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PERFORMANCE STUDY AND THERMAL PROFILE CHARACTERIZATION OF LOW TEMPERATURE VISCOSITY BATH IN DIFFERENT TEMPERATURE RANGES

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ABSTRACT

A new Viscosity bath has been entered the services in Thermal Metrology Laboratory-National Institute for Standards, NIS-Egypt in order to use in maintain and extend the national viscosity scale in wide temperature ranges, international comparison and routine calibration of viscometers. The medium of the bath should be homogenous enough in temperature so many thermal factors taken into account to estimate the temperature gradient, homogeneity, stability and thermal profile distribution with the related uncertainty to each parameter. The study carried out by two Standards Platinum Resistance Thermometer (SPRT) calibrated at fixed point according to ITS-90.

INTRODUCATION

Viscosity laboratory decided to extend the national viscosity scale in low temperature range down to -30°C, new viscosity bath works with low temperature range using dry denatured ethanol is used as the bath medium because its property to absorb moisture from the atmosphere is removed from it. The oil bath model Koehler LKV4000 low temperature kinematic viscosity bath contains several upper holes to receive four viscometers at the same time, there isan additional small hole to insert the Standard Platinum Resistance Thermometers (SPRTs) to measure the temperature variation during the viscosity measurements. The cooling unit within the bath stabilize the bath temperature to desired setting within ± 0.02°C. The bath is filled with approximately 14L of ethanol as a medium to put inside it the viscometers in order to calibrate glass viscometer under test with references known oils or even known viscometers with unknown oils under test. the main target is realize the kinematic viscosity tests with glass capillary viscometers according to the ASTM D445 (ASTM, 1992) test method and related test specifications. The SPRTs SN 234, 247 has been calibrated at fixed point according to ITS-90 (Preston-Thomas, 1990).

Experimental arrangement

The bath filed with 14L of ethanol then the SPRTs have been inserted into the medium at different positions and levels. Five levels taken into the account from the top side down to the bottom separate equally from each other's, at each level the thermometer inserted in five positions as four at the corners and one at the center of the level as shown in Figure 1. So, twenty five position introduced into the study at each temperature set point, the range of interest is from -30 °C up to 10 °C. The measurements carried out at -30°C, -20°C, -10 °C and 10 °C. The two SPRT connected at the same time to resistance bridge model ASL F700 conjugated with standard resistor and the measuring system connected to PC working under LABVIEW environment.

Metrological Characterizations

Homogeneity is the main parameter should be studied to optimize and establish a suitable uniform medium realize the National Viscosity Scale. In order to find a closed value to the homogeneity as possible, thermal gradient taken into account and observed as a change of a temperature readings of a thermometer according to a change of its position inside a calibration bath (Pornpatkul, 2012). Basic gradients that can

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be observed are vertical and horizontal gradient but sometimes more appropriate to define axial and a radial gradient.

