Calibration of a Radiosonde Humidity Sensor using the Low-temperature Low-pressure Humidity Chamber at KRISS

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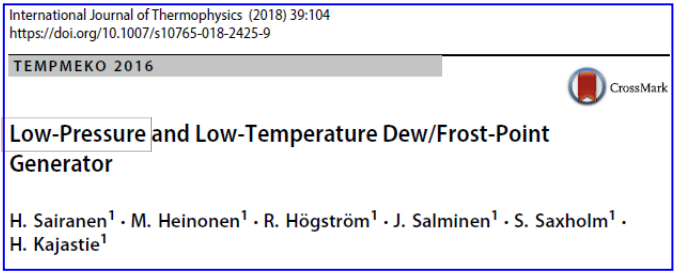
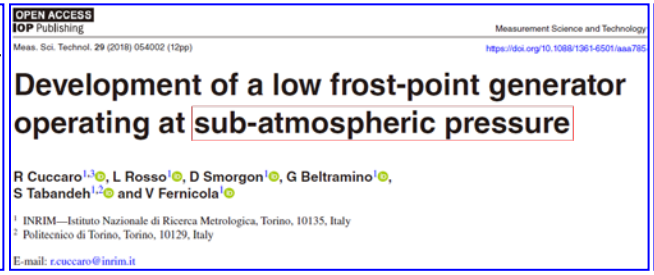
Calibration facilities for radiosonde humidity sensors

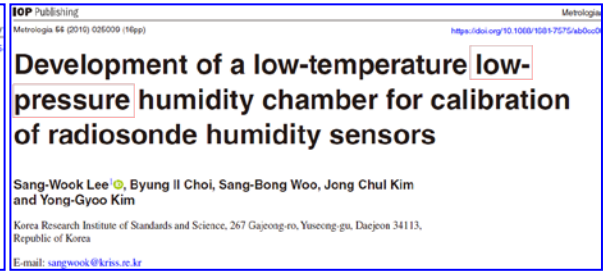
- Humidity measurement conditions in upper air
  - Temperature (< -80 ºC)
  - Pressure (< 10 hPa)
  - Frost-point temperature (< -90 ºC)
- Quality control of humidity measurements
  - SI-traceable calibration of humidity sensors using ground facilities
  - Low-pressure low-temperature humidity generators



VTT in Finland



INRIM in Italy

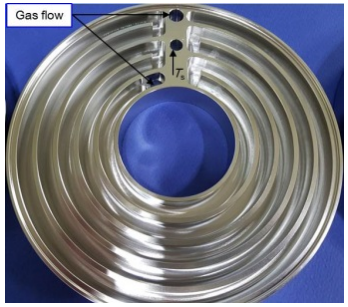


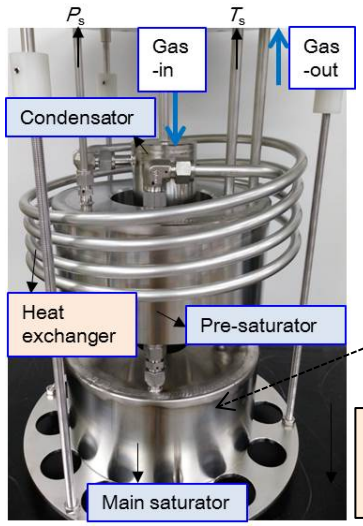
KRISS in Korea

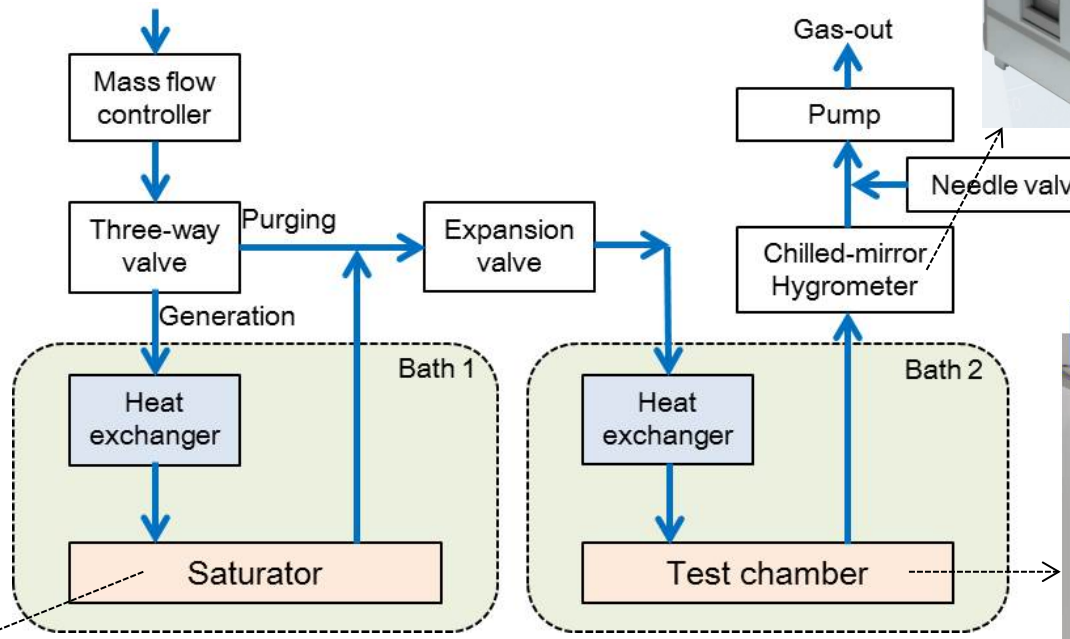
Humidity calibration facility at KRISS

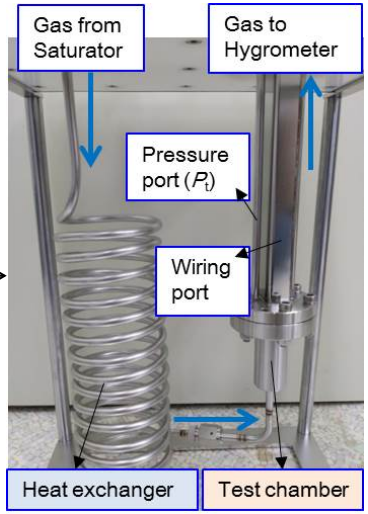
- Low-temperature Low-pressure humidity chamber
  - Two-temperature two-pressure (2T2P) humidity generator

Hygrometer: Validation









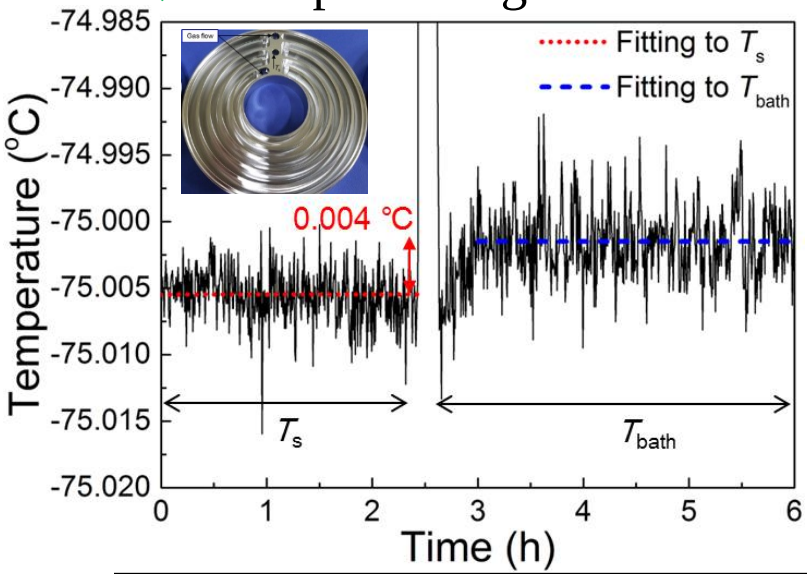
Saturator: Generation of well-defined vapor pressure

