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INTERLABORATORY COMPARISON OF DIGITAL THERMOMETER BETWEEN THE TEMPERATURE RANGE FROM -40 °C TO 420 °C

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Abstract – A national interlaboratory comparison on thermometry field was carried out between the temperature range was -40 °C and 420 °C according to International Temperature Scale of 1990 (ITS-90)[1] with the co-operation of TURKAK (Turkish Accreditation Agency) and TUBITAK – UME (National Metrology Institute of Turkey). 14 national laboratories were participated in this interlaboratory comparison.

The details and the results of this national comparison will be given in this paper.

Keywords: ITS-90, interlaboratory comparison

1. INTRODUCTION

One of the main criteria demonstrating the competence of calibration laboratory is the successful participation in interlaboratory comparisons [2]. Real capability of the laboratory including claimed uncertainties could be proved based on the results of comparisons, evaluated either through E_n-criteria or other acceptable measures. As a number of accredited laboratories with scope covering calibration services in the field of thermometry has been increasing, the demand for organization of interlaboratory comparison with participation of accredited laboratories occur. Based on this fact, two interlaboratory comparisons were carried out for the calibration.

Two national comparisons in the field of temperature were initiated by the cooperation of TURKAK and TUBITAK UME in 2006. One of them was calibration of the thermocouples between the temperature range 500 °C and 1100 °C and the second one was comparison of laboratories local realisation of ITS-90 between the range -40 °C and 420 °C using a digital thermometer. The organization scheme of the comparison is shown in Fig.1.

The temperature difference and its uncertainties of the results of participating laboratories and E_n values will be presented in this paper.

2. CIRCULATING INSTRUMENT

2.1. Description

The circulated instrument (manufactured by Fluke-Hart Scientific, model 1522, serial number A39527/643341) was a Pt-100 thermometer with its display called as digital thermometer. The display has a resolution of 0.001 °C.

The thermometer was very fragile so it must be handled with extreme care. When not in use, it should be stored in a safe place in the groove of the protecting foam. The SPRT was hand-carried from UME to participating laboratories and vice versa.

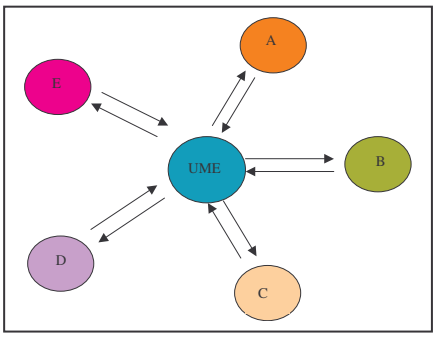
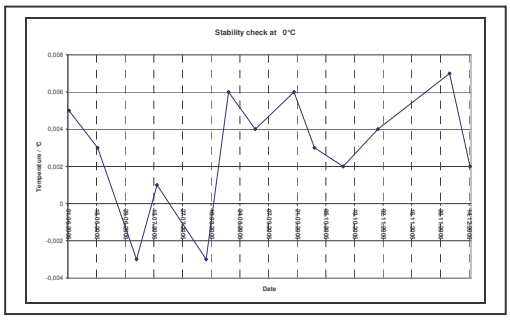


Fig. 1. Organization scheme of comparison

2.2. Stability

When the circulated thermometer was returned to TUBITAK UME, it was measured at temperatures 0 °C and 100 °C for the stability checks using deviation from the reference value. The stability checks at 0°C and 100°C are shown in Fig.2.



a. Stability check at 0 °C

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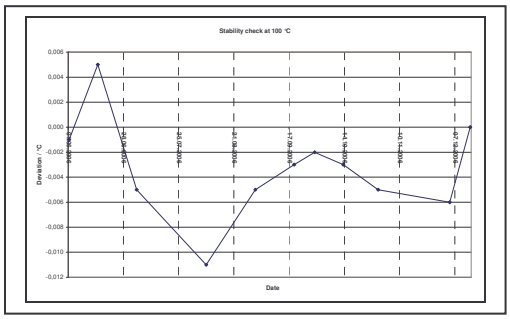

b. Stability check at 100 °C

Fig. 2. Stability check at 0 °C and 100 °C

3. MEASUREMENT

The temperature range in this interlaboratory comparison was from -40 °C to 420 °C. The technical protocol of comparison was prepared by TUBITAK UME and published at the website of TURKAK.

