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**Quantitative Analysis of Iron Ore Concentrate,
Using Laser Induced Breakdown Spectroscopy (LIBS)
in On-Line, Real-Time Mode.**

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Product: Iron Ore Concentrate

1. Technical task

- Sample assessment and potential accuracy estimation for on-line, real-time LIBS analysis on a conveyor belt.
- Quantitative analysis of Fe, SiO₂, S, Al₂O₃, CaO, TiO₂.

2. Samples

20 samples of iron ore concentrate were received for testing by the LIBS system.

The following table describes the chemical content of the samples:

#	Sample	Fe, %	SiO ₂ , %	S, %	Al ₂ O ₃ , %	CaO, %	TiO ₂ , %
1	S1	65.72	4.327	0.032	0.265	0.311	0.165
2	S2	66.67	3.679	0.021	0.253	0.15	0.136
3	S3	67.15	3.21	0.012	0.24	0.096	0.122
4	S4	66.45	4.154	0.15	0.206	0.048	0.113
5	S5	65.74	4.69	0.089	0.333	0.119	0.198
6	S6	65.71	4.878	0.174	0.302	0.083	0.149
7	S7	67.14	3.291	0.166	0.21	0.02	0.1
8	S8	66.37	3.972	0.073	0.222	0.062	0.161
9	S9	66.11	4.592	0.124	0.243	0.063	0.103
10	S10	66.47	4.307	0.041	0.214	0.043	0.082
11	S11	66.17	4.208	0.066	0.28	0.119	0.176
12	S12	66.55	3.833	0.087	0.272	0.098	0.162
13	S13	66.4	4.332	0.068	0.183	0.139	0.065
14	S14	66.01	4.625	0.077	0.22	0.152	0.095
15	S15	66.4	3.722	0.021	0.254	0.283	0.148
16	S16	65.63	5.231	0.159	0.288	0.05	0.078
17	S17	66.87	3.495	0.086	0.208	0.155	0.108
18	S18	66.6	3.737	0.115	0.243	0.154	0.122
19	S19	66.48	3.705	0.045	0.216	0.261	0.129
20	S20	66.67	3.873	0.087	0.236	0.087	0.109

3. Experimental section

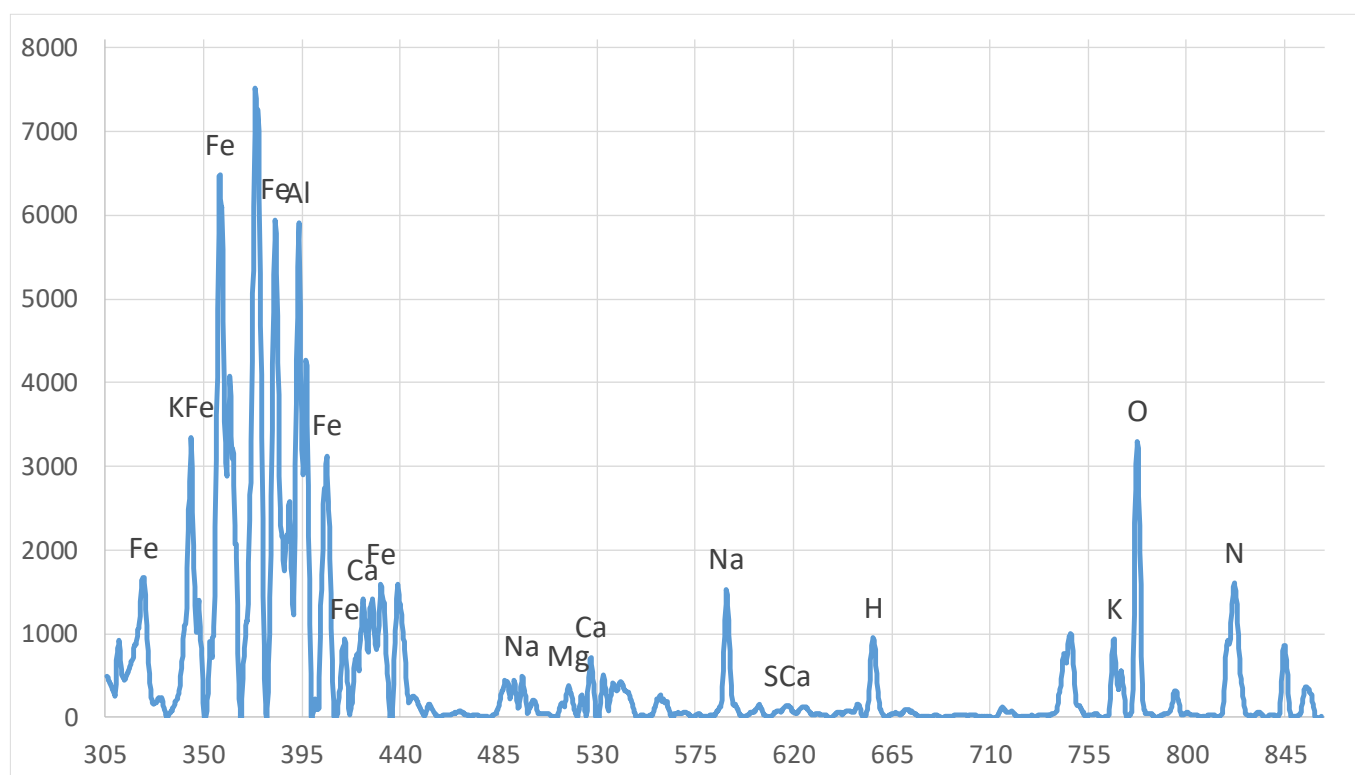
The samples were analyzed on a mini conveyor system forming narrow line of the material on a conveyor belt.

