Beebird™ QCL-based NH_3 Analyzer Testing Report (2020.2.14)

1. Performance Testing

The following tests were carried out in HealthyPhoton R&D laboratory. The ambient temperature is 15°C~20°C, the relative humidity is 55%~75%, and the air pressure is about 1 atm.

1.1. Concentration step test

Before the test, the instrument was calibrated with 21.1 ppm standard ammonia (the relative expansion uncertainty (k = 2) was 5%) and high purity nitrogen (N_2).

A flowmeter was used to prepare the gas sample with different concentrations of ammonia for testing, which are 0 ppm, 5 ppm, 10 ppm, 15 ppm, 20 ppm, 15 ppm, 10 ppm, 5 ppm, 0 ppm. The test time for each concentration is 10 minutes. The results are shown in Figure 1 (b), in which the black points are the concentration readings of the tested analyzer.

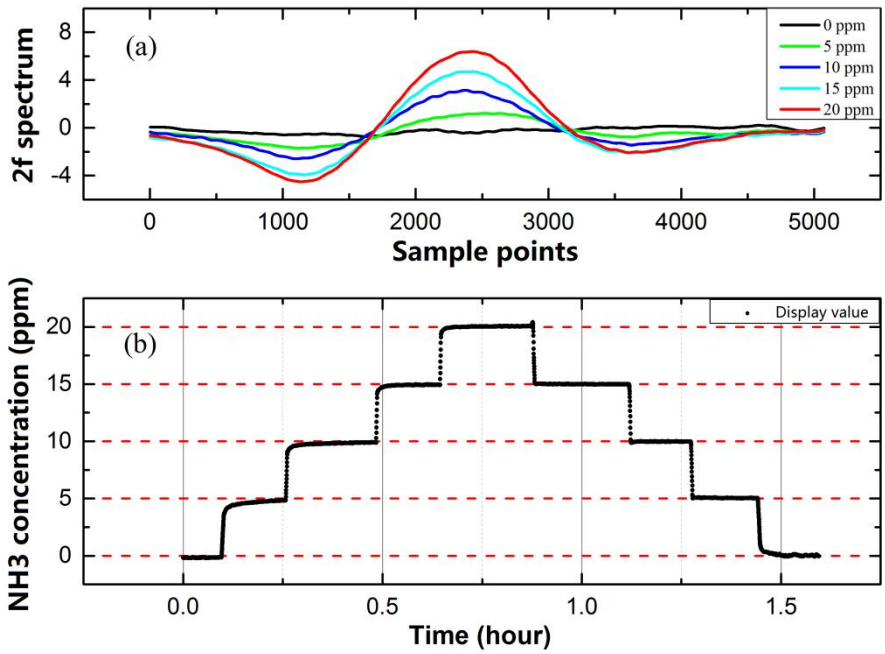

Figure 1 Concentration step test: (a) 2f spectrum of different NH_3 concentration
(b) The Beebird™ analyzing module readings

1.2. Accuracy

For each concentration step in the test shown in Sec. 1.1, we took the concentration average of two minutes after stabilization as the measured value. Table 1 shows that the maximum deviation between the measured value and the actual setup concentration is only 0.6%.

Table 1 Data for measurement error caculations

*Absolute error = measured value - actual concentration，relative error = absolute error/actual concentration

Actual concentration (ppm)	0.00	5.00	10.00	15.00	20.00
Measured value (ppm)	0.03	5.03	9.97	14.96	20.08
*Absolute error (ppm)	0.03	0.03	-0.03	-0.04	0.08
*Relative error	-	0.6%	-0.3%	-0.3%	0.4%

1.3. Linearity

The linear analysis was performed for the measured values shown in Table 1 with respect to the setup concentrations. In Figure 2, the linear correlation coefficient R^2 is 0.99995, which shows high linearity.