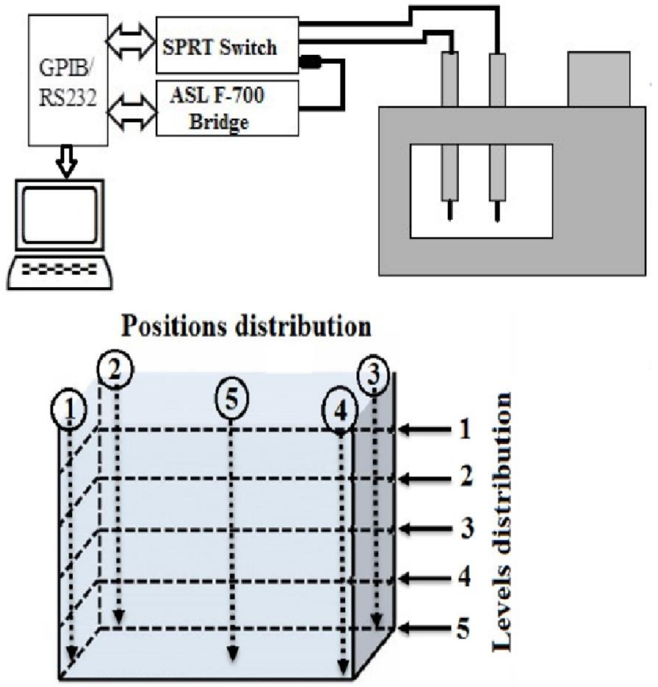

Figure 1. Schematic diagram of levels and position distribution

Table 1. Temperature distribution measurements using SPRT SN 234

L	Temperature$\langle T_{Py}^{Lx}\rangle^*$ SPRT 234					
1	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L1}\rangle$	-30.00138	-20.02123	-10.02138	10.02811
	2	$\langle T_{P2}^{L1}\rangle$	-30.00149	-20.02127	-10.02154	10.02823
	3	$\langle T_{P3}^{L1}\rangle$	-30.00152	-20.02129	-10.02167	10.02841
	4	$\langle T_{P4}^{L1}\rangle$	-30.00144	-20.02139	-10.02172	10.02852
	5	$\langle T_{P5}^{L1}\rangle$	-30.00131	-20.02156	-10.02183	10.02857
2	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L2}\rangle$	-30.00121	-20.02134	-10.02136	10.02822
	2	$\langle T_{P2}^{L2}\rangle$	-30.00124	-20.02156	-10.02176	10.02847
	3	$\langle T_{P3}^{L2}\rangle$	-30.00157	-20.02144	-10.02149	10.02833
	4	$\langle T_{P4}^{L2}\rangle$	-30.00156	-20.02165	-10.02159	10.028342
	5	$\langle T_{P5}^{L2}\rangle$	-30.00192	-20.02154	-10.02158	10.02897
3	**P**	**T**	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L3}\rangle$	-30.00198	-20.02183	-10.02222	10.02865
	2	$\langle T_{P2}^{L3}\rangle$	-30.00204	-20.02194	-10.02234	10.02860
	3	$\langle T_{P3}^{L3}\rangle$	-30.00213	-20.02211	-10.02256	10.02880
	4	$\langle T_{P4}^{L3}\rangle$	-30.00209	-20.02256	-10.02277	10.02832
	5	$\langle T_{P5}^{L3}\rangle$	-30.00221	-20.02252	-10.02281	10.02854
4	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L4}\rangle$	-30.00202	-20.02238	-10.02321	10.02910
	2	$\langle T_{P2}^{L4}\rangle$	-30.00218	-20.02241	-10.02333	10.02930
	3	$\langle T_{P3}^{L4}\rangle$	-30.00232	-20.02244	-10.02345	10.02949
	4	$\langle T_{P4}^{L4}\rangle$	-30.00241	-20.02253	-10.02377	10.02961
	5	$\langle T_{P5}^{L1}\rangle$	-30.00221	-20.02259	-10.02281	10.02983
5	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L5}\rangle$	-30.00265	-20.02244	-10.02312	10.03017
	2	$\langle T_{P2}^{L5}\rangle$	-30.00273	-20.02257	-10.02319	10.03032
	3	$\langle T_{P3}^{L5}\rangle$	-30.00279	-20.02269	-10.02341	10.03048
	4	$\langle T_{P4}^{L5}\rangle$	-30.00281	-20.02274	-10.02369	10.03069
	5	$\langle T_{P5}^{L5}\rangle$	-30.00280	-20.02272	-10.02389	10.03083

Uncertainty contribution of an axial gradient is determined as maximum temperature difference between two different positions in axial direction. The radial gradient is a maximum temperature difference between two different positions in a radial direction. So, three thermal factors were discussed as follows;

Thermal profile distribution

Consider that the temperature T_{Py}^{Lx} denotes to the temperature at level Lx and position Py, the two SPRT measure the temperature at different positions and levels as shown in Table 1 and 2.