Spectral data was received using spectrometers with the following ranges: $\lambda = 306 - 862$ nm and $\lambda = 236 - 356$ nm. These ranges were chosen as most suitable for elements of interest.

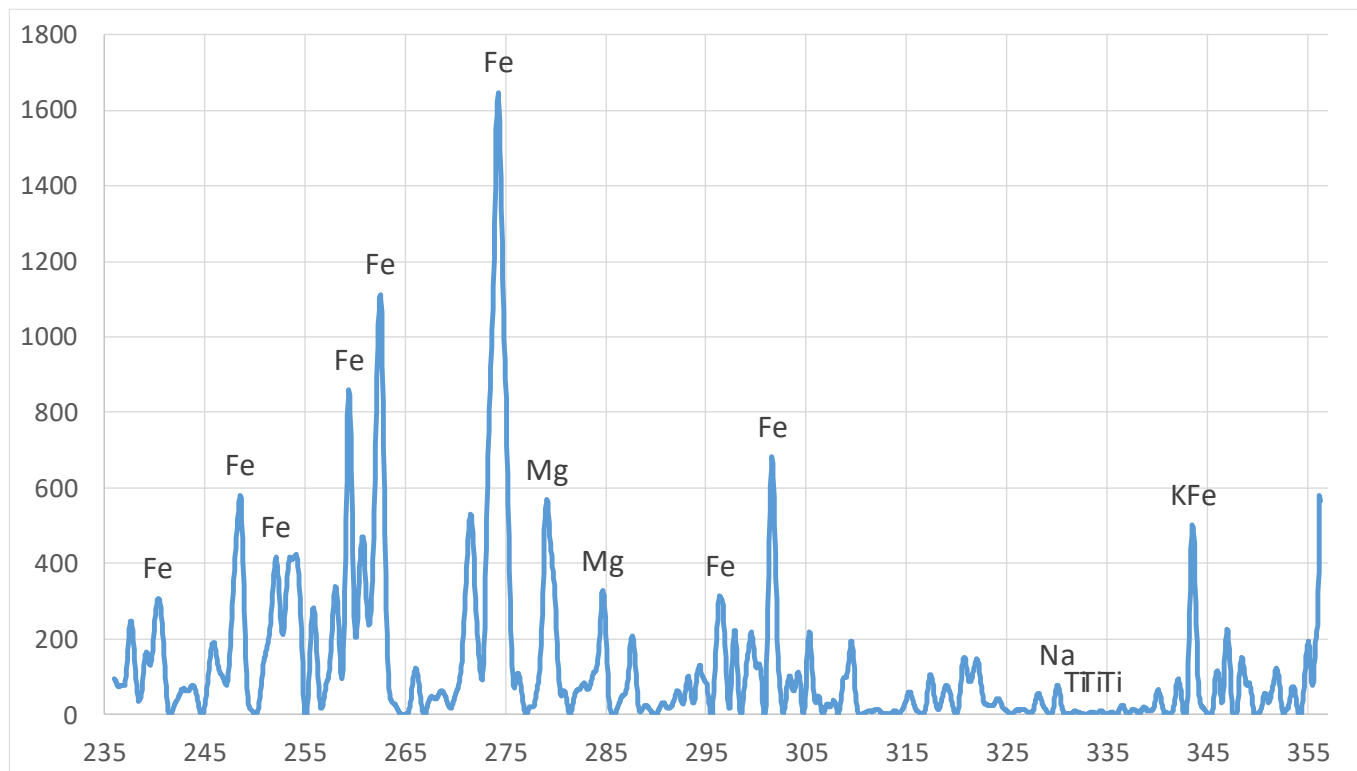
4. Qualitative spectral analysis

Typical LIBS spectrums of analyzed material are shown below. The spectral lines of particular elements are identified.