Test chamber: Calibration of sensors

Humidity generation by the saturator

Saturator performance at atmospheric pressure

Temperature gradient



Saturation efficiency

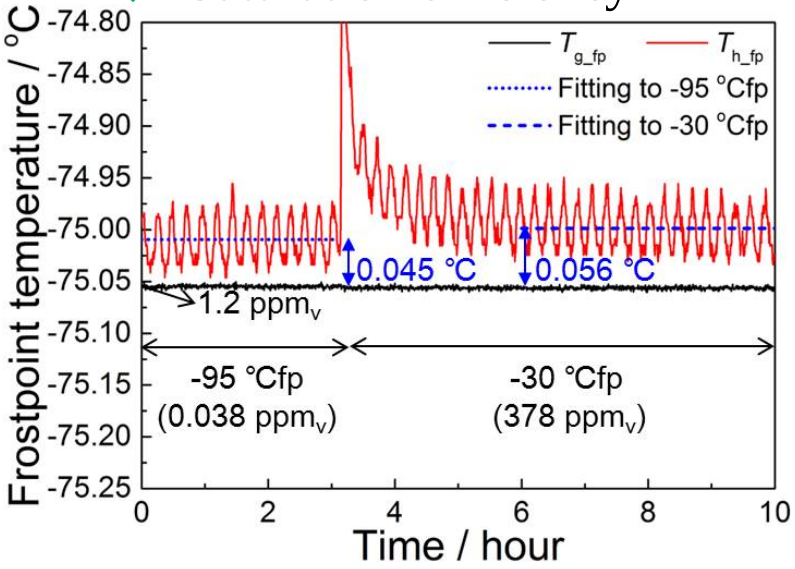
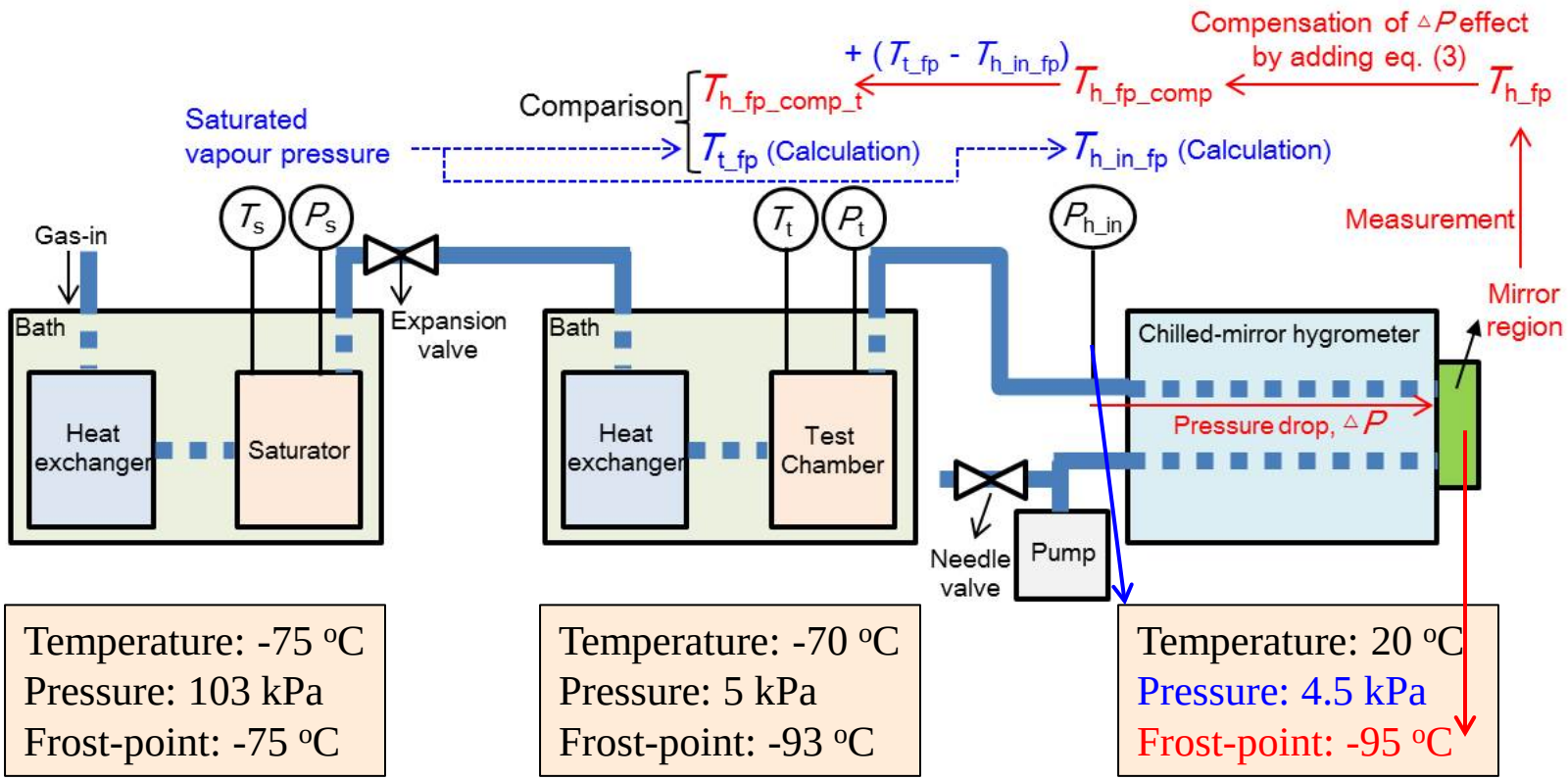


Table 1. Uncertainty budget on frost-point temperature of the saturator at $T_s = -75$ °C and at atmospheric pressure.

Uncertainty component	Unit	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to uncertainty (°C)
Saturator temperature stability	°C	0.0038	Normal	1	0.0038
Saturator temperature gradient	°C	0.0023	Rectangular	1	0.0023
PRT calibration	°C	0.025	Normal	1	0.025
Multimeter accuracy	Ω	0.002	Rectangular	2.528 °C Ω^{-1}	0.0051
Saturation efficiency	°C	0.0064	Rectangular	1	0.0064
Combined standard uncertainty ($k = 1$)	°C				0.0267
Expanded uncertainty ($k = 2$)	°C				0.0533

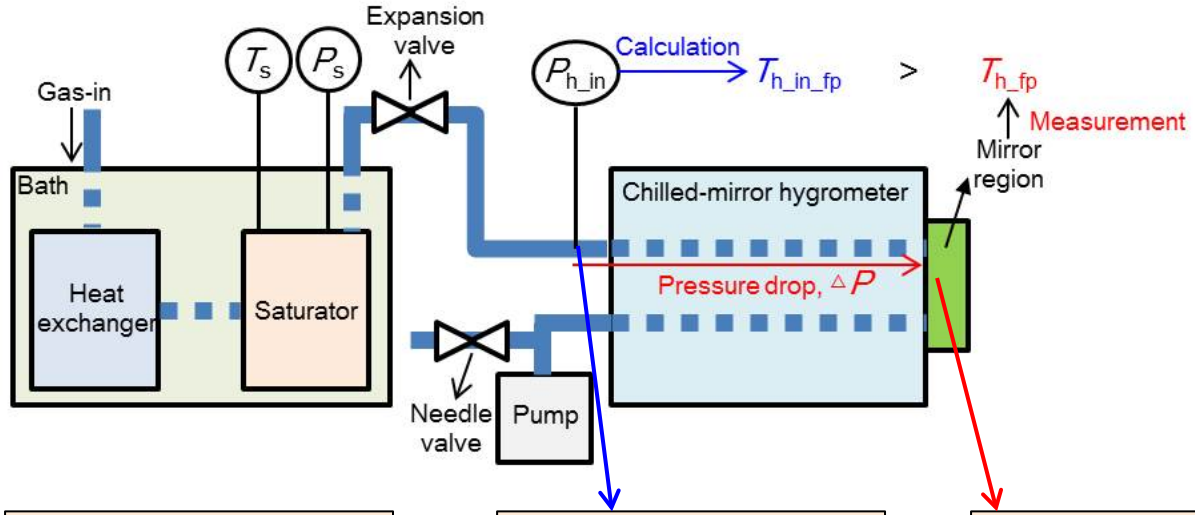
Difficulty in humidity validation at low pressure