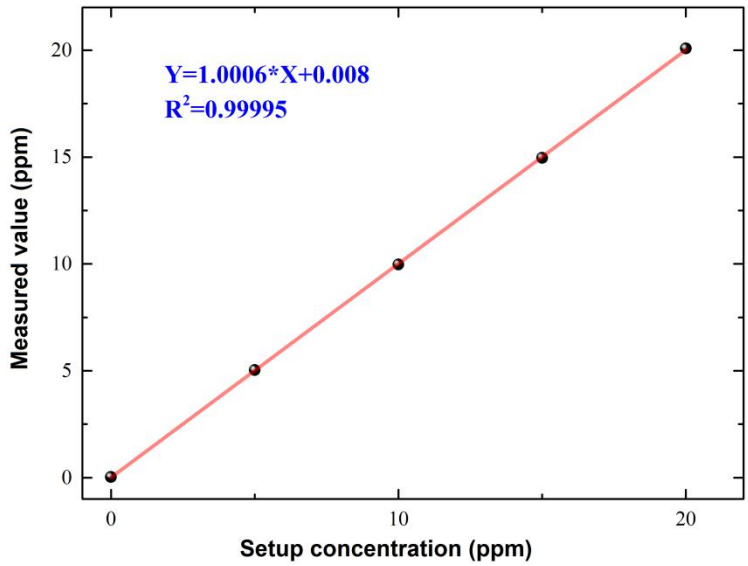

Figure 2 Illustration for linearity

1.4. Response time

The Beebird™ module's absorption cell was purged with high-purity nitrogen until the reading stabilizes to 0 ppm. At this time, a standard concentration of 21.1 ppm ammonia gas is passed in. The required time for the analyzer reading to change from 2.1 ppm (10% of the concentration, T10) to 19.0 ppm (90% of the concentration, T10) is the response time. This gives a response time of 28 seconds.

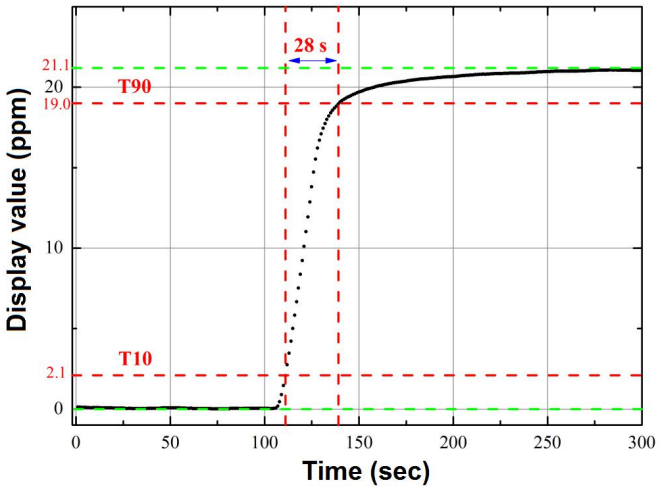

Figure 3 Illustration for the calculation of response time

1.5. Short-time stability (Allan deviation)

Allan deviation analysis is an important method to characterize the short-term stability of measurement equipment. It can obtain the ultimate detection accuracy and optimal integration (average) time. Figure 4 illustrates the Allan deviation of our Beebird™ module, which shows that the measurement accuracy for one second is 0.07 ppm. When the integration time reaches 30 seconds, it can achieve a limit measurement accuracy of 0.015 ppm, which can fully meet the needs of ammonia slip measurement.