Range: $\lambda = 306 - 862$ nm



Range: $\lambda = 236 - 356 \text{ nm}$

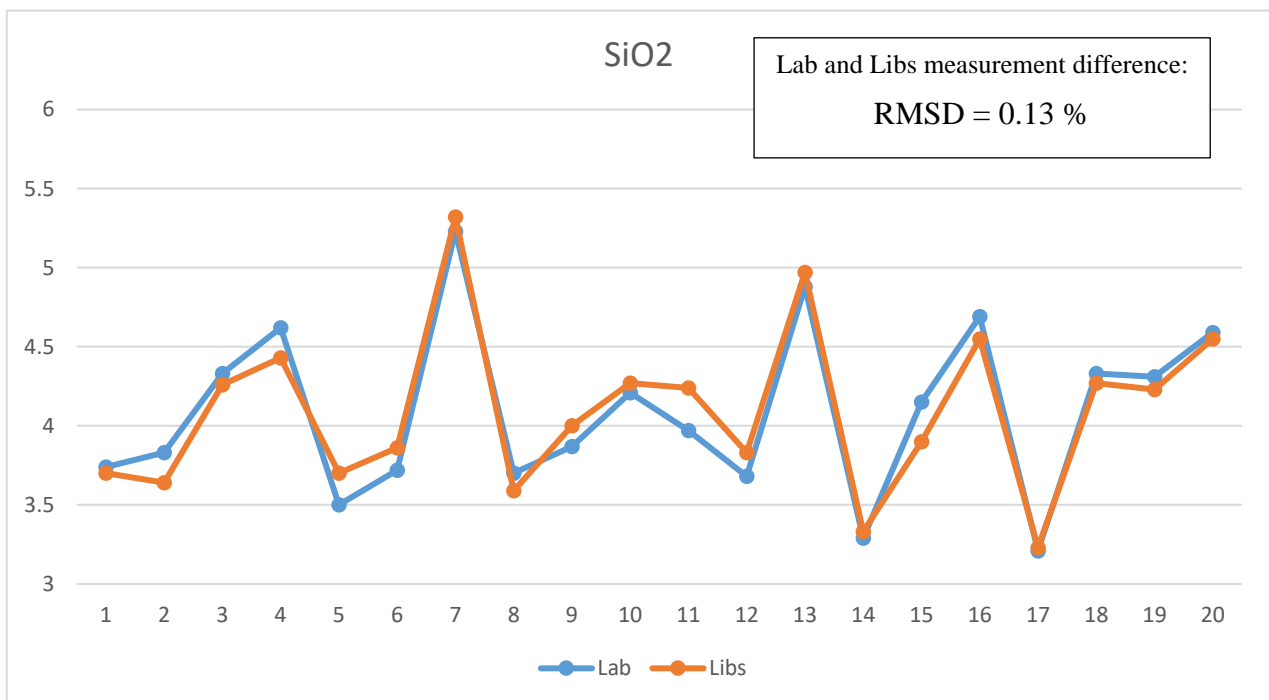
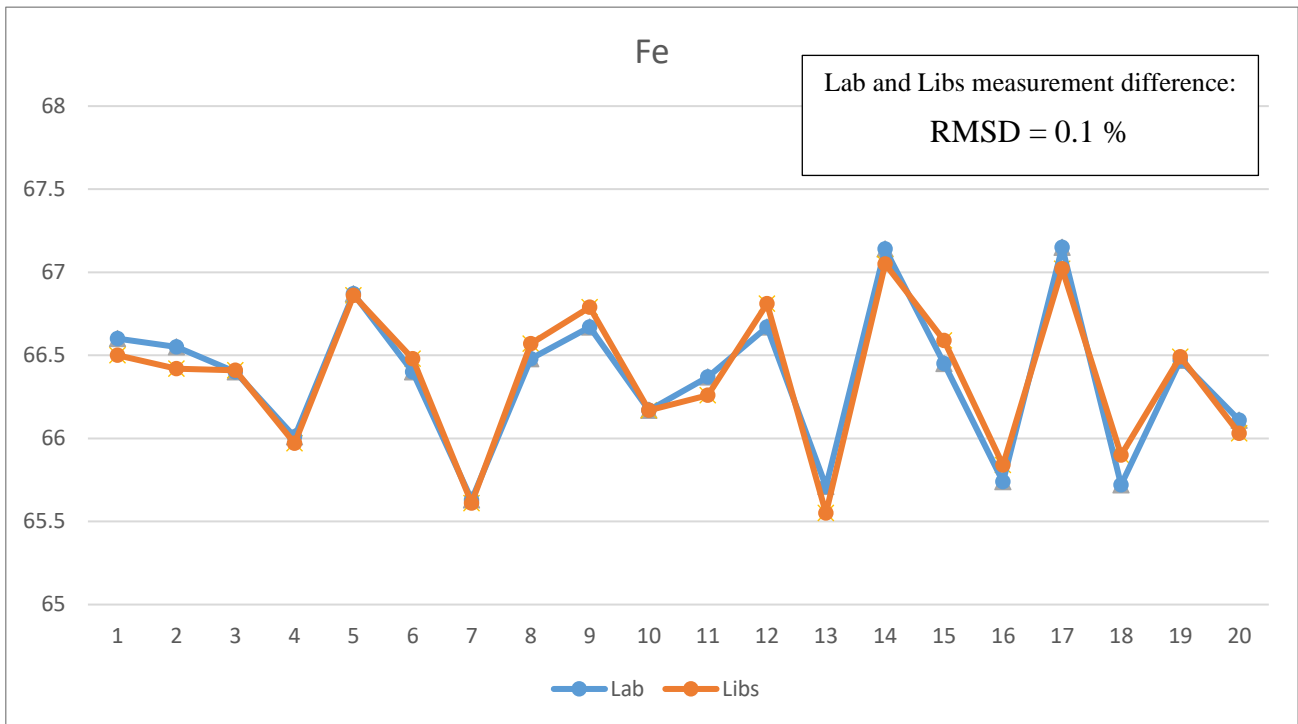


