10	0.02248	0.00004	3x 50
0.02313	13. Feb	0.1133	10	0.02248	0.00004	3x 50
0.04198	6. Feb	0.0101	20	0.04075	0.00004	3x 50
0.04198	16. Feb	0.1133	20	0.04075	0.00004	3x 50
0.05499	18. Feb	0.0101	25	0.05366	0.00004	3x 50
0.05499	21. Feb	0.1133	25	0.05368	0.00004	3x 50
0.07084	22. March	0.0101	30	0.06927	0.00004	3x 50
0.07084	25. Feb	0.1133	30	0.06899	0.00004	3x 50
0.0985	25. March	0.0101	37	0.09713	0.00004	3x 50
0.0985	1. March	0.1133	37	0.09131	0.00011	3x 50

For information only

Results:

Ultrapure water

Nominal conductivity (µS/cm)	Cell	Temp-erature °C	Difference in cell constant (result – nominal) (cm-1)	Expanded Uncertainty (cm-1)	Coverage factor
0.02313	0.0101	10	-0,00025	0.00003	2
0.02313	0.1133	10	-0,00959	0.00028	2
0.04198	0.0101	20	-0,00025	0.00002	2
0.04198	0.1133	20	-0,00726	0.00027	2
0.05499	0.0101	25	-0,00021	0.00002	2
0.05499	0.1133	25	0,00019	0.00058	2
0.07084	0.0101	30	-0,00015	0.00002	2
0.07084	0.1133	30	-0,00069	0.00216	2
0.0985	0.0101	37	-0,00004	0.00002	2
0.0985	0.1133	37	-0,00509	0.00131	2

For information only

Measurement Method:

The conductivity of the ultra-pure water is determined traceable to the SI using the primary measuring device (national standard) for conductivity of the Physikalisch-Technische Bundesanstalt (PTB).The constant of this cell is determined by a geometrical approach. The distance between the concentric electrodes is varied in a controlled and traceable way. The method is de-scribed in the PTB operational procedure AA 3.13-6.

Instrument Calibration:

The circulation type conductivity cell is installed in-line with the primary PTB cell. Ultra-pure water provided by the Millipore Elix UV-Milli-Q Gradient A10 runs through the primary cell, the cells to be calibrated and again through the primary cell at 1L/min. The cell constant is determined and the cell connected to the conductivity instrument Thornton 200CR is calibrated.
The complete equipment including the impedance bridge, cable and temperature sensors is calibrated at frequencies between 40 Hz and 200 Hz and at the measurement temperature.
Conductivity of the ultra-pure water measured using the circulation type conductivity cell connected to the Thornton 200CR conductivity instrument.

Uncertainty:

Major uncertainty contributions

Uncertainty table for the difference at 25 °C - nominal conductivity 0.06 µS/cm cell 0.0101

Uncertainty source	Estimate	Standard uncertainty	Sensitivity coefficient	Contribution to standard uncertainty
X_I	x_I	$U(a_{xe})$	C_I	$u_I(y)$
Kappa, S/m	5.366E-6	1.976E-09	1.844E+05	3.643E-04
Resistance, Ohm	184350.3	191.1	5.366E-06	1.026E-03

Standard uncertainty: 0.00001 cm^{-1}
Expanded uncertainty (k=2): 0.00002 cm^{-1}

Uncertainty table for the difference at 25 °C - nominal conductivity 0.06 µS/cm cell 0.1133

Uncertainty source	Estimate	Standard uncertainty	Sensitivity coefficient	Contribution to standard uncertainty
X_I	x_I	$U(a_{xe})$	C_I	$u_I(y)$
Kappa, S/m	5.369E-06	1.824E-09	2.114E+06	3.855E-03
Resistance, Ohm	2113894.8	5362.1	5.369E-06	2.879E-02

Standard uncertainty: 0.00029 cm^{-1}
Expanded uncertainty (k=2): 0.00058 cm^{-1}

Appendix B Measurement Report SP

SP registration: F7 00869

Date: 2007-01-10

Laboratory:

SP Technical Research Institute of Sweden, Box 857, 501 15 Borås, Sweden

Transfer Standard with two conductivity cells, 0.1133 and 0.0101

	Date Received	Date Sent
Transfer standards	2006-12-08 from PTB	2007-01-08 sent to DFM

Measurement results:

Ultrapure water

Nominal conductivity *(μS/cm)*	Date Measured	Cell	Temp-erature °C	Result *(μS/cm)*	Standard Deviation *(μS/cm)*	Number of Measurements
0.0605	4–5 Jan 2007	0.0101	25	0.0595	0.0007	2
0.0595	4–5 Jan 2007	0.1133	25	0.0585	0.0007	2
0.1125	4–5 Jan 2007	0.0101	37	0.1115	0.0007	2
0.1130	4–5 Jan 2007	0.1133	37	0.1075	0.0007	2

Conductivity level around 1 μS/cm

Nominal conductivity *(μS/cm)*	Date Measured	Cell	Temp-erature °C	Result *(μS/cm)*	Standard Deviation *(μS/cm)*	Number of Measurements	Ambient pressure[2)] *(mbar)*
1.304	21-22 Dec 2006	0.0101	25	1.312	0.006	3	-
1.301	21-22 Dec 2006	0.1133	25	1.205	0.005	3	-
1.617	21-22 Dec 2006	0.0101	37	1.613	0.005	3	-
1.580	21-22 Dec 2006	0.1133	37	1.436	0.004	3	-

Results:

Ultrapure water

Nominal conductivity *(µS/cm)*	Cell	Temp-erature °C	Difference (result – nominal value) (µS/cm)	Standard uncertainty of the difference *(µS/cm)*	Coverage factor	Expanded Uncertainty *(µS/cm)*
0.0605	0.0101	25	-0.001	0.001	2	0.002
0.0595	0.1133	25	-0.001	0.001	2	0.002
0.1125	0.0101	37	-0.001	0.001	2	0.002
0.1130	0.1133	37	-0.0055	0.001	2	0.002

Conductivity level around 1 µS/cm

Nominal conductivity *(µS/cm)*	Cell	Temp-erature °C	Difference (result – nominal value) (µS/cm)	Standard uncertainty of the difference *(µS/cm)*	Coverage factor	Expanded Uncertainty *(µS/cm)*
1.304	0.0101	25	0.008	0.018	2	0.036
1.301	0.1133	25	-0.096	0.018	2	0.036
1.617	0.0101	37	-0.004	0.018	2	0.036
1.580	0.1133	37	-0.144	0.018	2	0.036

Measurement Method:

The instrument used was a Knick Laboratory Conductivity Meter 703 (SP #301130), four electrode cell WTW LR 352/01 with a cell constant 0.100. The conductivity is displayed with three decimal figures in µS/cm. Measurements were made without temperature compensation. The automatic frequency optimisation of the instruments was used. The measuring borosilicate glass vessel has a volume of approximate 50 ml.
The temperature in the thermostatic bath (M3 Lauda SP #300559) was measured with a temperature meter Fluke 2180A (SP #301131) with a resolution of 0.01 °C and a measuring uncertainty of less than ± 0.02°C. The uncertainty of the temperature in the measuring vessel is estimated to be ± 0.03 °C.

Instrument Calibration

Around 1 µS/cm – At this level the Knick Conductivity meter was calibrated with a KCl solution with a calculated electrolytic conductivity.

Potassium chloride, KCl, purity > 99.5 % from Merck, dried at 500 °C for 3 h, was used for preparing the stock calibration solution. Ultrapure water for dissolving the KCl was equilibrated with air by over night – conductivity ca 0.9 µS/cm. The KCl stock solution (0.01 molal) was prepared on weight basis taking into account the air buoyancy of the water and KCl and homogenised by shaking over night. The LD polyethylene bottles used were only half filled in order to ensure equilibrium with air. The purity of the Merck KCl for conductivity measurement was assigned to be 99.80 % by comparing with stock solutions prepared from a KCl of 99.992 % purity from Slovak Metrology Institute. The calculated electrolytic conductivity of the stock solution prepared from Merck KCl was verified by measurement at DFM and the difference was less than 0.02 %[i].