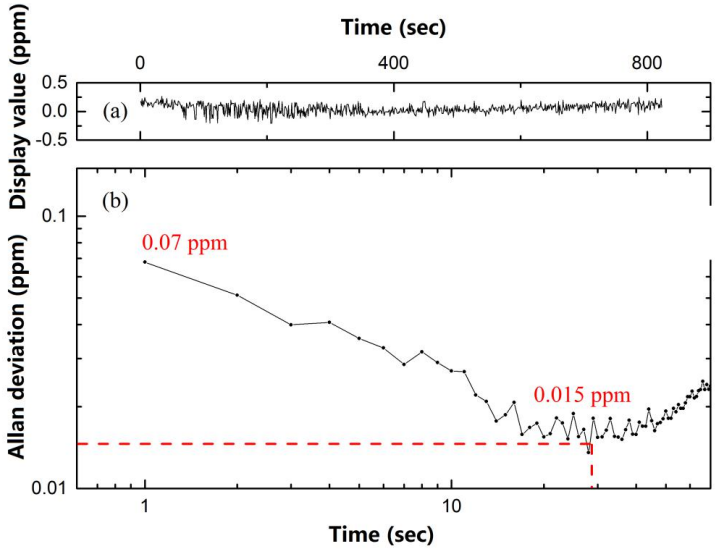

Figure 4 Allan deviation analysis:(a) zero gas test
(b) Calculation of Allan deviation using the zero gas measurement

1.6. Long-term stability test—zero and span drift

In order to quantitatively evaluate the long-term stability of the module, the drift test was performed according to the method specified in the national environmental protection standard HJ 76-2017. During the test, the module was continuously powered on for four days. The span drift test was performed with 21.1 ppm standard ammonia, and the results are shown in Table 2. The zero drift test was performed with high-purity nitrogen gas, and the test results are shown in Table 3. Each measured value is an average reading of 30 minutes.

According to the calculation method in HJ76-2017, the span drift is 1.5% and the zero drift is 0.3%. As both are less than 2%, Beebird™ meets the requirements of long-term online ammonia slip measurement.

Table 2 Results of the span drift test

	Day 1	Day 2	Day 3	Day 4
Measured value (ppm)	20.99	21.16	21.24	21.21
Absolute error (ppm)	-0.10	0.06	0.13	0.11
Relative error (%)	-0.48	0.27	0.63	0.54

Table 3 Results of the zero drift test

	Day 1	Day 2	Day 3	Day 4
Measured value (ppm)	0.08	0.1	0.03	0.03

2. Mid-infrared, near-infrared comparison test

At room temperature (T = 296 K), the strongest line intensity of the ammonia molecule in the range of 8 to 10 μm (1000 to 1200 cm^{-1}) is about 60 times that of 1.5 μm, as shown in Figure 5. Due to the weak spectral lines and the overlapping interference of the water molecule's spectral lines, the measurement accuracy of ammonia analyzers based on near-infrared (NIR) laser is limited to a certain extent. The Beebird™ analyzer based on mid-infrared (MIR) laser avoids the above problems and shows higher measurement accuracy and precision.

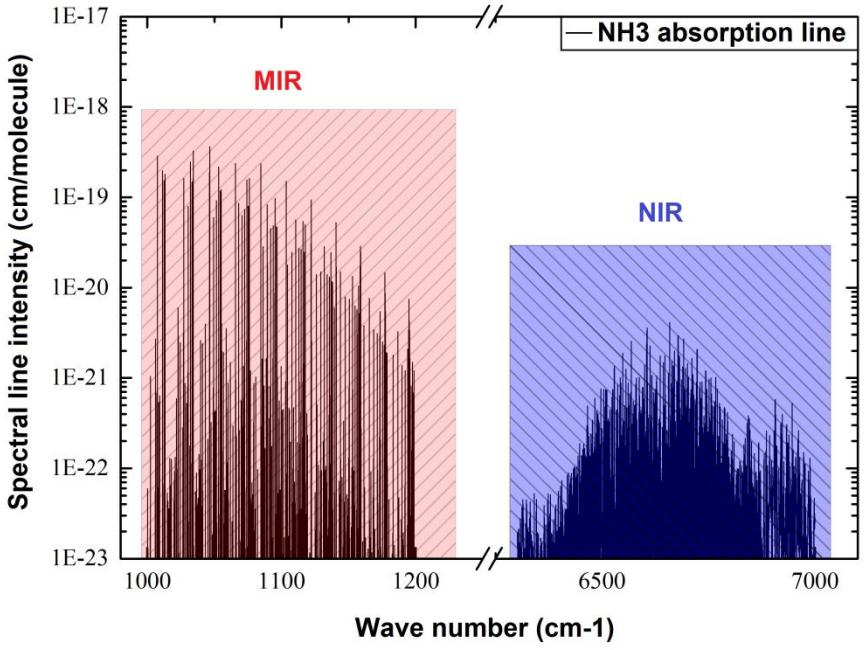

Figure 5 Spectral line intensity of ammonia molecules in the NIR and MIR bands at 296 K (the y ordinate is logarithmic)