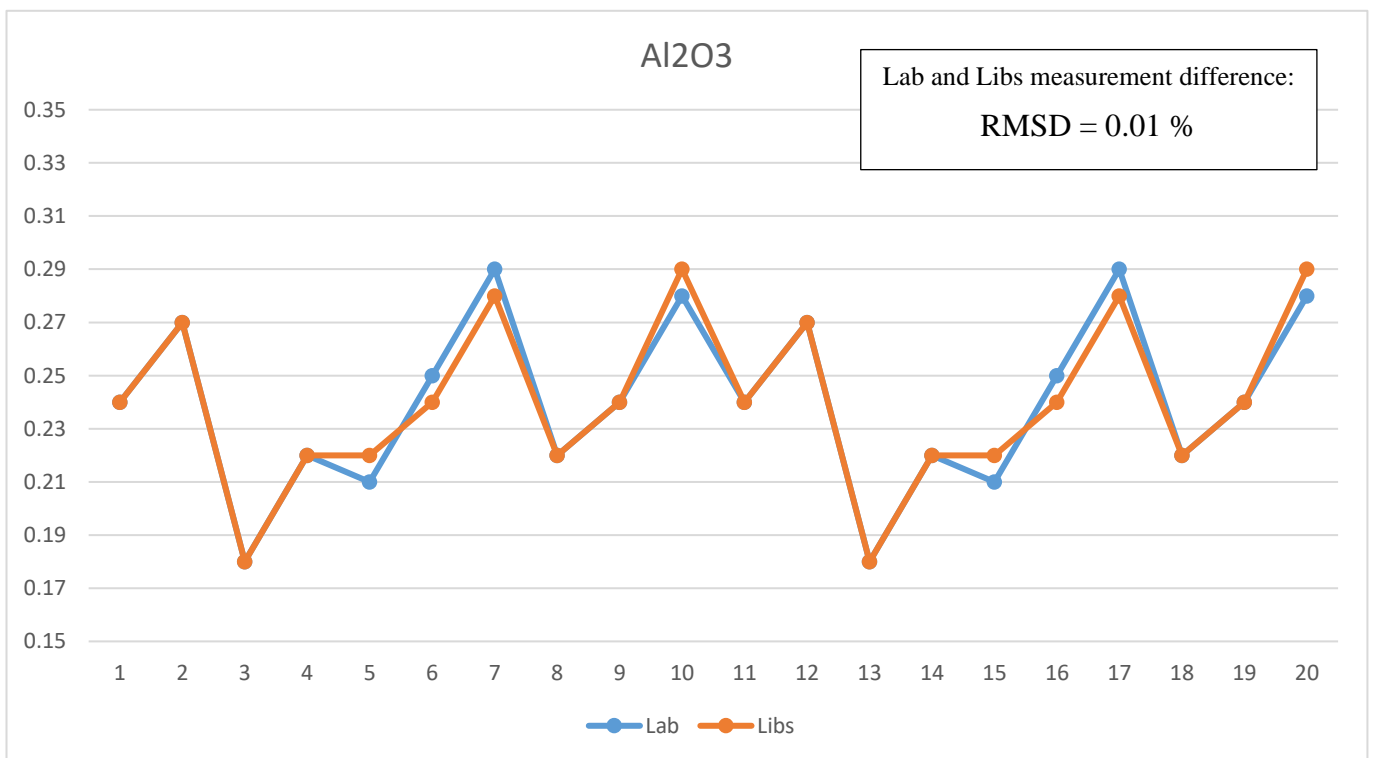
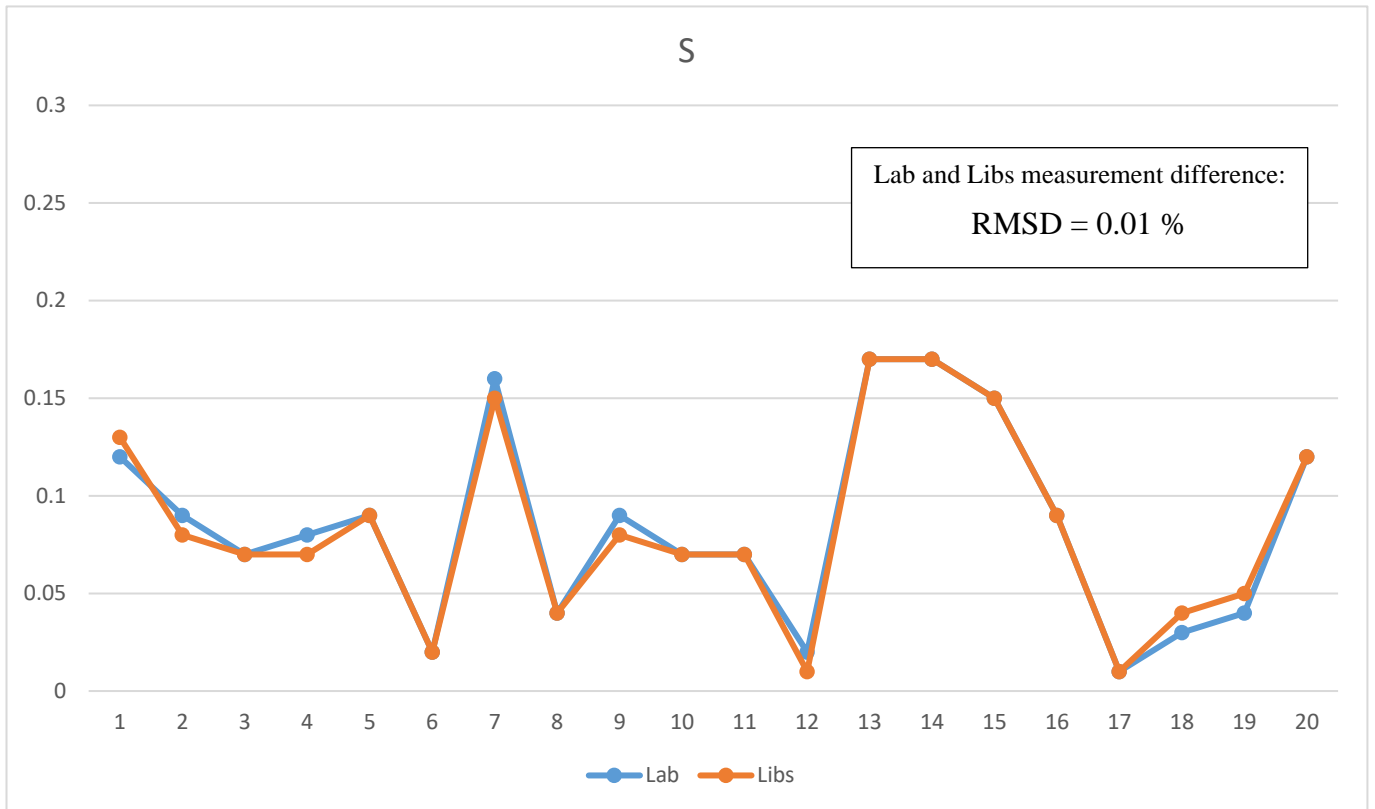
Low signal to noise level and clearly identifiable spectral lines allowed to develop a preliminary calibration algorithm for quantitative analysis.