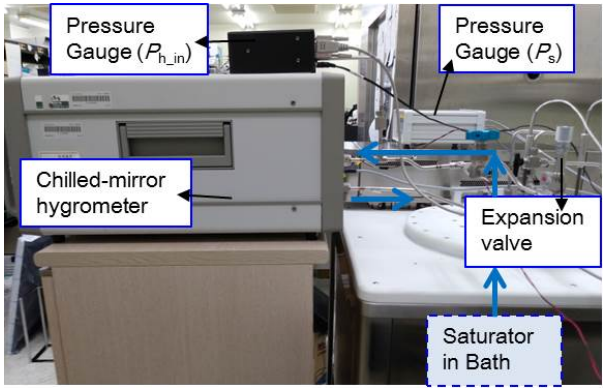
- A pressure drop inside hygrometer → Drop of frost-point temperature



Compensation of low-pressure effects

- Scheme for compensating pressure drop ($\triangle P$) inside the hygrometer





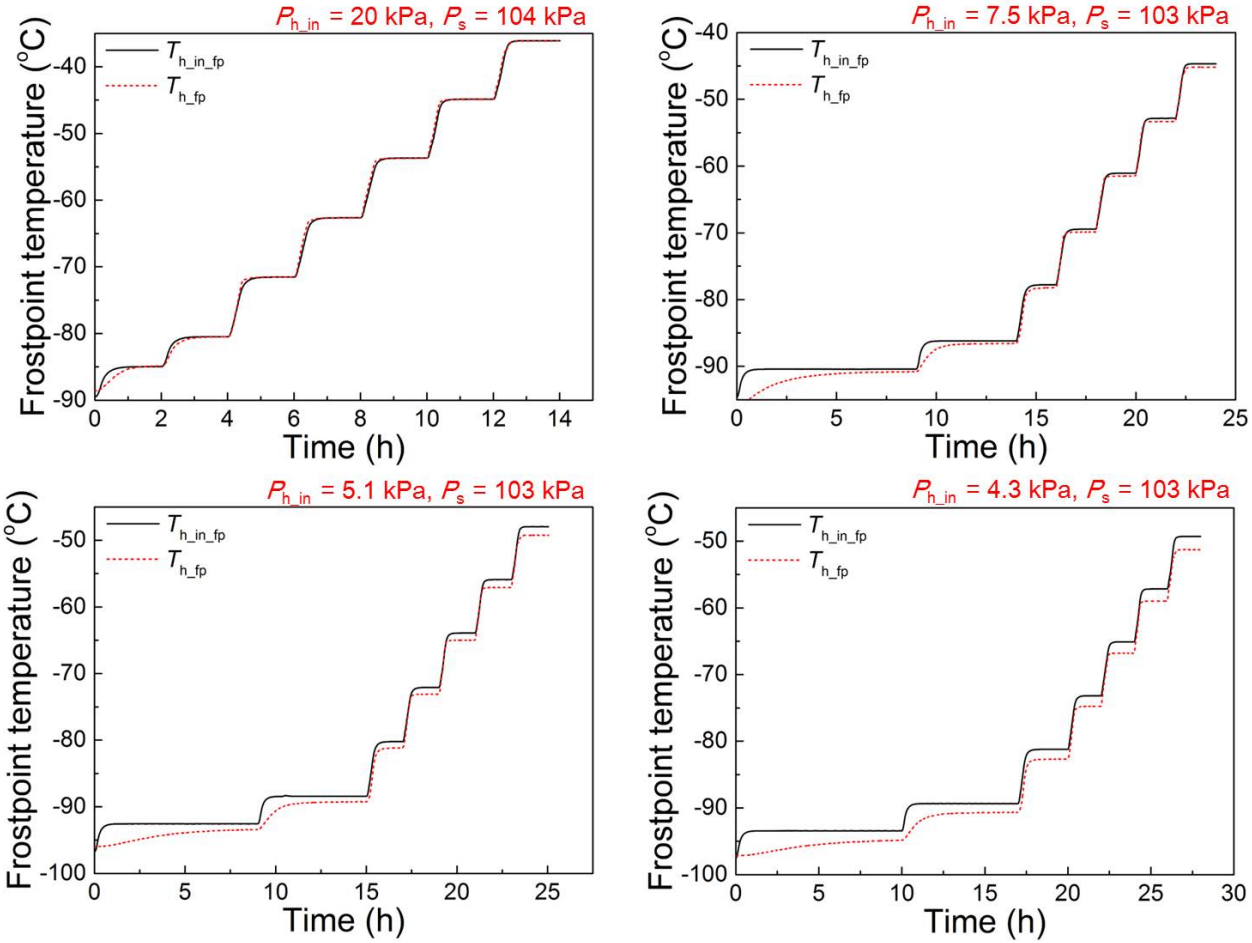
Temperature: -75 °C
Pressure: 103 kPa
Frost-point: -75 °C

Temperature: 20 °C
Pressure: 5 kPa
Frost-point: -93 °C

Temperature: 20 °C
Pressure: 4.5 kPa
Frost-point: -95 °C

Validation of generated humidity

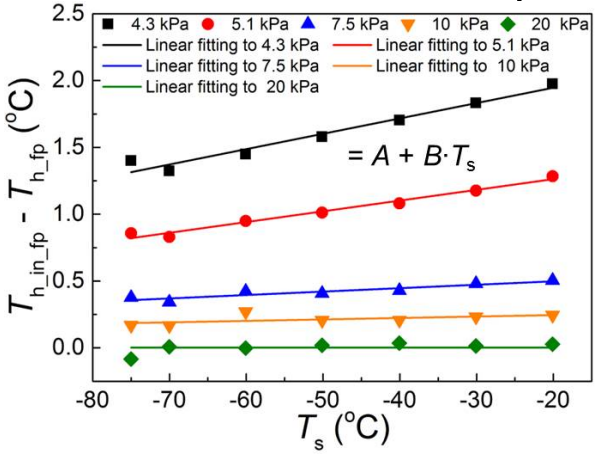
- Humidity generation and measurement at low pressures
  - Difference between the generator and the hygrometer