The cell was calibrated with dilute solutions of KCl. The calibration solutions were prepared by on-line dilution of the stock solution using *SP ultrapure water system*. The nominal values were calculated from the Kohlrausch equation using the molar conductivity (equivalent conductance) for KCl at infinite dilution from Handbook of Chemistry and Physics, 2003 and the IUPAC values[ii] for electrolytic conductivity at 25 °C for 0.01 molal KCl and pure water as reference points. The root mean square of the differences shown in Table 1, 0.017 µS/cm is taken as an estimate of the standard uncertainty of the bias of the instrument in the range 0.5 to 5 µS/cm. The standard uncertainty of the calculated nominal value is 0.006 µS/cm. The expanded uncertainty, U, for measurement of electrolytic conductivity in the range 0.5 to 5 µS/cm with the SP instrument, is estimated by combining the standard uncertainties to be:

$U = 2 \cdot \sqrt{0{,}017^2 + 0{,}006^2} = 0{,}036$ µS/cm.

Examples of the uncertainty calculations of the nominal value is given in Appendix 1

Table 3 Calibration of SP instrument using the *SP ultrapure water system* for on-line dilution of KCl

Nominal value		SP measurements	Difference
Conductivity	Uncertainty (k=2)	Conductivity	Conductivity
(µS/cm)	(µS/cm)	(µS/cm)	(µS/cm)
0.5628	0.0056	0.5689	0.021
1.392	0.011	1.397	0.005
1.480	0.011	1.480	<0.001
5.372	0.029	5.340	-0.03
5.605	0.029	5.602	-0.003

SP ultrapure water system for calibration - The ultrapure water system is used for calibration of conductivity meters in the range 0.06 to 10 µS/cm. The system is designed to make a controlled dilution of a KCl stock solution up to 5000 times without carbon dioxide contamination from the laboratory environment. Ultrapure water from a commercial polishing unit with stabilised flow (100-200 g/min), pressure (about 400 Pa) and temperature (in the range 18 to 40 °C) is on-line diluted using a titration burette with a flow (0.05 to 1 ml/min). The solutions are mixed in a one litre vessel before on-line measurements are performed. Calibration is performed by comparing the indication of the calibration object with the theoretical calculated conductivity.

Ultrapure water – The cell constant of this instrument has been verified by the calibration in the range 0.5 to 5 µS/cm. The expanded uncertainty in the on-line ultrapure water system of the difference at ultrapure water level is estimated to be less than 0.002 µS/cm.

Sample Handling before measurement:

All measurements were done in an on-line system.

Major uncertainty contributions

Uncertainty table for the difference at 25 °C - nominal conductivity 1.4 µS/cm cell 0.0101. Similar uncertainty at 37 °C and also cell 0.1133.

Uncertainty source	Estimate	Assumed distribution	Standard uncertainty	Sensitivity coefficient	Contribution to standard uncertainty
X_I	x_I		$U(a_{xe})$	C_I	$u_I(y)$
Instrument calibration	-	-	0.017[1]	1	$17 \cdot 10^{-3}$
Water flow	177.96	Normal	0.47	$-8.0 \cdot 10^{-3}$	$3.7 \cdot 10^{-3}$
Measurement on transfer standard	1.312	Normal	$2.9 \cdot 10^{-3}$	1	$2.9 \cdot 10^{-3}$

KCl molar conductivity	149.790	Rectangular	0.289	$9.5 \cdot 10^{-3}$	$2.7 \cdot 10^{-3}$
KCl flow	0.17000	Rectangular	$0.23 \cdot 10^{-3}$	8.3	$1.9 \cdot 10^{-3}$
Temperature	25.00	Rectangular	0.04	1.5	$1.7 \cdot 10^{-3}$
Pure water conductivity	0.061	Rectangular	0.003	1	$1.7 \cdot 10^{-3}$

[1]Root Mean Square of the differences obtained from calibration in the range 0.5 to 5 µS/cm.