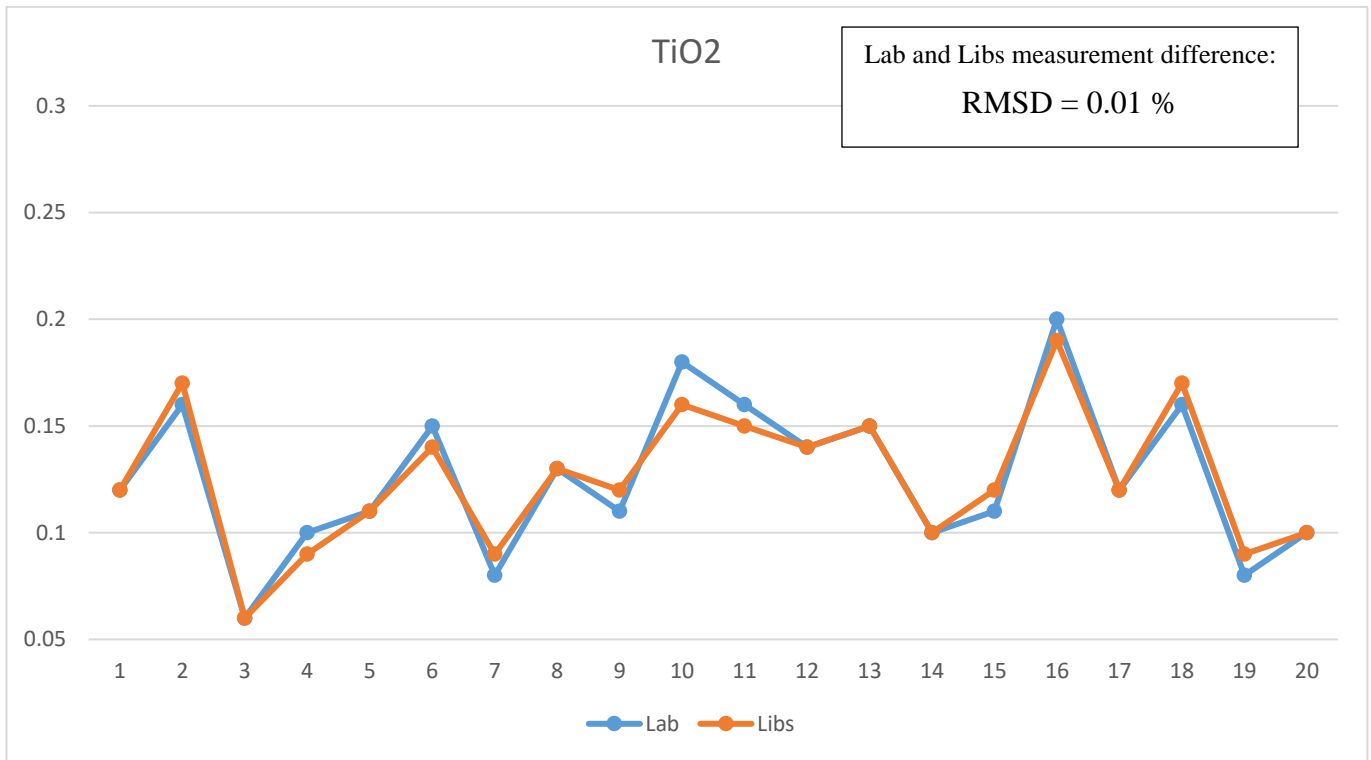