Table 2. Temperature distribution measurements using SPRT SN 247

L	Temperature$\langle T_{Py}^{Lx}\rangle$ SPRT 247					
1	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L1}\rangle$	-30.00184	-20.02176	-10.02196	10.02844
	2	$\langle T_{P2}^{L1}\rangle$	-30.00190	-20.02182	-10.02178	10.02867
	3	$\langle T_{P3}^{L1}\rangle$	-30.00201	-20.02174	-10.02181	10.02843
	4	$\langle T_{P4}^{L1}\rangle$	-30.00199	-20.02191	-10.02190	10.02887
	5	$\langle T_{P5}^{L1}\rangle$	-30.00188	-20.02185	-10.02198	10.02889
2	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L2}\rangle$	-30.00170	-20.02158	-10.02176	10.02860
	2	$\langle T_{P2}^{L2}\rangle$	-30.00178	-20.02174	-10.02181	10.02866
	3	$\langle T_{P3}^{L2}\rangle$	-30.00198	-20.02179	-10.02189	10.02895
	4	$\langle T_{P4}^{L2}\rangle$	-30.00192	-20.02168	-10.02197	10.02887
	5	$\langle T_{P5}^{L2}\rangle$	-30.00197	-20.02194	-10.02191	10.02893
3	**P**	**T**	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L3}\rangle$	-30.00214	-20.02196	-10.02285	10.02897
	2	$\langle T_{P2}^{L3}\rangle$	-30.00243	-20.02218	-10.02239	10.02914
	3	$\langle T_{P3}^{L3}\rangle$	-30.00258	-20.02254	-10.02263	10.02945
	4	$\langle T_{P4}^{L3}\rangle$	-30.00278	-20.02279	-10.02279	10.02976
	5	$\langle T_{P5}^{L3}\rangle$	-30.00292	-20.02289	-10.02289	10.028983
4	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L4}\rangle$	-30.00219	-20.02213	-10.02253	10.02945
	2	$\langle T_{P2}^{L4}\rangle$	-30.00234	-20.02229	-10.02274	10.02968
	3	$\langle T_{P3}^{L4}\rangle$	-30.00256	-20.02237	-10.02281	10.02979
	4	$\langle T_{P4}^{L4}\rangle$	-30.00289	-20.02259	-10.02289	10.02987
	5	$\langle T_{P5}^{L1}\rangle$	-30.00299	-20.02287	-10.02292	10.02999
5	P	T	**-30.00**	**-20.00**	**-10.00**	**10.00**
	1	$\langle T_{P1}^{L5}\rangle$	-30.00398	-20.02368	-10.02389	10.03633
	2	$\langle T_{P2}^{L5}\rangle$	-30.00421	-20.02382	-10.02417	10.03651
	3	$\langle T_{P3}^{L5}\rangle$	-30.00437	-20.02397	-10.02444	10.03723
	4	$\langle T_{P4}^{L5}\rangle$	-30.00461	-20.02418	-10.02464	10.03820
	5	$\langle T_{P5}^{L5}\rangle$	-30.00482	-20.02479	-10.02492	10.03915

*<> *brackets indicates to the average*

Temperature Stability

The stability of the bath shows lower variation within the regulation specification of the bath. The fluctuation was monitored at different positions and levels as shown in Figure 2 for SPRT SN-234 at setting point -10.0°C. The stability calculated at each level in the center point for continuous several hours (Ghazanfar, 2013).

$$T_{stability} = \frac{(\Delta t_{max} - \Delta t_{min})}{2} \quad (1)$$

During the progressive study of the performance of the Bath, it is found that the stability was better than 0.015°C.

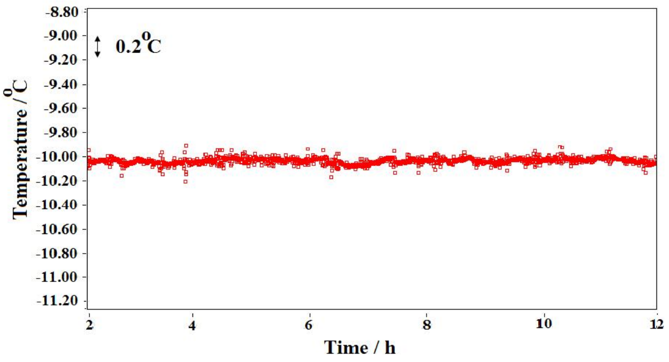

Figure 2. Temperature stability at the center of the bath at -10 °C.

Thermal Gradient

The vertical gradient in a bath is termed “axial uniformity”. The horizontal gradient in a bath is termed “radial uniformity” (EURAMET, 2011).