The circulated thermometer was calibrated by TUBITAK UME temperature laboratory before initiating comparison according to the technical protocol. There were 11 different temperature points to be measured in the temperature range of -40 °C and 420 °C.

TUBITAK UME Temperature Laboratory used its customary procedure that is also used for secondary level industrial calibrations. For the measurements, the temperature of the liquid bath was adjusted to be as close as possible to relevant temperature values at the technical protocol. Two Standard Platinum resistance Thermometers (SPRTs) were used during all measurements in the liquid baths to assess the uncertainty arising from the temperature source. Special care was taken to ensure that all the thermometers were at the same immersion depth.

During the measurements, the temperature value of circulating thermometer was read against the reference temperature values indicated by SPRTs. At least 10 cycles of measurement were completed at each comparison point.

Upon receipt of the circulating thermometer, the temperature at ice point was measured by participating laboratory. The temperature value at ice point was sent to UME. After receiving approval from UME to proceed with the comparison, each participating laboratory according their own measurement procedure.

After finishing measurements, measurement procedure, equipments used at the comparison, measured temperature values with their uncertainties were reported by each participating laboratory.

When the circulating instrument was returned to TUBITAK UME, it was measured at temperatures 0 °C and 100 °C for the stability checks.

After finishing the comparison, the circulated thermometer was calibrated by TUBITAK UME.

3. RESULTS

During evaluation, TUBITAK - UME values were regarded as reference values (t_{ref}) and the deviation of the participant laboratories' values with the given uncertainties were calculated.

By using the assigned measurement and uncertainty values of the participants laboratories, the temperature difference (D_i) and the uncertainty (U_{Di}) for each laboratory has been calculated according to the formulas [3]

$$D_i = D_{t_{labi}-t_{ref}} = t_{Lab_i} - t_{ref} \quad (1)$$

$$U_{D_i} = \sqrt{(U_{Labi})^2 + (U_{ref})^2 + (U_{stability})^2} \quad (2)$$

For each comparison temperature value the differences between the participant laboratories and the uncertainty of these differences have been calculated according to the formulas below:

$$D_{i,j} = (t_{Lab_i} - t_{ref}) - (t_{Labj} - t_{ref})$$
$$D_{i,j} = t_{labi} - t_{labj} \quad (3)$$

$$U_{D_{i,j}} = \sqrt{(U_{Labi})^2 + (U_{Labj})^2} \quad (4)$$

The temperature differences and their uncertainties between each participating laboratories at the selected temperatures are shown in Tables 1-4.

Table 1. The temperature differences, $D_{i,j,}$ (upper triangle) and their uncertainties, $U_{i,j,}$, (lower triangle) between each participating laboratories at -40 °C

-40 °C	Lab1	Lab2	Lab3	Lab4	Lab5	Lab6	Lab7	Lab8	Lab9	Lab10	Lab11	Lab12	Lab13	Lab14
Lab1	--	0,000	-0,006	-0,008	-0,003	-0,004	0,000	0,005	-0,009	0,005	-0,023	0,005	0,005	0,005
Lab2	0,241	--	-0,006	-0,007	-0,003	-0,004	0,000	0,006	-0,009	0,006	-0,023	0,006	0,006	0,006
Lab3	0,026	0,241	--	-0,001	0,003	0,002	0,006	0,012	-0,003	0,012	-0,017	0,012	0,012	0,012
Lab4	0,023	0,241	0,026	--	0,005	0,003	0,007	0,013	-0,001	0,013	-0,016	0,013	0,013	0,013
Lab5	0,045	0,244	0,047	0,045	--	-0,001	0,003	0,008	-0,006	0,008	-0,020	0,008	0,008	0,008
Lab6	0,065	0,248	0,066	0,065	0,076	--	0,004	0,010	-0,005	0,010	-0,019	0,010	0,010	0,010
Lab7	1,604	1,622	1,604	1,604	1,605	1,605	--	0,006	-0,009	0,006	-0,023	0,006	0,006	0,006
Lab8	0,016	0,240	0,020	0,017	0,042	0,063	1,604	--	-0,015	0,000	-0,029	0,000	0,000	0,000
Lab9	0,072	0,250	0,073	0,072	0,082	0,094	1,606	0,070	--	0,015	-0,014	0,015	0,015	0,015
Lab10	0,101	0,260	0,102	0,101	0,108	0,118	1,607	0,100	0,122	--	-0,029	0,000	0,000	0,000
Lab11	0,121	0,268	0,122	0,121	0,127	0,136	1,608	0,120	0,139	0,156	--	0,029	0,029	0,029
Lab12	0,016	0,240	0,020	0,017	0,042	0,063	1,604	0,000	0,070	0,100	0,120	--	0,000	0,000
Lab13	0,016	0,240	0,020	0,017	0,042	0,063	1,604	0,000	0,070	0,100	0,120	0,000	--	0,000
Lab14	0,016	0,240	0,020	0,017	0,042	0,063	1,604	0,000	0,070	0,100	0,120	0,000	0,000	--