To verify the above judgment, we used a commercial near-infrared laser ammonia analyzer and our Beebird™ ammonia analysis module to make a comparative test. A standard gas with an ammonia concentration of 80.2 ppm and high-purity nitrogen were used to obtain different concentrations of ammonia. The concentrations in the test were 0 ppm, 80.2 ppm, 20.1 ppm, 16.0 ppm, 12.0 ppm, 8.2 ppm, and 4.0 ppm. The test results are shown in Figure 6. The solid red line is the configured concentration, the blue dotted line is the measurement of the NIR laser ammonia analyzer, and the black dotted line is the measurement of our MIR-based Beebird™ module.

It can be clearly seen from Figure 6 that the Beebird™ has faster response time and more accurate measurement results. Table 4 gives a detailed comparison of the two analyzers. The NIR analyzer has the response time about 85 seconds, and its measurement result has a significant deviation from the actual concentration (maximum 62/.5%). The response time of Beebird™ is about 30 seconds, and the maximum deviation is 1.7%.

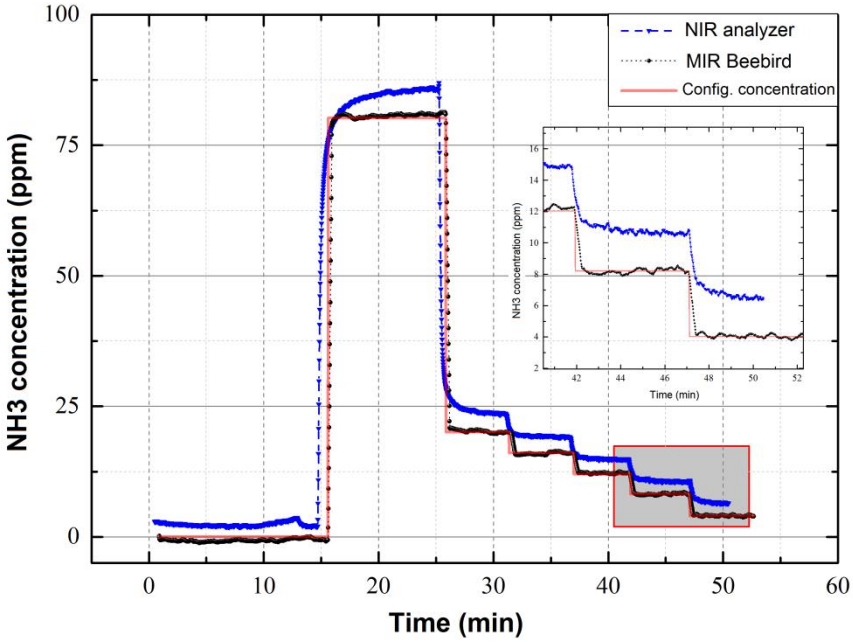

Figure 6 Comparison test result

Table 4 Detailed compariaon between NIR and MIR (Beebird™) analyzers

Config. Concentration (ppm)	**NIR** measured value (ppm)	Absolute error (ppm)	Relative error (%)	**MIR** measured value (ppm)	Absolute value (ppm)	Relative error (%)
0	2.3	2.3	-	-0.1	-0.1	-
80.2	86.1	5.9	7.4	80.7	0.5	0.6
20.1	23.9	3.8	18.9	19.8	-0.3	-1.5
16.0	19.6	3.6	22.5	16.1	0.1	0.6
12.0	15.3	3.3	27.5	12.2	0.2	1.7
8.2	10.9	2.7	32.9	8.3	0.1	1.2
4.0	6.5	2.5	62.5	4.0	0	0