Vertical Thermal Gradient

Figures from 3to 10 show the temperature gradient due to thermometer depths through five levels at different setting points for SPRTs SN 234 and SN 247.

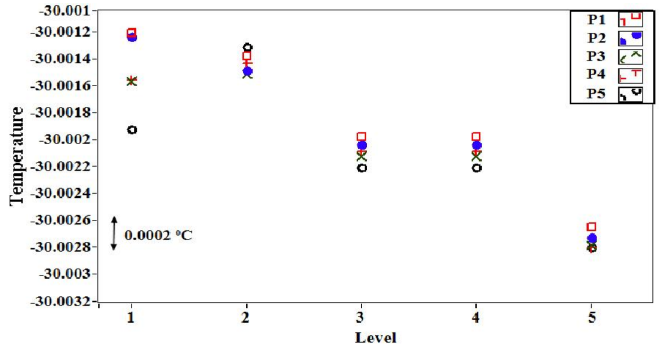

Figure 3. Thermal axial gradient at -30.0 °C for SPRT SN 234.

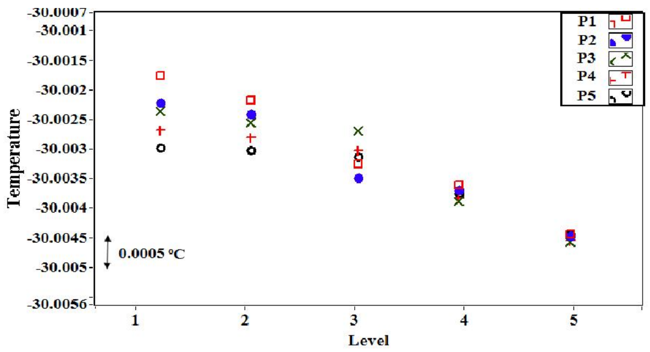

Figure 4. Thermal axial gradient at -30.0 °Cfor SPRT SN 247.

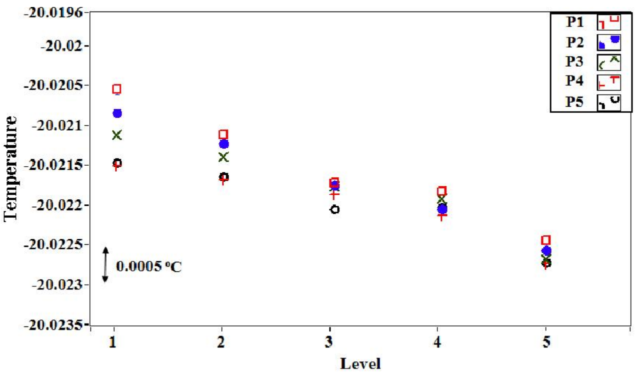

Figure 5.Thermal axial gradient at -20.0 °C for SPRT SN 234.

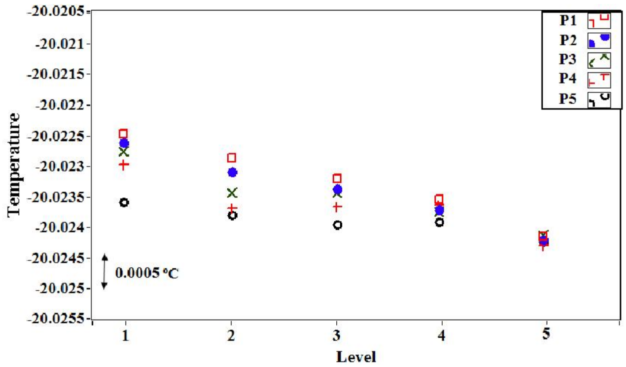

Figure 6. Thermal axial gradient at -20.0 °C for SPRT SN 247.