Table 2. The temperature differences, $D_{i,j,}$ (upper triangle) and their uncertainties, $U_{i,j,}$, (lower triangle) between each participating laboratories at 0 °C

0 °C	Lab1	Lab2	Lab3	Lab4	Lab5	Lab6	Lab7	Lab8	Lab9	Lab10	Lab11	Lab12	Lab13	Lab14
Lab1	--	-0,006	0,003	-0,003	-0,001	0,005	0,000	-0,007	-0,007	-0,006	0,001	0,044	-0,058	-0,002
Lab2	0,052	--	0,009	0,003	0,005	0,011	0,006	-0,001	0,000	0,000	0,007	0,050	-0,052	0,004
Lab3	0,022	0,052	--	-0,006	-0,004	0,002	-0,003	-0,010	-0,009	-0,009	-0,002	0,041	-0,061	-0,005
Lab4	0,023	0,052	0,022	--	0,002	0,008	0,003	-0,004	-0,004	-0,003	0,004	0,047	-0,055	0,001
Lab5	0,019	0,051	0,018	0,019	--	0,006	0,001	-0,006	-0,006	-0,005	0,002	0,045	-0,057	-0,001
Lab6	0,064	0,080	0,064	0,064	0,063	--	-0,005	-0,012	-0,011	-0,011	-0,004	0,039	-0,063	-0,007
Lab7	0,063	0,079	0,063	0,063	0,062	0,087	--	-0,007	-0,006	-0,006	0,001	0,044	-0,058	-0,002
Lab8	0,062	0,078	0,062	0,062	0,061	0,086	0,086	--	0,001	0,001	0,008	0,051	-0,051	0,005
Lab9	0,052	0,071	0,052	0,052	0,051	0,080	0,079	0,078	--	0,001	0,007	0,050	-0,052	0,004
Lab10	0,101	0,112	0,101	0,101	0,100	0,118	0,117	0,117	0,112	--	0,007	0,050	-0,052	0,004
Lab11	0,121	0,130	0,121	0,121	0,120	0,135	0,135	0,134	0,130	0,156	--	0,043	-0,059	-0,003
Lab12	0,211	0,216	0,211	0,211	0,210	0,219	0,219	0,218	0,216	0,233	0,242	--	-0,102	-0,046
Lab13	0,070	0,084	0,070	0,070	0,069	0,092	0,091	0,091	0,084	0,121	0,138	0,221	--	0,056
Lab14	0,048	0,067	0,047	0,048	0,046	0,077	0,076	0,075	0,067	0,110	0,128	0,215	0,082	--

Table 3. The temperature differences, $D_{i,j}$, (upper triangle) and their uncertainties, $U_{i,j}$, (lower triangle) between each participating laboratories at 180 °C