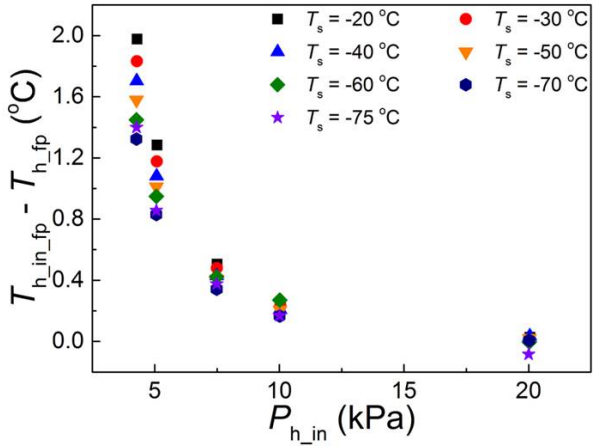


Validation of generated humidity

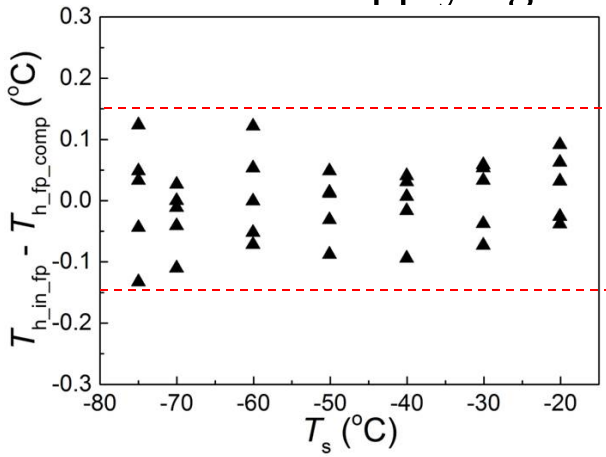
Compensation for low-pressure effects

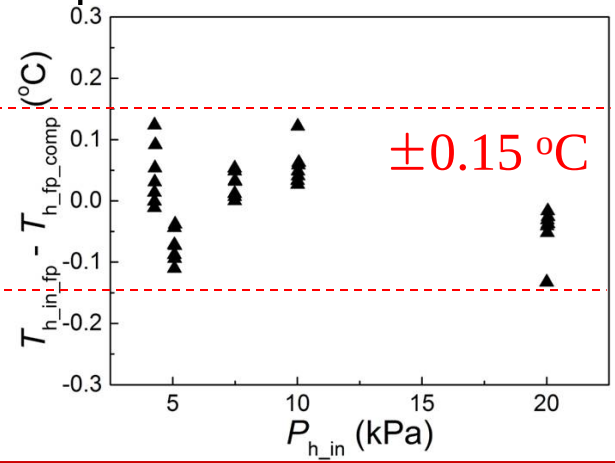
- Formulation of the compensation





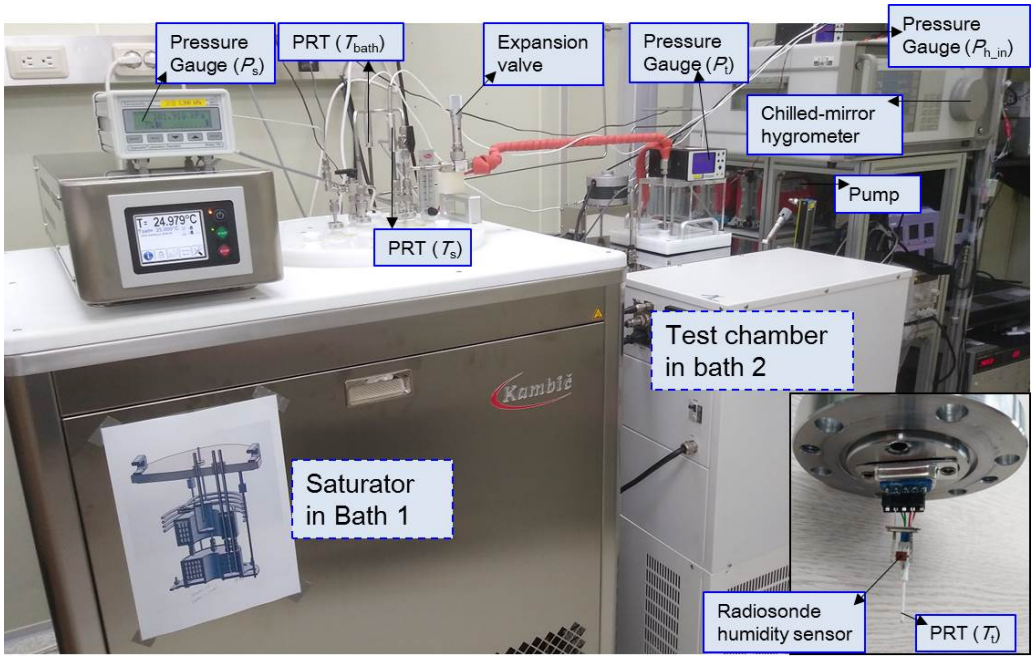
- Residuals after applying the compensation formula





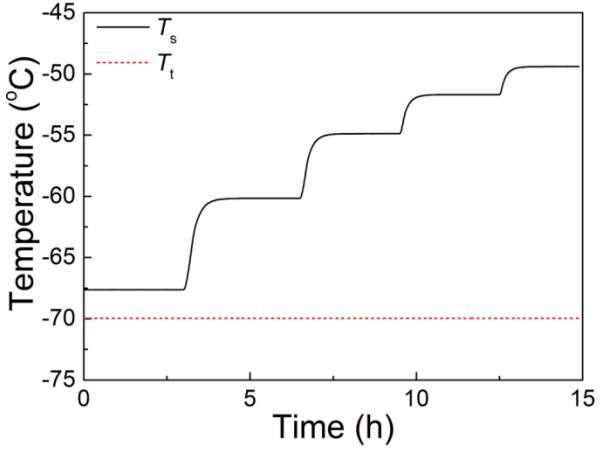
Low-temperature Low-pressure humidity chamber

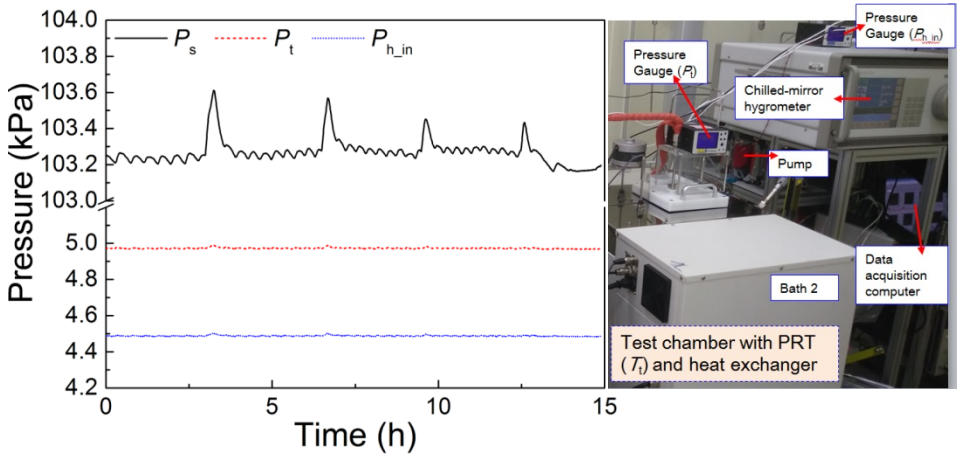
- Operation range in test chamber
  - The humidity sensor meets
    - Temperature: (-70 – 30) ^{o}C
    - Pressure: (50 – 1000) hPa
    - Dew/frost point temperature: (-90 – 20) ^{o}Cdp/fp
    - Relative humidity: (2 – 100) %rh