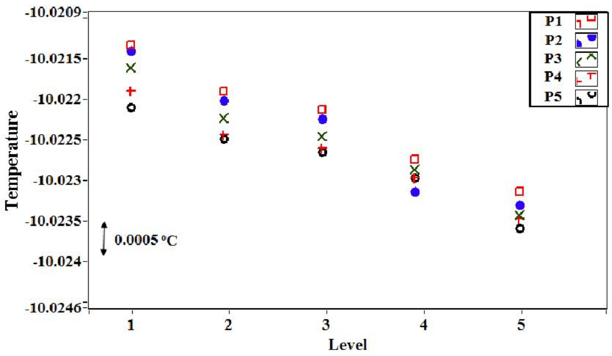

Figure 7. Thermal axial gradient at -10.0 °C for SPRT SN 234.

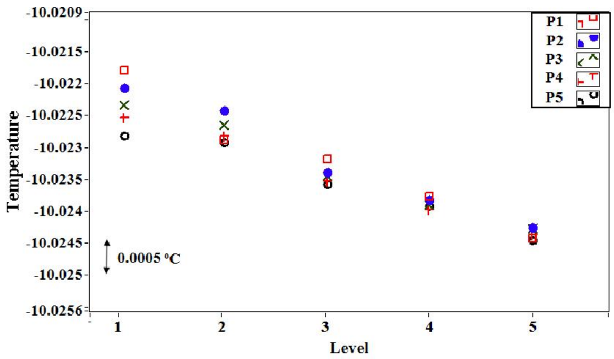

Figure 8. Thermal axial gradient at-10.0 °C for SPRT SN 247.

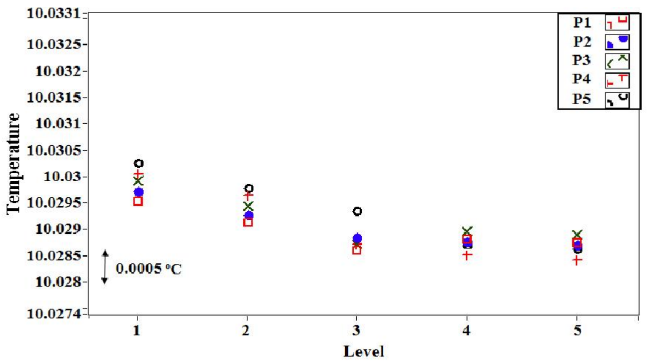

Figure 9. Thermal axial gradient at 10.0 °C for SPRT SN 234.

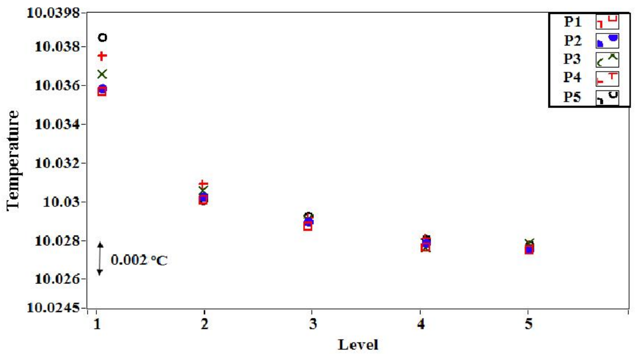

Figure 10. Thermal axial gradient at 10.0 °C for SPRT SN 247.

Horizontal Thermal Gradient

Figures from 11 to 18 show the temperature gradient due to thermometer positions at each level at different setting points for SPRTs SN 234 and SN 247.

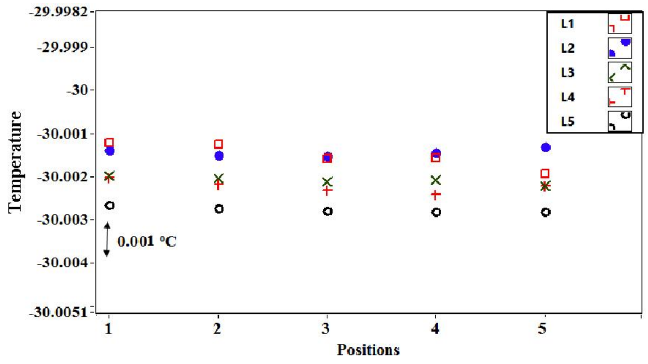

Figure 11. Thermal radial gradient at -30.0 °C for SPRT SN 234.

