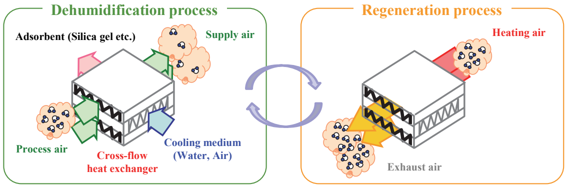
Water Vapor Adsorption Behaviors of Thermosensitive Polymer Gels for Desiccant Humidity Control System

Introduction

Desiccant humidity control system with cross-flow heat exchanger type adsorber

- **Humidity** can be controlled efficiently by using **thermal energy below 373 K**.
- Sensible and latent cooling loads can be controlled **independently**.



◎ Improvement of utilization ratio of adsorbent during dehumidification process

◎ Reduction of temperature rise of supply air

Both **sensible heat of adsorber** and **heat of adsorption** is actively **removed** by flowing **cooling air**.

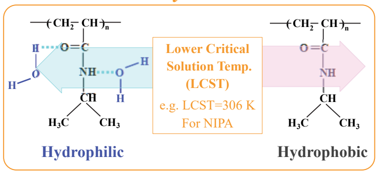
○ Simpler system than that with water coolant

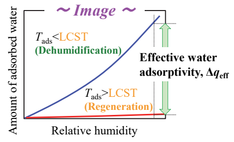
△ **Batch system**

Two adsorbers are needed to produce dehumidified air continuously.

For performance improvement of the system:

"Thermosensitive Polymer Gel" was focused as adsorbent for water vapor adsorption.





Thermosensitive polymer gel may be effective to increase Δq_{eff} greatly.

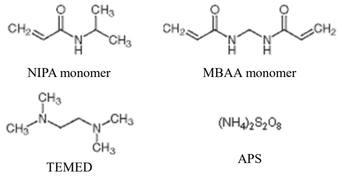
In this study:

- Poly(N-isopropylacrylamide) gel cross-lined with N,N'-methylenebisacrylamide (Cross-linked NIPA gel) were prepared.
- Water adsorption characteristics of the cross-linked NIPA gels prepared at various conditions was investigated.
- Applicability of the gel to desiccant humidity control system was roughly evaluated.

Experimental

~ Starting material ~

Monomer : NIPA (N-isopropylacrylamide)
Crosslinker : MBAA (N,N'-methylenebisacrylamide)
Polymerization accelerator : TEMED (N,N,N',N'-tetramethylethylenediamine)
Polymerization initiator : APS (Ammonium peroxodisulfate)



~ Characterization ~

➢ **Morphology of NIPA gel**

Apparatus: Field-emission SEM (FE-SEM, JSM-7500F, JEOL Ltd.)

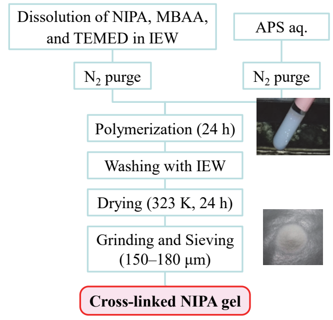
➢ **Water adsorptivity of NIPA gel**

Sample weight: 50-100 mg
Apparatus: Volumetric gas adsorption apparatus (Belsorp 18, MicrotracBEL Corp.)
Degas condition: 373 K, 24 h
Adsorption condition: 298-323 K

https://www.jeol.co.jp/products/detail/JSM-7500F.html

~ Preparation ~

➢ **Cross-linked NIPA gel**



Polymerization conditions

NIPA monomer	500–1,500 mol/m³
MBAA monomer	25–250 mol/m³
TEMED	10–100 mol/m³
APS	1–20 mol/m³
Polymerization temp.	283–323 K

➢ **NIPA homopolymer**

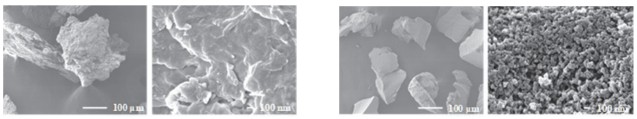
NIPA: TEMED: APS = 1,000:10:1 mol/m³
Polymerization: 283 K

➢ **MBAA homopolymer**

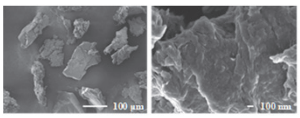
MBAA: TEMED: APS = 50:10:1 mol/m³
Polymerization: 283 K

Results & Discussion

Morphology of homopolymers and cross-linked NIPA gel



(a) NIPA homopolymer (b) MBAA homopolymer



(c) Cross-linked NIPA gel (NIPA:MBAA:TEMED:APS=1000:50:10:1)

Fig. SEM images of homopolymers & cross-linked NIPA gel

- ✓ NIPA homopolymer : Scale-like surface
- ✓ MBAA homopolymer : Smooth surface (Low mag.) A lot of grains (High mag.)
- ✓ Cross-linked NIPA gel : Scale-like surface

Effect of NIPA & MBAA concentrations on water adsorptivity

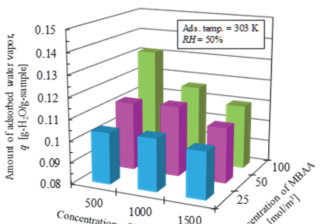


Fig. Effects of NIPA and MBAA concentrations on the water vapor adsorption capacities of cross-linked NIPA gels