180 °C	Lab1	Lab2	Lab3	Lab4	Lab5	Lab6	Lab7	Lab8	Lab9	Lab10	Lab11	Lab12	Lab13	Lab14
Lab1	--	0,024	0,027	0,000	-0,003	0,004	-0,002	0,031	-0,014	0,055	-0,060	2,137	0,466	-0,009
Lab2	0,184	--	0,003	-0,025	-0,028	-0,020	-0,026	0,007	-0,038	0,031	-0,084	2,113	0,442	-0,033
Lab3	0,044	0,182	--	-0,028	-0,031	-0,023	-0,029	0,004	-0,041	0,028	-0,087	2,110	0,439	-0,036
Lab4	0,050	0,183	0,043	--	-0,003	0,005	-0,002	0,032	-0,014	0,055	-0,059	2,138	0,467	-0,008
Lab5	0,039	0,181	0,029	0,038	--	0,008	0,002	0,035	-0,010	0,059	-0,056	2,141	0,470	-0,005
Lab6	0,072	0,190	0,067	0,071	0,064	--	-0,006	0,027	-0,018	0,051	-0,064	2,133	0,462	-0,013
Lab7	0,036	0,180	0,025	0,035	0,014	0,062	--	0,033	-0,012	0,057	-0,058	2,139	0,468	-0,007
Lab8	0,088	0,197	0,084	0,087	0,081	0,101	0,080	--	-0,045	0,024	-0,091	2,106	0,435	-0,040
Lab9	0,097	0,201	0,093	0,097	0,091	0,109	0,090	0,120	--	0,069	-0,046	2,151	0,480	0,005
Lab10	0,154	0,234	0,152	0,154	0,151	0,162	0,150	0,170	0,175	--	-0,115	2,082	0,411	-0,064
Lab11	0,154	0,234	0,152	0,154	0,151	0,162	0,150	0,170	0,175	0,212	--	2,197	0,526	0,051
Lab12	3,000	3,005	3,000	3,000	3,000	3,001	3,000	3,001	3,001	3,004	3,004	--	-1,671	-2,146
Lab13	0,269	0,322	0,268	0,269	0,267	0,274	0,267	0,279	0,282	0,306	0,306	3,012	--	-0,475
Lab14	0,123	0,215	0,121	0,123	0,119	0,133	0,118	0,143	0,148	0,191	0,191	3,002	0,292	--

Table 4. The temperature differences, $D_{i,j}$, (upper triangle) and their uncertainties, $U_{i,j}$, (lower triangle) between each participating laboratories at 420 °C

420 °C	Lab1	Lab2	Lab3	Lab4	Lab5	Lab6	Lab7	Lab8	Lab9	Lab10	Lab11	Lab12	Lab13	Lab14
Lab1	--	0,075	0,049	-0,012	-0,022	-0,140	-0,018	-0,015	-0,015	-0,502	-0,154	4,553	-2,403	-0,015
Lab2	0,293	--	-0,026	-0,087	-0,097	-0,215	-0,093	-0,090	-0,090	-0,577	-0,229	4,478	-2,478	-0,090
Lab3	0,108	0,307	--	-0,061	-0,071	-0,189	-0,067	-0,064	-0,064	-0,551	-0,203	4,504	-2,452	-0,064
Lab4	0,136	0,318	0,164	--	-0,009	-0,128	-0,006	-0,003	-0,003	-0,489	-0,142	4,565	-2,391	-0,003
Lab5	0,067	0,295	0,113	0,140	--	-0,118	0,004	0,007	0,007	-0,480	-0,132	4,575	-2,381	0,007
Lab6	0,098	0,303	0,134	0,158	0,104	--	0,122	0,125	0,125	-0,362	-0,014	4,693	-2,263	0,125
Lab7	2,303	2,321	2,305	2,307	2,304	2,305	--	0,003	0,003	-0,484	-0,136	4,571	-2,385	0,003
Lab8	0,041	0,290	0,100	0,130	0,053	0,089	2,303	--	0,000	-0,487	-0,139	4,568	-2,388	0,000
Lab9	0,041	0,290	0,100	0,130	0,053	0,089	2,303	0,000	--	-0,487	-0,139	4,568	-2,388	0,000
Lab10	0,402	0,494	0,412	0,421	0,403	0,410	2,337	0,400	0,400	--	0,348	5,055	-1,901	0,487
Lab11	0,402	0,494	0,412	0,421	0,403	0,410	2,337	0,400	0,400	0,566	--	4,707	-2,249	0,139
Lab12	3,000	3,014	3,002	3,003	3,000	3,001	3,782	3,000	3,000	3,027	3,027	--	-6,956	-4,568
Lab13	8,110	8,115	8,111	8,111	8,110	8,110	8,431	8,110	8,110	8,120	8,120	8,647	--	2,388
Lab14	0,041	0,290	0,100	0,130	0,053	0,089	2,303	0,000	0,000	0,400	0,400	3,000	8,110	--

Also the E_n value (normalized error) has been calculated according to the formula given below and its absolute value should be lower than unity [4]:

$$E_n = \frac{t_{Lab_i} - t_{ref}}{\sqrt{(U_{Labi})^2 + (U_{ref})^2}} \qquad (5)$$

Good agreement between the laboratories was found in this interlaboratory comparison. Only a few E_n values are grater than unity. The normalized errors for the selected temperatures (-40 °C, 0 °C, 180 °C and 420 °C) can be seen in Figures 3-6.