Standard uncertainty: $0.018 \cdot 10^{-3}$.µS/cm
Expanded uncertainty (k=2….): 0.036 µS/cm

Appendix to SP report

Conductivity app. 1.4 µS/cm

KCl stock solution prepared 060620 - Bottle 3 Merck KCl, purity >99.5 %. Assigned purity Merck KCl for conductivity 99.80 %. Calculated purity 99.82 % from DFM measurements. Mesurement performed 060630 KCl flow 0.17 ml/min

Model Equation:

{Calculation of the conductivity in µS/cm from C moles/litre KCl solution}
$k=(k_{H2O}+1000*C*(\Lambda_o-b*sqrt(C)))*f_{temp};$
{Calculation of on-line prepared KCl solution in moles/litre measured byt the conductivity meter}
$C=flow_{KCl}/(flow_{H2O}/\rho_{H2O})*C_1*\rho_{KCl};$
{Calculation of concentration of KCl stock solution in moles/kg}
$C_1=m_{KCl}/m_{dil}/Mw_{KCl}*f_{purity};$
$m_{KCl}=w_{KCl}*f_{KCl};$
$m_{H2O}=w_{H2O}*f_{H2O};$
$m_{dil}=m_{KCl}/1000+m_{H2O};$

List of Quantities:

Quantity	Unit	Definition
k	µS/cm	
k_{H2O}	µS/cm	Conductivity of pure water
C	mol/l	KCl concentration
Λ_o	µScm²/mol	Equivalent conductivity for KCl,
b		Constant in Kohlrauchs equation for binary salts
f_{temp}		
$flow_{KCl}$	ml/min	Burette flow
ρ_{H2O}	Kg/l	Density of water
C_1	Mol/kg	KCl stock solution
ρ_{KCl}	Kg/l	Density of KCl 0.01 mol/kg
Mw_{KCl}	g/mol	
$flow_{H2O}$	g/min	Total flow - mass corrected for air bouyancy
m_{dil}	kg	Stock solution preparation - mass of KCl + water
f_{purity}		Purity KCl
w_{KCl}	G	amount KCl - indication of balance
m_{KCl}	G	weight KCl corrected for air bouyancy
w_{H2O}	kg	weight H2O corrected for air buoyancy
m_{H2O}	kg	amount H2O - indication of balance
f_{KCl}		air buoyancy factor for KCl density 1.984
f_{H2O}		air buoyancy factor for water

k_{H2O}:
Type B rectangular distribution
Value: 0.061 µS/cm
Halfwidth of Limits: 0.003 µS/cm

Λ_o:
Type B rectangular distribution
Value: 149.79 µScm²/mol
Halfwidth of Limits: 0.5 µScm²/mol

b:
Type B rectangular distribution
Value: 94.6
Halfwidth of Limits: 0.2

f_{temp}:
Type B rectangular distribution
Value: 1
Halfwidth of Limits: 0.002

$flow_{KCl}$:
Type B rectangular distribution
Value: 0.17 ml/min
Halfwidth of Limits: 0.0004 ml/min

ρ_{H2O}:
Type B rectangular distribution
Value: 0.99705 kg/l
Halfwidth of Limits: 0.0001 kg/l

ρ_{KCl}:
Type B rectangular distribution
Value: 0.9997 kg/l
Halfwidth of Limits: 0.0004 kg/l

Mw_{KCl}:
Type B normal distribution
Value: 74.5510 g/mol
Expanded Uncertainty: 0.0009 g/mol
Coverage Factor: 2

$flow_{H2O}$:
Type A
Method of observation: Direct
Number of observation: 3

No.	Observation
1	177.03
2	178.5
3	178.35

Arithmetic Mean: 177.960 g/min
Standard Deviation: 0.81 g/min
Standard Uncertainty: 0.467 g/min
Degrees of Freedom: 2

f_{purity}:
Type B rectangular distribution
Value: 0.998
Halfwidth of Limits: 0.0005

w_{KCl}:
Type B rectangular distribution
Value: 1.4212 g
Halfwidth of Limits: 0.0008 g

w_{H2O}:
Type B rectangular distribution
Value: 1.9057 kg
Halfwidth of Limits: 0.0002 kg

f_{KCl}:
Type B rectangular distribution
Value: 1.00045
Halfwidth of Limits: 0.00003

f_{H2O}:
Type B rectangular distribution
Value: 1.00104
Halfwidth of Limits: 0.0001