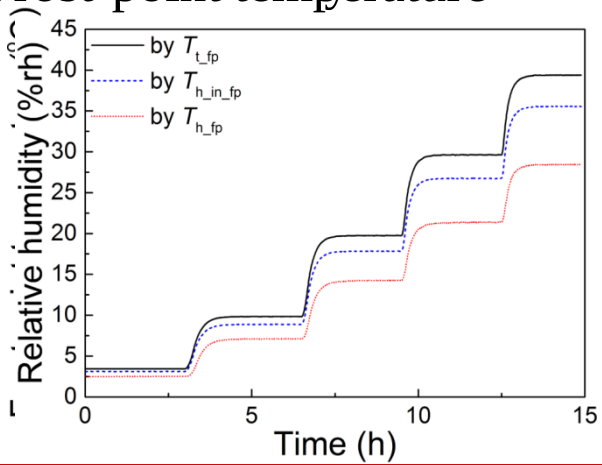
Humidity generation & validation I

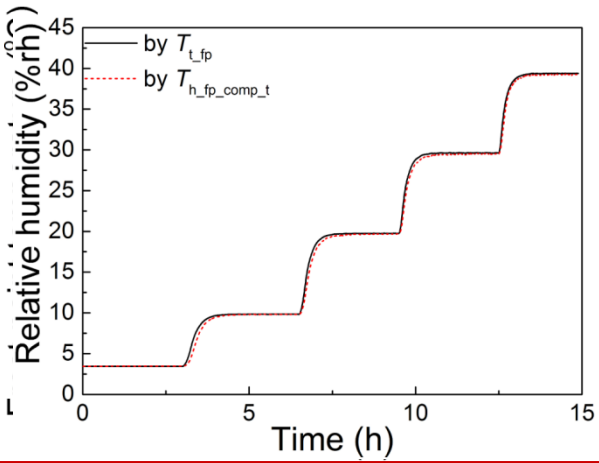
- -70 °C & 5 kPa in test chamber
  - Temperature & pressure





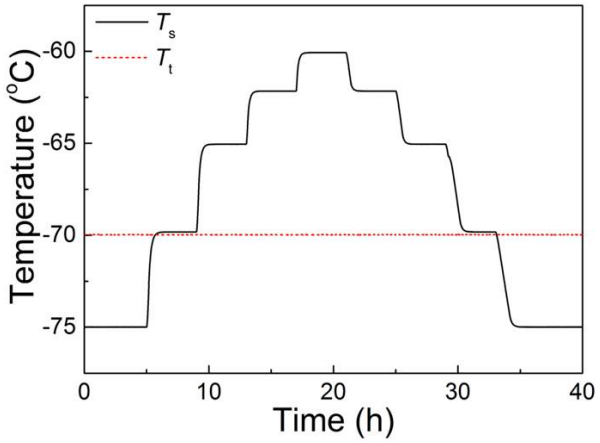
  - Relative humidity

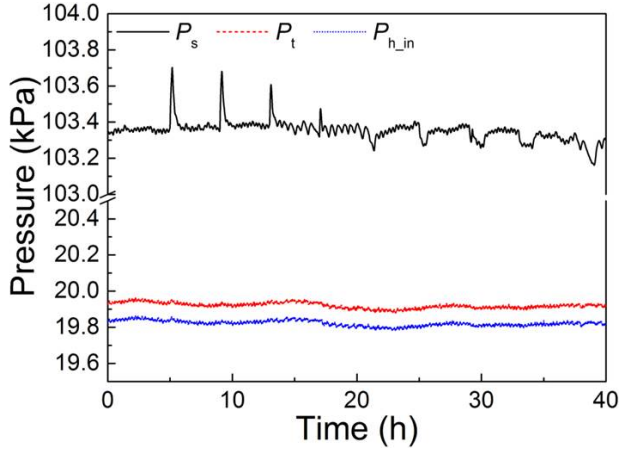




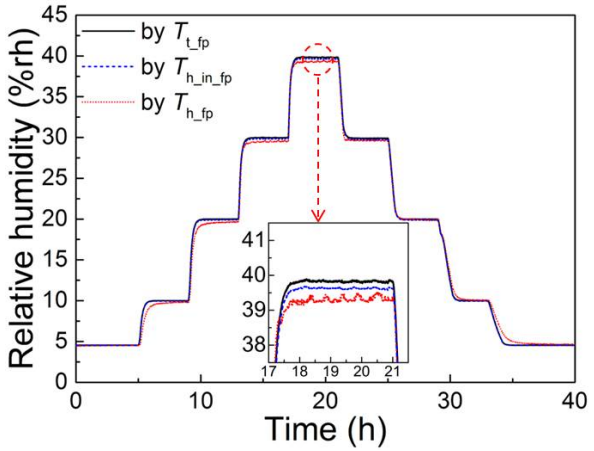
Humidity generation & validation II

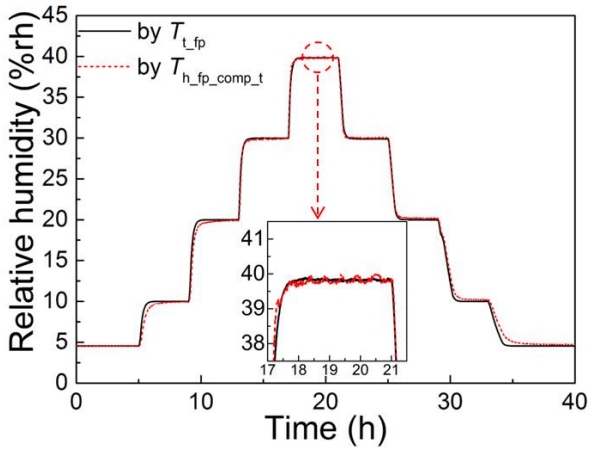
- -70 °C & 20 kPa in test chamber
  - Temperature & pressure





  - Relative humidity





Uncertainty

- -70 ºC & 4.6 kPa in test chamber

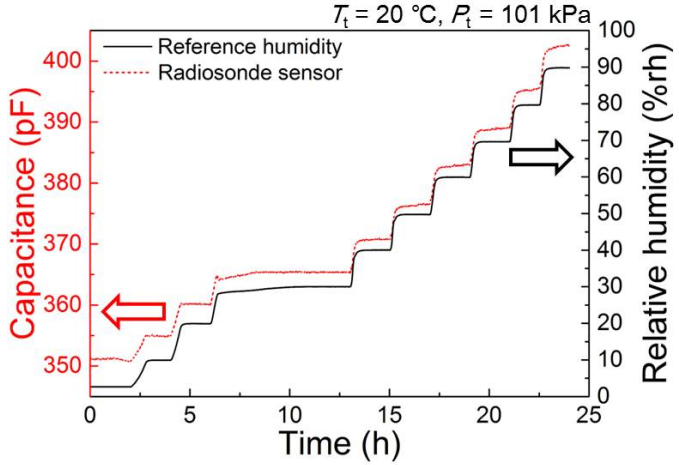
Table 4. Uncertainty budget on relative humidity at $T_t = -70$ °C and $P_t = 4.6$ kPa.