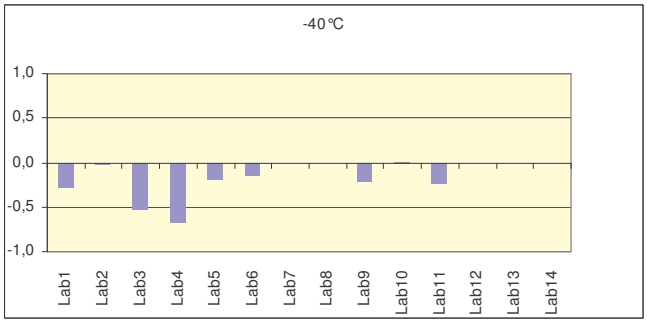

Fig. 3. The normalized error at -40 °C

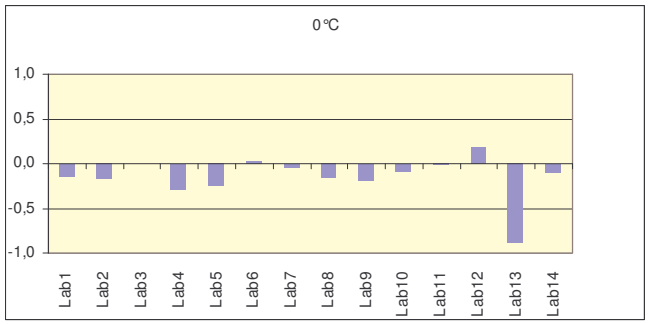

Fig. 4. The normalized error at 0 °C

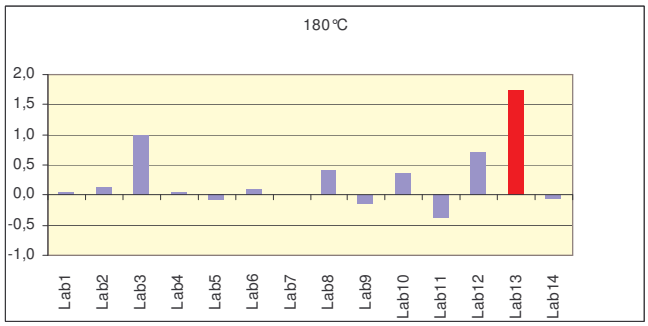

Fig. 5. The normalized error at 180 °C

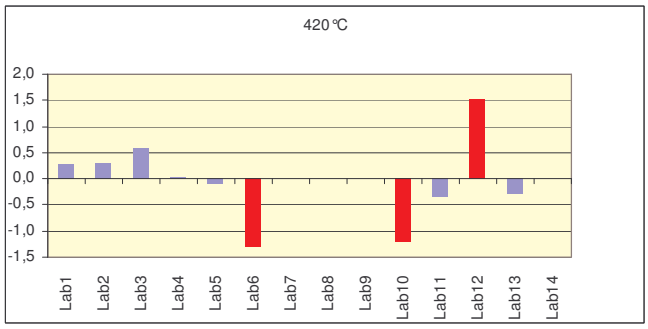

Fig. 6. The normalized error at 420 °C

4. CONCLUSIONS

Fourteen national laboratories were participated in the national interlaboratory comparison of digital thermometer with Pt-100 probe between the temperature range -40 °C and 420 °C according to ITS-90 with the co-operation of TURKAK and TUBITAK – UME.

The interlaboratory comparison was conducted as star comparison. The pilot laboratory of this comparison was UME Temperature Laboratory constituting the link between the participant laboratories.

The comparison was carried out according to the comparison protocol nevertheless it was observed that some participant laboratories' comparison report was not conformable with the protocol and the report sent to TURKAK was not containing whole the necessary information. The evaluation of the comparison was made by

the pilot laboratory. The temperature deviation from reference value and the uncertainty of each participant laboratory was calculated. Besides, for each comparison temperature value the differences between the participant laboratories $D_{i,j}$ and the uncertainty of these differences $U_{Di,j}$ have been calculated. Finally for each comparison temperature value, the E_n values of each participant laboratory have been determined.

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