Uncertainty Budget:

Quantity	Value	Standard Uncertainty	Degrees of Freedom	Distribution	Uncertainty Contribution	Index
k_{H2O}	0.06100 µS/cm	$1.73\cdot10^{-3}$ µS/cm	∞	rectangular	$1.7\cdot10^{-3}$ µS/cm	9.5 %
C	$9.4932\cdot10^{-6}$ mol/l	$28.5\cdot10^{-9}$ mol/l	3			
Λ_o	149.790 µScm²/mol	0.289 µScm²/mol	∞	rectangular	$2.7\cdot10^{-3}$ µS/cm	23.8 %
b	94.600	0.115	∞	rectangular	$-3.4\cdot10^{-6}$ µS/cm	0.0 %
f_{temp}	1.00000	$1.15\cdot10^{-3}$	∞	rectangular	$1.7\cdot10^{-3}$ µS/cm	9.3 %
$flow_{KCl}$	0.170000 ml/min	$231\cdot10^{-6}$ ml/min	∞	rectangular	$1.9\cdot10^{-3}$ µS/cm	11.8 %
ρ_{H2O}	0.9970500 kg/l	$57.7\cdot10^{-6}$ kg/l	∞	rectangular	$82\cdot10^{-6}$ µS/cm	0.0 %
C_1	$9.97007\cdot10^{-3}$ mol/kg	$4.42\cdot10^{-6}$ mol/kg	∞			
ρ_{KCl}	0.999700 kg/l	$231\cdot10^{-6}$ kg/l	∞	rectangular	$330\cdot10^{-6}$ µS/cm	0.3 %
Mw_{KCl}	74.551000 g/mol	$450\cdot10^{-6}$ g/mol	50	normal	$-8.6\cdot10^{-6}$ µS/cm	0.0 %
$flow_{H2O}$	177.960 g/min	0.467 g/min	2	normal	$-3.7\cdot10^{-3}$ µS/cm	44.0 %
m_{dil}	1.909104 kg	$160\cdot10^{-6}$ kg	∞			
f_{purity}	0.998000	$289\cdot10^{-6}$	∞	rectangular	$410\cdot10^{-6}$ µS/cm	0.5 %
w_{KCl}	1.421200 g	$462\cdot10^{-6}$ g	∞	rectangular	$460\cdot10^{-6}$ µS/cm	0.7 %
m_{KCl}	1.421840 g	$463\cdot10^{-6}$ g	∞			
w_{H2O}	1.905700 kg	$115\cdot10^{-6}$ kg	∞	rectangular	$-86\cdot10^{-6}$ µS/cm	0.0 %
m_{H2O}	1.907682 kg	$160\cdot10^{-6}$ kg	∞			
f_{KCl}	1.0004500	$17.3\cdot10^{-6}$	∞	rectangular	$25\cdot10^{-6}$ µS/cm	0.0 %
f_{H2O}	1.0010400	$57.7\cdot10^{-6}$	∞	rectangular	$-82\cdot10^{-6}$ µS/cm	0.0 %
k	1.48021 µS/cm	$5.61\cdot10^{-3}$ µS/cm	10			

Results:

Quantity	Value	Expanded Uncertainty	Coverage factor	Coverage
K	1.480 µS/cm	0.011 µS/cm	2.00	95% (normal)
C_1	$9.9701\cdot10^{-3}$ mol/kg	0.089 % (relative)	2.00	95% (normal)

References

[i] Report from Nordtest project 04162: Primary calibration for electrolytic conductivity for measurement of water purity, www.nordicinnovation.net, published april 2007.

[ii] Pratt KW, Koch WF, Wu YC, Berezansky PA. Molality-based primary standards of electrolytic conductivity (IUPAC Technical Report). Pure Appl Chem 2001; 73:1783–93.