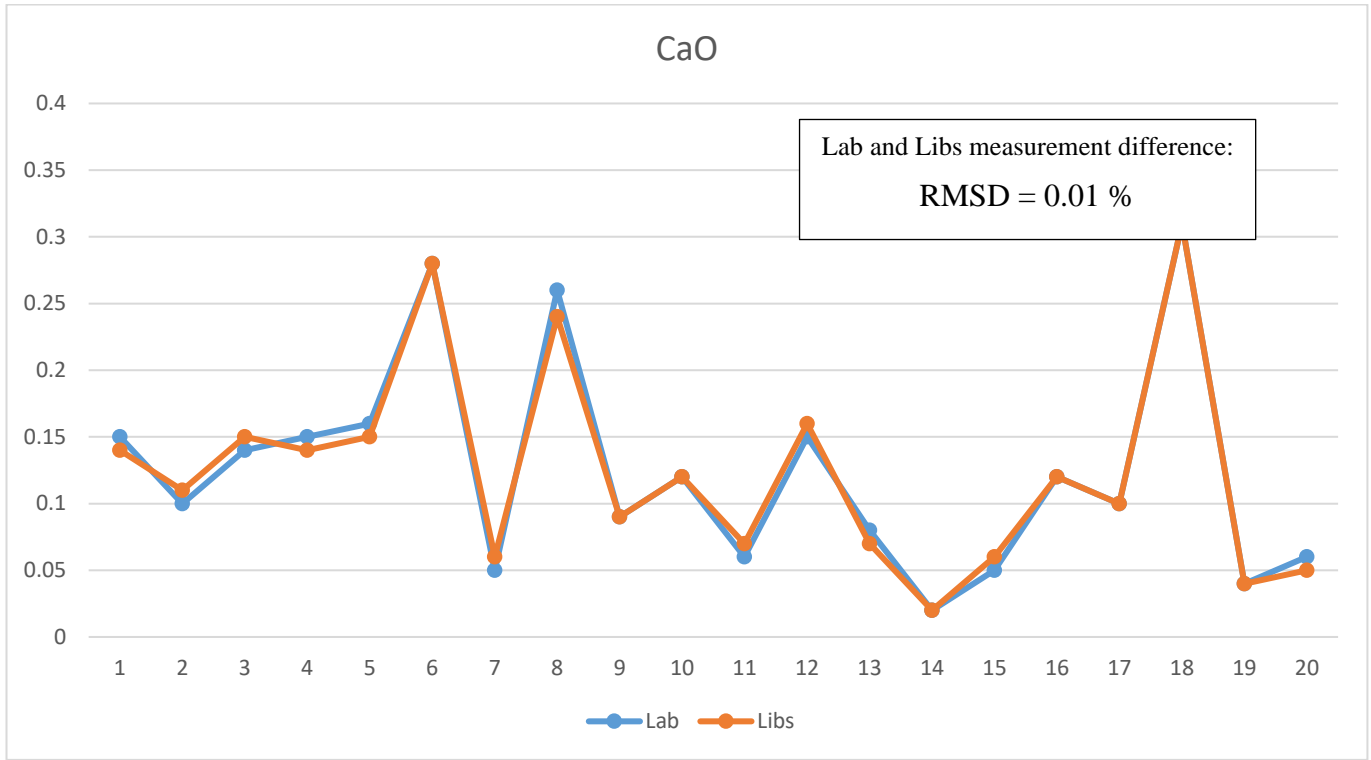
5. Quantitative analysis