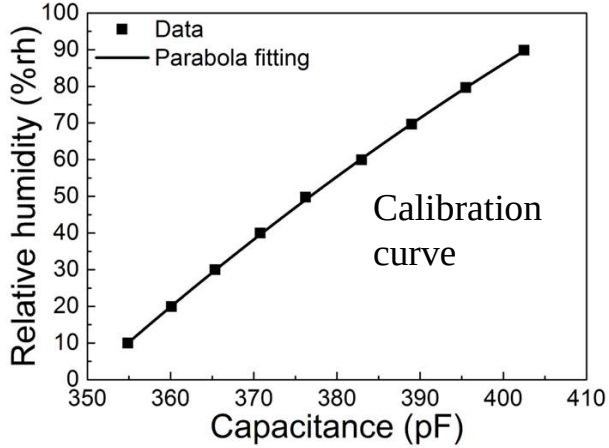
Relative humidity at $T_t = -70$ °C, $P_t = 20$ kPa	%rh	10.10	20.18	30.16	40.05	10.10	20.18	30.16	40.05	10.10	20.18	30.16	40.05
Uncertainty component	Unit	Standard uncertainty				Sensitivity coefficient				Contribution to uncertainty			
Saturator temperature, $u(T_s)$	°C	0.026	0.026	0.026	0.026	1.350	2.571	3.735	4.860	0.035	0.067	0.097	0.126
Saturator pressure, $u(P_s)$	kPa	0.040	0.040	0.040	0.040	0.097	0.194	0.290	0.385	0.004	0.008	0.012	0.015
Saturation vapour pressure in saturator, $u_r(e_{is}(T_s))$	Pa	0.001 63	0.002 90	0.004 03	0.005 05	8.528	8.528	8.523	8.534	0.014	0.025	0.034	0.043
Enhancement factor in saturator, $u_r(f(P_s,T_s))$		0.000 37	0.000 34	0.000 33	0.000 32	10.034	20.061	29.992	39.829	0.004	0.007	0.010	0.013
Test chamber temperature, $u(T_t)$	K	0.032	0.032	0.032	0.032	−1.399	−2.796	−4.181	−5.552	−0.045	−0.089	−0.134	−0.178
Test chamber pressure, $u(P_t)$	kPa	0.020	0.020	0.020	0.020	2.184	4.366	6.531	8.662	0.043	0.087	0.130	0.172
Saturation vapour pressure in test chamber, $u_r(e_{ws}(T_t))$	Pa	0.002	0.002	0.002	0.002	19.252	38.493	57.554	76.433	0.035	0.069	0.103	0.137
Enhancement factor in test chamber, $u_r(f(T_t,P_t))$		0.000 00	0.000 00	0.000 00	0.000 00	−10.034	−20.063	−30.012	−39.835	0.000	0.000	0.000	0.000
Saturator efficiency, u (Efficiency)	°C	0.006	0.006	0.006	0.006	1.652	3.162	4.608	6.009	0.011	0.020	0.029	0.038
Adsorption/desorption, u(Ads./Des.)	°C	0.073	0.025	0.024	0.024	1.652	3.162	4.608	6.009	0.120	0.080	0.111	0.145
hygrometer pressure gradients, $u(\Delta P)$	°C	0.153	0.153	0.153	0.153	1.652	3.162	4.608	6.009	0.252	0.483	0.703	0.917
Combined standard uncertainty, $u_c(RH)$ $(k = 1)$	%rh									0.291	0.515	0.751	0.981
Expanded uncertainty, $u(RH)$ $(k = 2)$	%rh									0.582	1.030	1.502	1.961