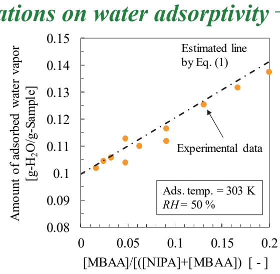


Fig. Relation between molar ratio of [MBAA]/([NIPA]+[MBAA]) & water adsorption capacities of cross-linked NIPA gels

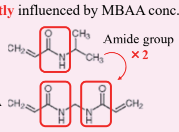
- ✓ NIPA conc. ↑ ⇒ Water adsorptivity ↓
- ✓ MBAA conc. ↑ ⇒ Water adsorptivity ↑

- ✓ Water adsorptivity at RH=50 % **linearly** increased as increasing MBAA conc.
- ✓ Exp. data are **good agreement** with estimated values. Water adsorptivity is **greatly** influenced by MBAA conc.

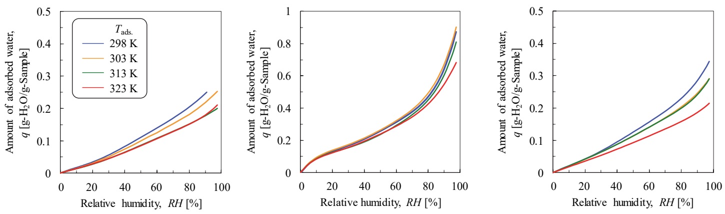
Estimated value :

$$q = \frac{[NIPA] \cdot MW_{NIPA} \cdot q_{NIPA} + [MBAA] \cdot MW_{MBAA} \cdot q_{MBAA}}{[NIPA] \cdot MW_{NIPA} + [MBAA] \cdot MW_{MBAA}}$$

[ ]: Molar concentration [mol/m³] , q_{NIPA} = 0.099 $g_{\text{-H2O}}/g_{\text{-NIPA homopolymer}}$
MW: Molecular weight [g/mol] , q_{MBAA} = 0.264 $g_{\text{-H2O}}/g_{\text{-MBAA homopolymer}}$ ×2.7



Thermosensitivity of NIPA gels to water vapor adsorption



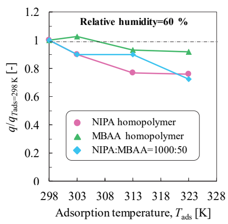


Fig. Thermosensitivity of homopolymers & cross-linked NIPA gels

- ✓ NIPA homopolymer : T_{ads}=298 K→313 K ⇒ $q/q_{Tads=298 K}$ **linearly decreased.** LCST of NIPA homopolymer = **306 K** in water

  Thermosensitivity of NIPA homopolymer to water vapor adsorption can be observed.
  BUT, thermosensitivity in dry condition is **not strong** as much as that soaked in liquid water.
- ✓ MBAA homopolymer : Temperature dependency of water vapor adsorptivity is **small**.
- ✓ Cross-linked NIPA gel : T_{ads}=313 K→323 K ⇒ $q/q_{Tads=298 K}$ greatly decreased
  Thermosensitivity of NIPA gel **shifted to higher temp.** (?)

Applicability of NIPA gel to desiccant humidity control system

Comparison of effective water adsorptivity in dehumidification of NIPA gel with conventional adsorbents

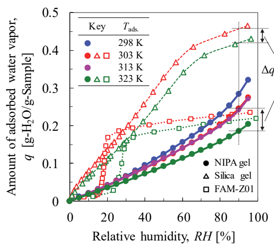


Fig. Water vapor adsorption isotherm of NIPA gel, silica gel, and FAM-Z01

Table 1 Effective water adsorptivities of adsorbents in dehumidification

	Effective water adsorptivity, Δq_{eff} [g-H_2O/g-Sample]			
	Case 1 A: 303 K, 60% D: 323 K, 60%	Case 2 A: 303 K, 90% D: 323 K, 90%	Case 3 A: 303 K, 60% D: 323 K, 21%	Case 4 A: 303 K, 90% D: 323 K, 31%
Cross-linked NIPA gel	**0.027**	**0.060**	0.104	0.190
Silica gel	0.004	0.029	**0.258**	**0.276**
FAM-Z01	0.006	0.013	0.180	0.054

*) A: Adsorption=Dehumidification, D: Desorption=Regeneration

- ✓ Temperature swing at a constant RH (Case 1&2);
  NIPA gel has **highest Δq_{eff}** ⇒ Thermosensitivity of NIPA gel is effective.
  But, Δq_{eff} is quite low.
- ✓ In more practical operation condition (Case 3&4);
  Δq_{eff} of NIPA gel is **lower** than silica gel.
  Water adsorptivity at a low temperature should be greatly increased.

Conclusion

- ◆ Water vapor adsorptivity of cross-linked NIPA gel increased with increasing MBAA monomer concentration and decreasing NIPA monomer concentration.
- ◆ NIPA homopolymer might show thermosensitivity around LCST of 306 K, but its thermosensitivity in dry condition is not strong as much as that soaked in liquid water.
- ◆ Water adsorptivity of the cross-lined NIPA gel is getting lower over 313 K, implying that thermosensitivity of the cross-linked NIPA gel shifted to higher adsorption temperature.
- ◆ A further increase in water adsorptivity at low adsorption temperature is required to apply NIPA gel to practical humidity control system.

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