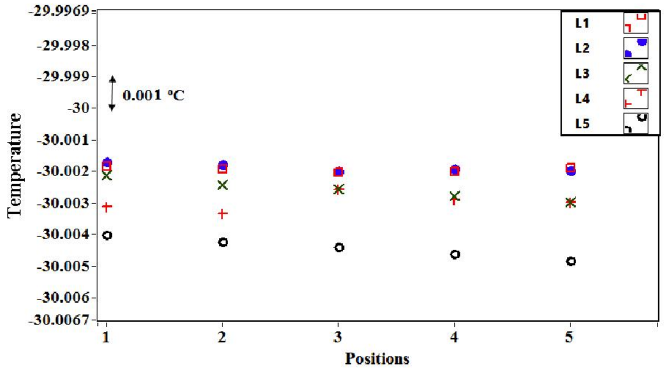

Figure 12. Thermal radial gradient at -30.0 °C for SPRT SN 247.

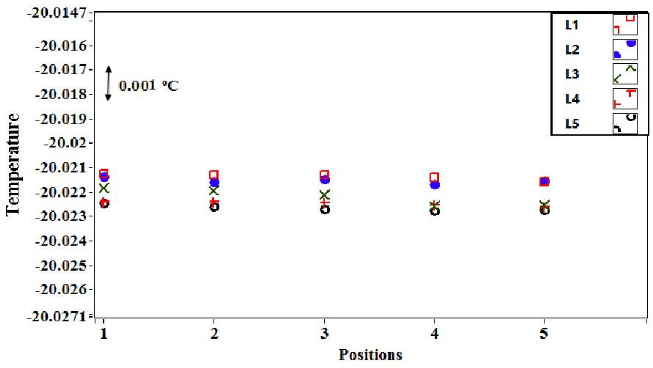

Figure 13. Thermal radial gradient at -20.0 °C for SPRT SN 234.

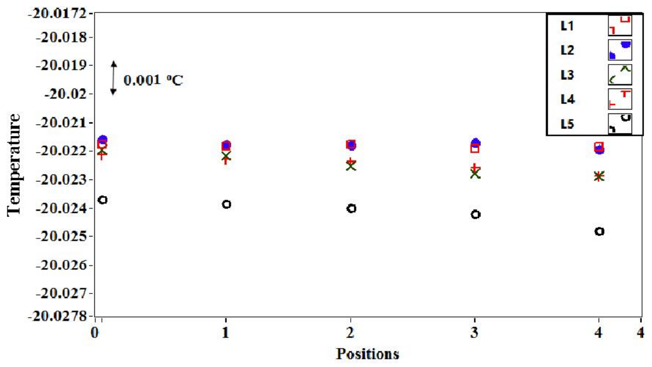

Figure 14. Thermal radial gradient at -20.0 °C for SPRT SN 247.

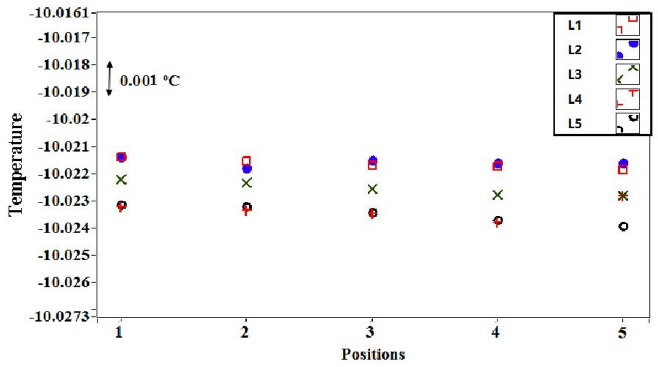

Figure 15. Thermal radial gradient at -10.0 °C for SPRT SN 234.