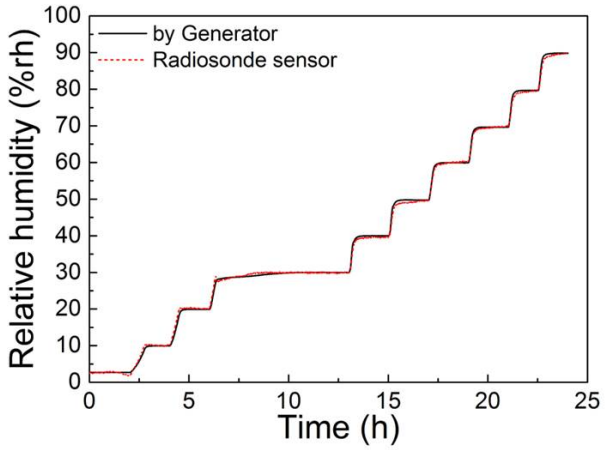
%rh

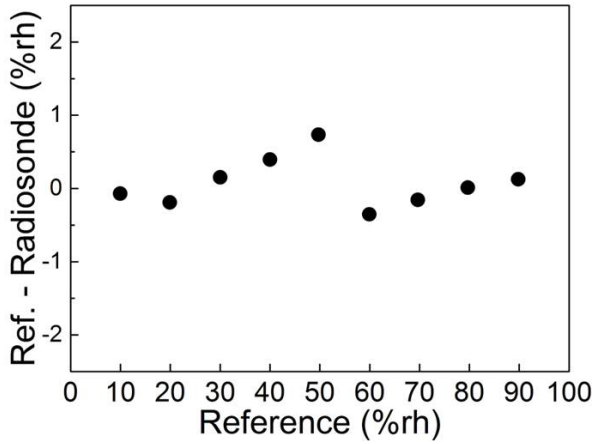
Calibration of a humidity sensor

- Calibration curve at room temperature
  - 20 °C & 100 kPa



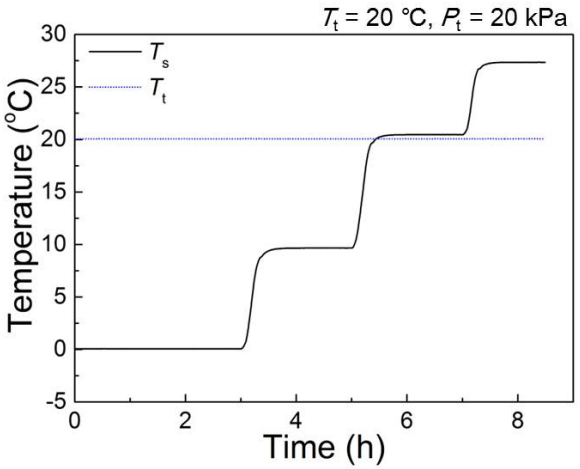


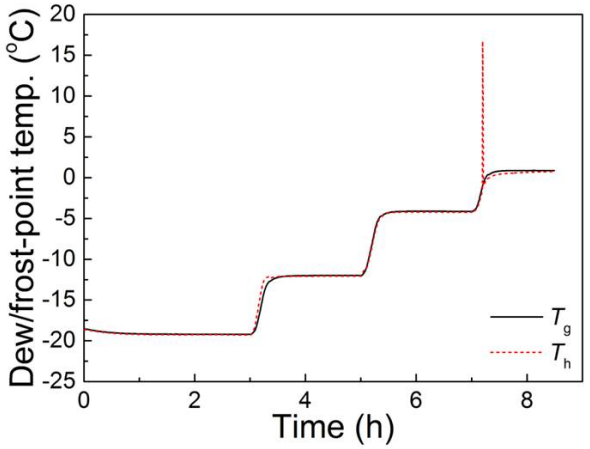


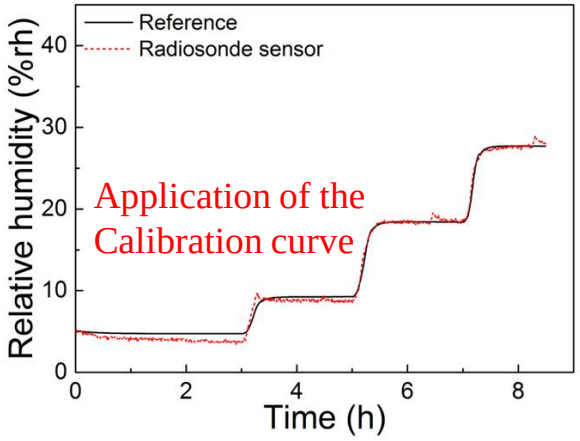


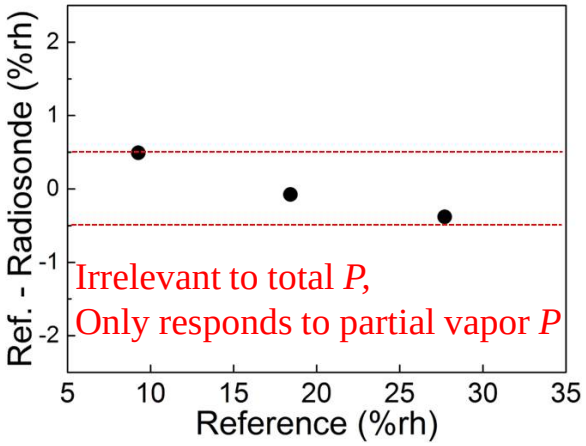
Calibration of a humidity sensor

- Testing low-pressure effects at room temperature
  - 20 °C & 20 kPa



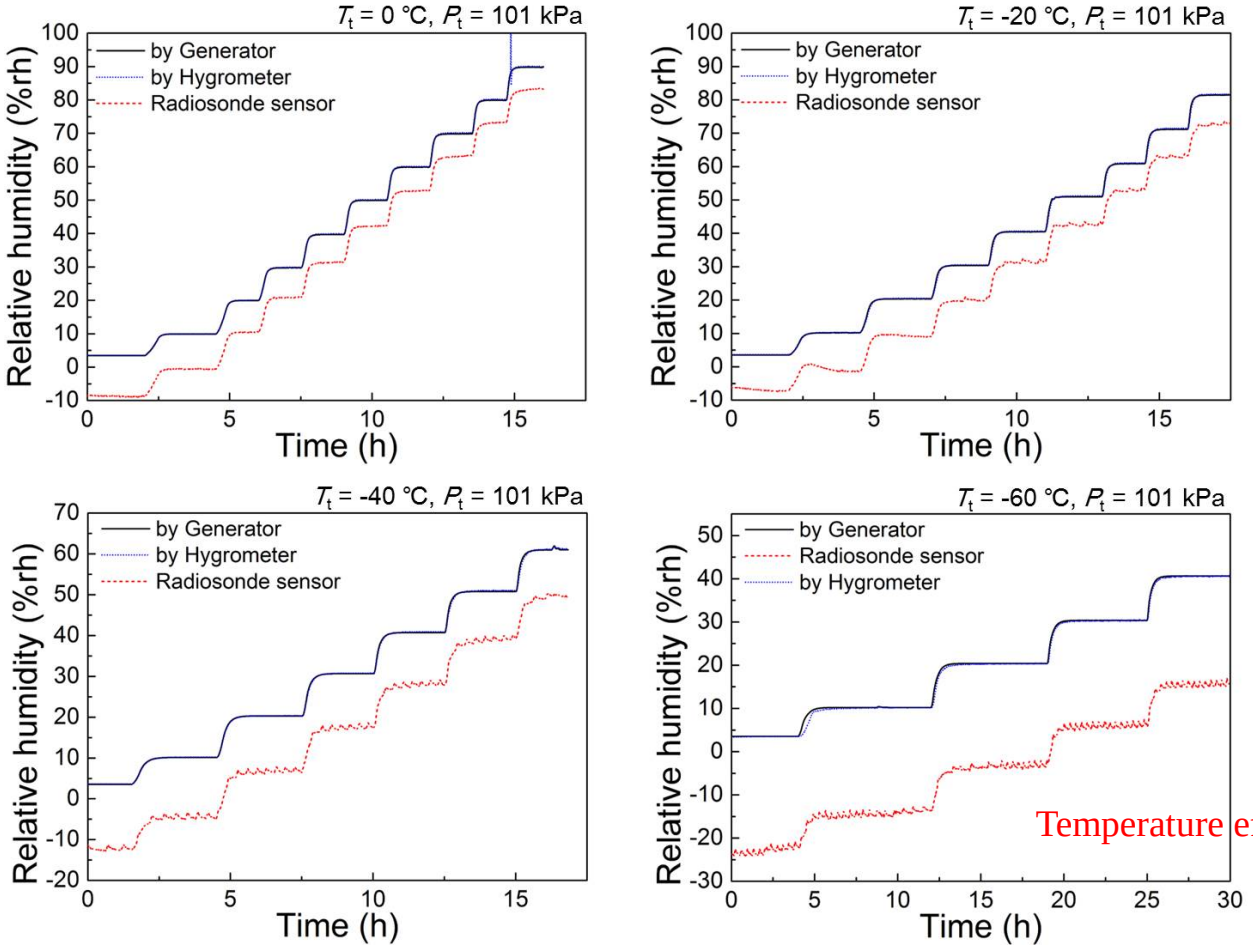






Calibration of a humidity sensor

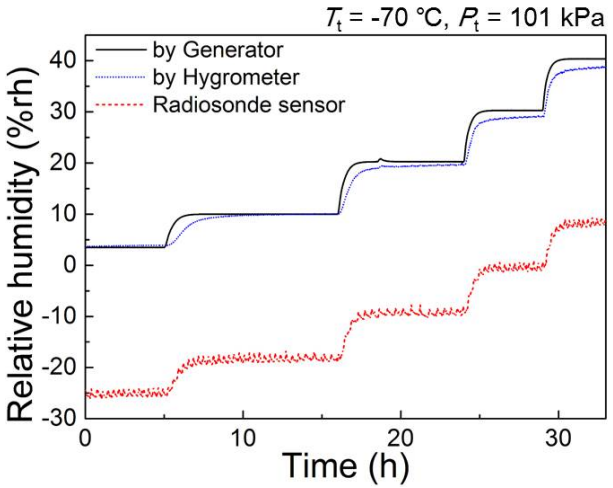
- Low-temperature effects
  - 0 °C, -20 °C, -40 °C, -60 °C (at 100 kPa)

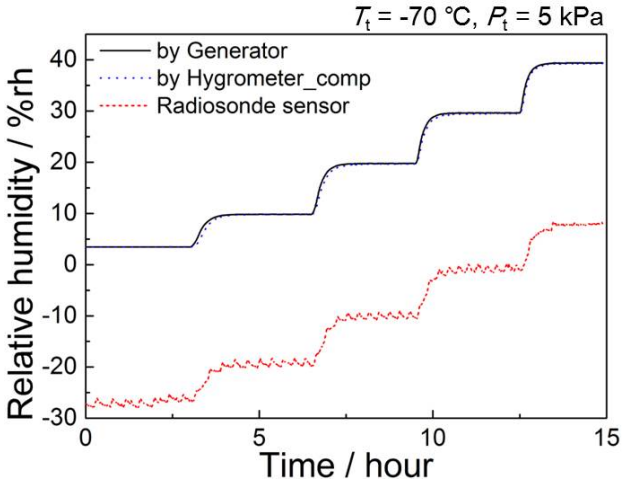


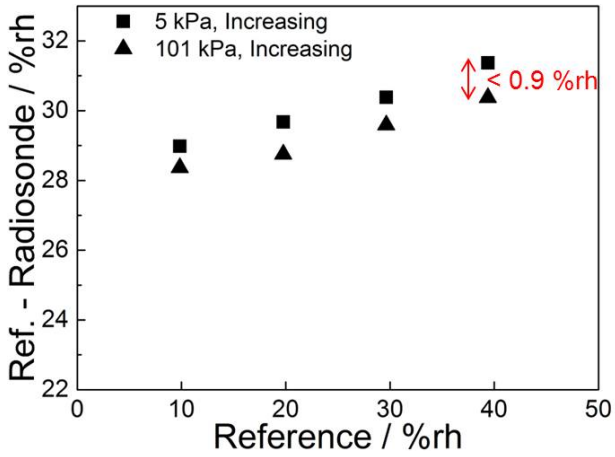
Temperature effect is significant !