A comparison between measurements of LIBS analyzer with preliminary calibrations and Customer Lab results are showed below. A detailed comparison with numeric values can be found in Annex 1.

Lab vs LIBS measurement comparison







The following table summarizes the measurement differences that were calculated using the developed calibration algorithm:

Parameter	Range of values in samples provided, %	RMSD, %
Fe	65.63 - 67.15	0.1
SiO ₂	3.21 - 5.23	0.13
S	0.01 - 0.17	0.01
Al ₂ O ₃	0.18 - 0.29	0.01
CaO	0.02 - 0.31	0.01
TiO ₂	0.06 - 0.2	0.01

Important note:

When comparing LIBS and Lab analysis, it should be noted that the LIBS error depends on the errors derived from sampling, splitting, and lab analysis of the samples provided for calibration.

6. Conclusions

- Conducted research of customer iron ore concentrate samples indicates that the material has clear LIBS spectrum analytical lines for the elements of interest with low noise/signal ratio.
- Preliminary calibration algorithms based on provided samples were developed. An analytical error of the preliminary calibration algorithms indicates the potential accuracy of the on-line measurement.

Comparison of LIBS and LAB results

Sample	Fe - Lab, %	Fe - Libs, %	Difference, %
S1	66.6	66.5	0.1
S2	66.55	66.42	0.13
S3	66.4	66.41	-0.01
S4	66.01	65.97	0.04
S5	66.87	66.86	0.01
S6	66.4	66.48	-0.08
S7	65.63	65.61	0.02
S8	66.48	66.57	-0.09
S9	66.67	66.79	-0.12
S10	66.17	66.17	0
S11	66.37	66.26	0.11
S12	66.67	66.81	-0.14
S13	65.71	65.55	0.16
S14	67.14	67.05	0.09
S15	66.45	66.59	-0.14
S16	65.74	65.84	-0.1
S17	67.15	67.02	0.13
S18	65.72	65.9	-0.18
S19	66.47	66.49	-0.02
S20	66.11	66.03	0.08
			RMSD, %
			0.1

Sample	SiO2 - Lab, %	SiO2 - Libs, %	Difference, %
S1	3.74	3.7	0.04
S2	3.83	3.64	0.19
S3	4.33	4.26	0.07
S4	4.62	4.43	0.2
S5	3.5	3.7	-0.21
S6	3.72	3.86	-0.13
S7	5.23	5.32	-0.09
S8	3.7	3.59	0.12
S9	3.87	4	-0.13
S10	4.21	4.27	-0.06
S11	3.97	4.24	-0.27
S12	3.68	3.83	-0.15
S13	4.88	4.97	-0.09
S14	3.29	3.33	-0.04
S15	4.15	3.9	0.26
S16	4.69	4.55	0.14
S17	3.21	3.23	-0.02
S18	4.33	4.27	0.06
S19	4.31	4.23	0.08
S20	4.59	4.55	0.04
			RMSD, %
			0.13

Sample	S - Lab, %	S - Libs, %	Difference, %
S1	0.12	0.13	-0.01
S2	0.09	0.08	0.01
S3	0.07	0.07	0
S4	0.08	0.07	0

S5	0.09	0.09	-0.01
S6	0.02	0.02	0
S7	0.16	0.15	0.01
S8	0.04	0.04	0
S9	0.09	0.08	0
S10	0.07	0.07	0
S11	0.07	0.07	0
S12	0.02	0.01	0.01
S13	0.17	0.17	0
S14	0.17	0.17	-0.01
S15	0.15	0.15	0
S16	0.09	0.09	0
S17	0.01	0.01	0
S18	0.03	0.04	-0.01
S19	0.04	0.05	-0.01
S20	0.12	0.12	0
			RMSD, %
			0.01

Sample	Al2O3 - Lab, %	Al2O3 - Libs, %	Difference, %
S1	0.24	0.24	0
S2	0.27	0.27	0.01
S3	0.18	0.18	0
S4	0.22	0.22	0
S5	0.21	0.22	-0.01
S6	0.25	0.24	0.02
S7	0.29	0.28	0.01

S8	0.22	0.22	0
S9	0.24	0.24	-0.01
S10	0.28	0.29	-0.01
S11	0.24	0.24	0
S12	0.27	0.27	0.01
S13	0.18	0.18	0
S14	0.22	0.22	0
S15	0.21	0.22	-0.01
S16	0.25	0.24	0.02
S17	0.29	0.28	0.01
S18	0.22	0.22	0
S19	0.24	0.24	-0.01
S20	0.28	0.29	-0.01
			RMSD, %
			0.01

Sample	CaO - Lab, %	CaO - Libs, %	Difference, %
S1	0.15	0.14	0.02
S2	0.1	0.11	-0.02
S3	0.14	0.15	-0.01
S4	0.15	0.14	0.01
S5	0.16	0.15	0.01
S6	0.28	0.28	0
S7	0.05	0.06	-0.01
S8	0.26	0.24	0.02
S9	0.09	0.09	0
S10	0.12	0.12	0

S11	0.06	0.07	-0.01
S12	0.15	0.16	-0.01
S13	0.08	0.07	0.02
S14	0.02	0.02	0
S15	0.05	0.06	-0.01
S16	0.12	0.12	0
S17	0.1	0.1	0
S18	0.31	0.31	0
S19	0.04	0.04	0
S20	0.06	0.05	0.01
			RMSD, %
			0.01

Sample	TiO2 - Lab, %	TiO2 - Libs, %	Difference, %
S1	0.12	0.12	0
S2	0.16	0.17	0
S3	0.06	0.06	0
S4	0.1	0.09	0
S5	0.11	0.11	0
S6	0.15	0.14	0.01
S7	0.08	0.09	-0.01
S8	0.13	0.13	0
S9	0.11	0.12	-0.01
S10	0.18	0.16	0.01
S11	0.16	0.15	0.01
S12	0.14	0.14	0
S13	0.15	0.15	0
S14	0.1	0.1	0

S15	0.11	0.12	-0.01
S16	0.2	0.19	0.01
S17	0.12	0.12	0.01
S18	0.16	0.17	-0.01
S19	0.08	0.09	-0.01
S20	0.1	0.1	0.01
			RMSD, %
			0.01