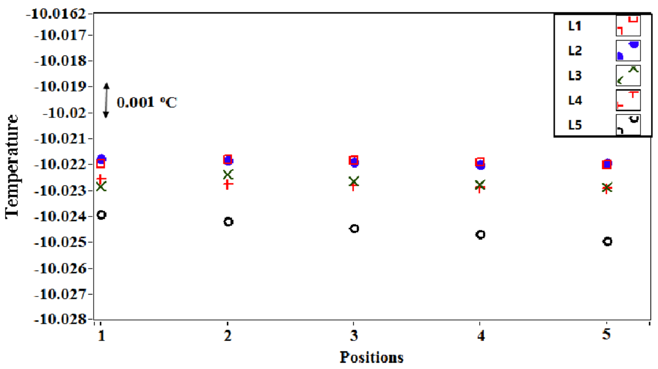

Figure 16. Thermal radial gradient at -10.0 °C for SPRT SN 247.

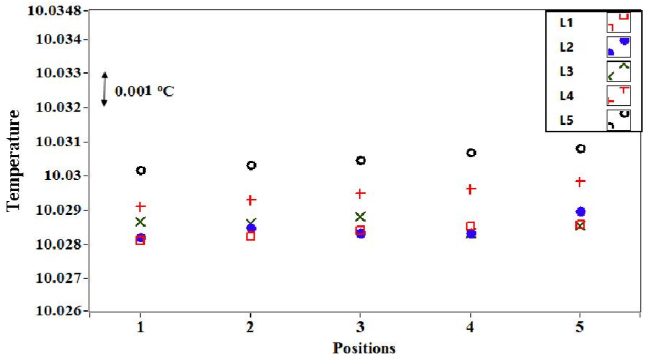

Figure 17. Thermal radial gradient at 10.0 °C for SPRT SN 234.

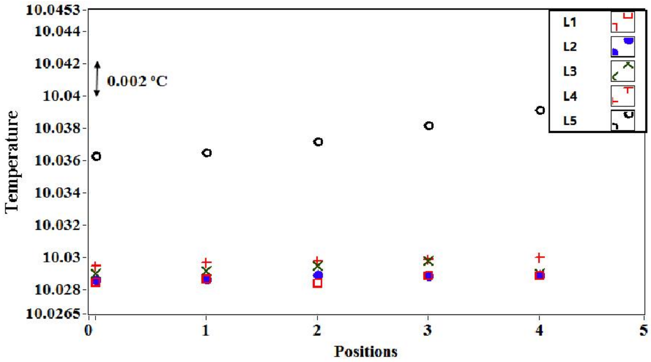

Figure 18. Thermal radial gradient at 10.0 °C for SPRT SN 247.

In order to calculated the thermal gradient which define from the following equation

$$\nabla T = \frac{\delta T}{\delta x} + \frac{\delta T}{\delta y} + \frac{\delta T}{\delta z}$$

The study was carried out on two dimensions vertical and horizontal.

The axial thermal gradient = 0.014.
The Radial thermal gradient = 0.012.

Uncertainty Estimation

The combined standard uncertainty of a measurement result is taken to represent the estimated standard deviation of the result. It is obtained by combining the individual standard uncertainties u_i, whether arising from Type A and Type B evaluation (GUM, 1995).

$$u_c^2(y) = \sum_{i=1}^{n} u_i^2(y)(2)$$

Combined uncertainty calculated from

$$U_c \;=\; \sqrt[2]{u_{St}^2 + u_{Ra}^2 + u_{Ax}^2 + u_{C.C}^2 + u_{T.B}^2 + u_{H.F}^2}$$

Table 3. Uncertainty for a metrology bath with a standard thermometer as the readout

Uncertainty Contributors	Symbol	Uncertainty (°C)
Stability	u_{St}	0.015
Radial uniformity	$u_{Ra.}$	0.012
Axial uniformity	u_{Ax}	0.014
Reference SPRTs calibration certificates	$u_{C.C}$	0.001
Thermometry Bridge	$u_{T.B}$	0.00027
Heat Flux from ambient	$u_{H.F}$	0.0022
Combined Standard Uncertainty (U_C)		0.023894
Expanded Uncertainty (k=2)		0.047788

Conclusion

An intensive work was carried out on studying the new metrological viscosity bath to realize the national viscosity scale in wide temperature ranges. The results show that the bath worked with stability better than 0.015 °C. Thermal profile distribution achieved by two SPRTs calibrated at ITS-90 to calculate the thermal gradient homogenty. Thermal axial and radial gradient equivalent to 0.014 °C and 0.012 °C respectively.

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