Calibration of a humidity sensor

- Low-pressure effect at low-temperature
  - -70 °C at 100 kPa & 5 kPa





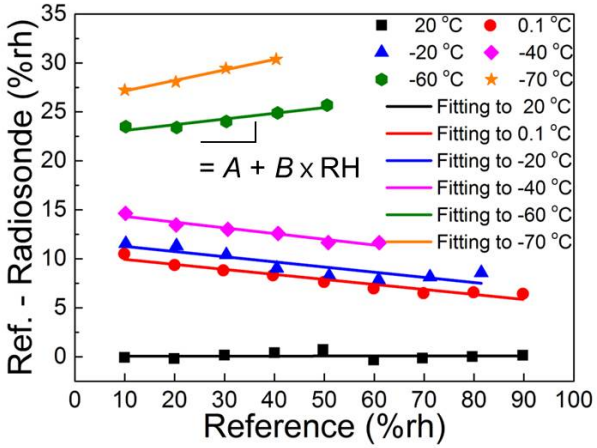


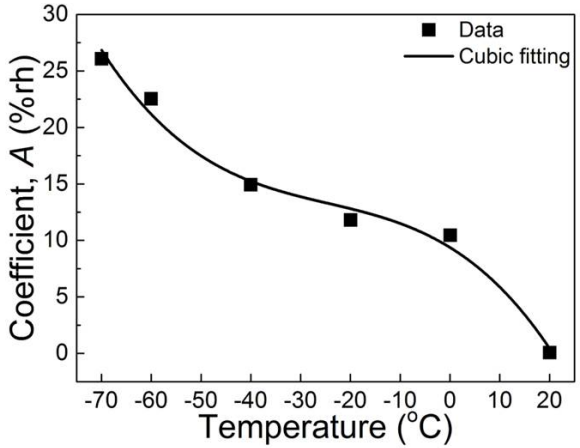
Pressure effect is small even at -70 °C and, thus, is considered as an uncertainty factor

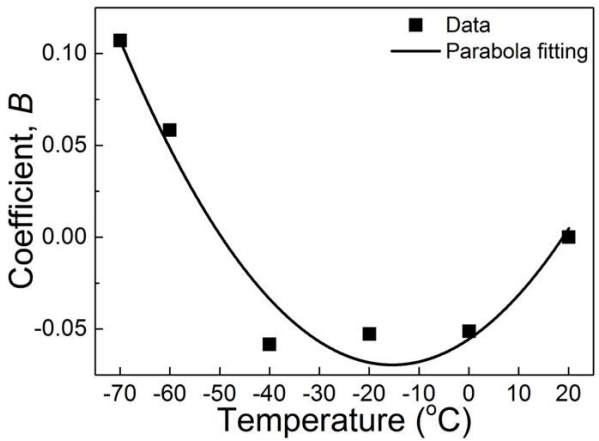
Calibration of a humidity sensor

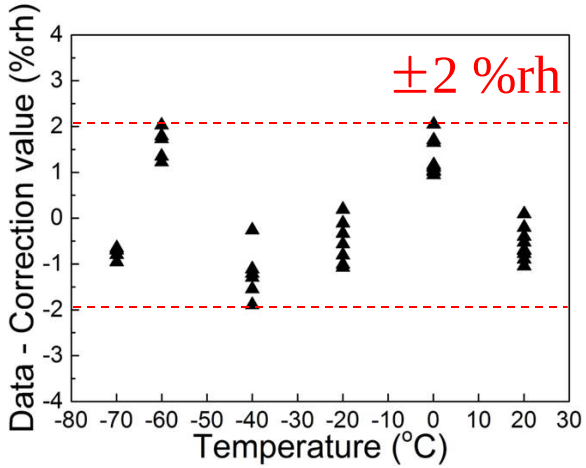
Compensation formula

- Empirical compensation formula covering (-70 – 20) °C & (50 – 1000) hPa









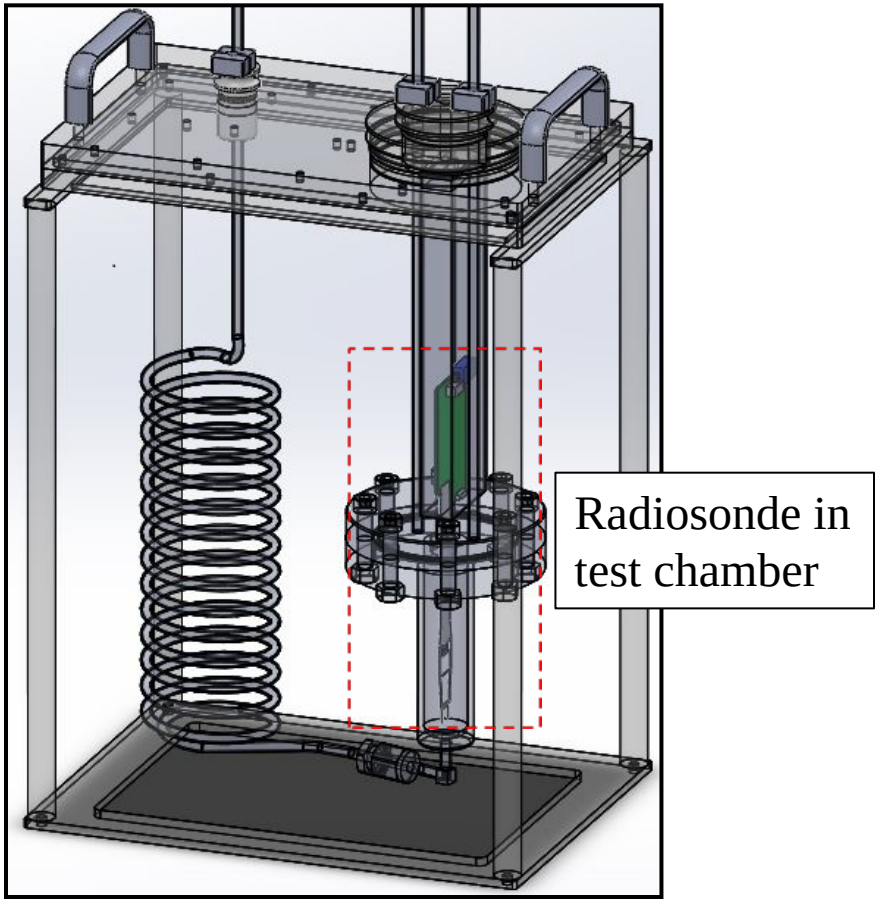
Uncertainty of the sensor

- Uncertainty including compensation of *P* & *T* effects
  - Temperature & pressure range: (-70 – 20) °C & (50 – 1000) hPa

Uncertainty component	Unit	Standard uncertainty	Probability distribution	Sensitivity coefficient	Contribution to uncertainty (%rh)
Unceratainty of humidity generator	%rh	0.98 %rh	Normal	1	0.98
Sensor stability	%rh	0.39 %rh	Normal	1	0.39
Sensor hysteresis	%rh	0.66 %rh	Rectangular	1	0.66
Pressure effect	%rh	0.50 %rh	Rectangular	1	0.50
Sensor reproducibility	%rh	0.65 %rh	Rectangular	1	0.65
Compensation formula	%rh	1.18 %rh	Rectangular	1	1.18
Combined standard uncer tainty (k = 1)	%rh				1.90
Expanded uncertainty (*k* = 2)	%rh				**3.80** %rh

Future works

- Compensation of a whole radiosonde
  - Just a humidity sensor → a whole radiosonde



Summary

- Low-temperature & low-pressure humidity chamber is developed
  - Operating in a two-temperature & two-pressure mode
  - Operating at low-temperature (-70 – 20) ^{o}C and low-pressure (50 – 1000) hPa
  - Generating dew/frost point temperature (-90 – 20) ^{o}Cdp/fp and relative humidity (2 – 100) %rh
  - Generated humidity is validated by an independent hygrometer
  - Expanded uncertainty of the humidity chamber is less than 2 %rh (k = 2).
- Radiosonde humidity sensor is calibrated using the chamber
  - Calibration range: (-70 – 20) ^{o}C & (50 – 1000) hPa
  - Temperature effect is significant whereas pressure effect is small
  - Temperature, pressure, hysteresis, reproducibility, and so on are considered.
  - Expanded uncertainty of the humidity sensor is 3.8 %rh (k = 2).
  - SI-traceable calibration at low-temperature and low-pressure

Thank you for your attention

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