第7講義
2012, Dec. 18

エネルギー・環境を支える新規機能性活性炭
(Novel Functional Activated Carbons for the Applications to Energy and Environmental Devices)

尹 聖昊
九州大学 先導物質化学研究所
yoon@cm.kyushu-u.ac.jp

Contents:
1. 活性炭の構造、細孔分析及び応用
2. 繊維状ナノ炭素の調製、構造及び応用

活性炭を用いた水の浄化

Structure of PAN based carbon fiber

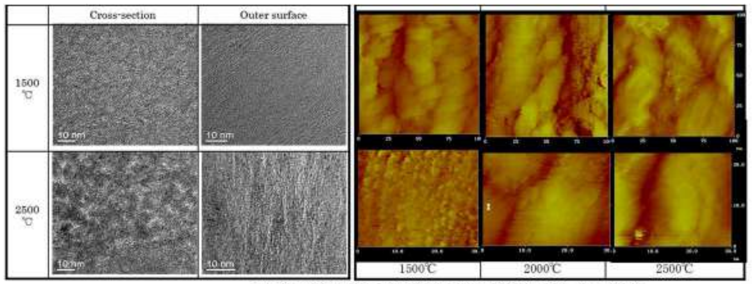
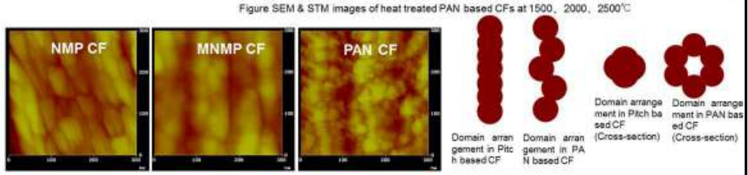
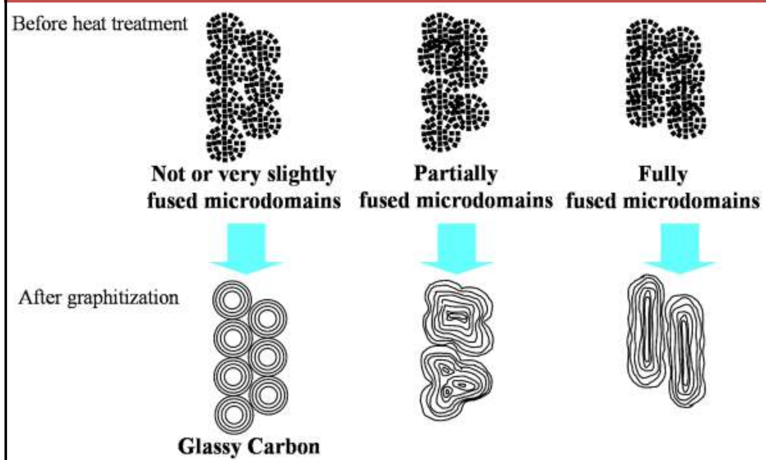


Figure SEM & STM images of heat treated PAN based CFs at 1500, 2000, 2500℃



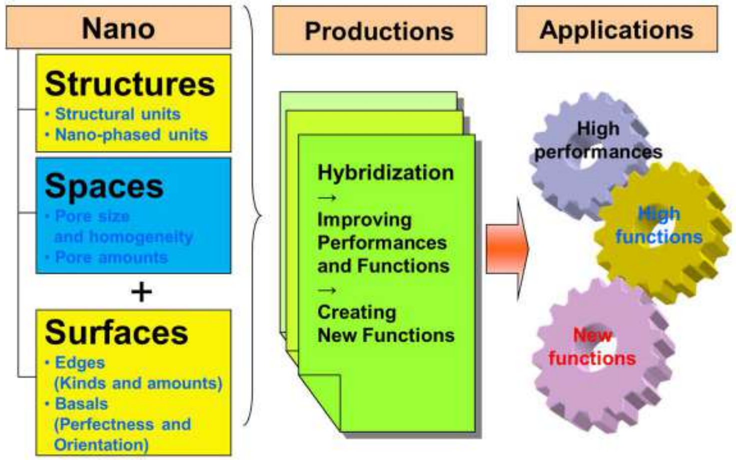
"Structural comparison of mesophase and PAN based carbon fibers"
S.H. Hong, S. H. Yoon, I. Mochida Carbon2006 (2006. 7) England

Control of structural units



IAMS, Kyushu University "Axial nano-scale microstructure in the graphitized fiber inherited from liquid crystal mesophase pitch"
Carbon, 34, 83-88 (1996) S. H. Yoon, Y. Korai, K.Yokogawa, S. Fukuyama, M. Yoshimura, I. Mochida

Carbon materials from the structural points



Best carbon?

Carbon is an Indispensable Material for Energy related Devices

Best Structure for Best Performance
↕
Best Selection

Best Selection

Scientific Cycle

- Structural Understanding
- Structure Preparation
- Working Mechanism
  - Molecular Level
  - Electrochemical
  - Catalytic / Kinetics
  - Molecular / Heat Transfer

Carbon

How to prepare the activated carbons

Selection of Precursor

- *Pore Framework / Density*
- *Properties of Pore Wall, Composition / Graphitic Extent*
- *Reactivity at Activation*
- *Non-graphitizable precursors like polymer, biomass and isotropic coke for usual AC or ACF*
- *Graphitizable precursors like anisotropic cokes or mesophase pitch for EDLC electrode materials*

Activation Procedures

- *CO_2, H_2O*
- *Alkali Hydroxides / Carbonates; More Research*
- *Selective Catalytic Gasification ; Catalyst Control*

❖Very Large Surface Area > 3000 m^2/g
❖Adequate Pore And Wall

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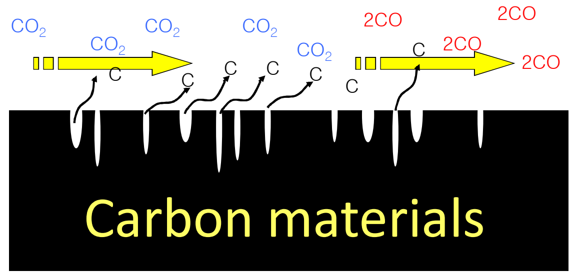
Activation



Activation reagents

- Air, CO2, Steam
- KOH (NaOH), ZnCl2

Chemical activation

$2KOH \rightarrow K_2O+H_2O$ (Dehydration)

Catalytic progress Under K2O

$C+H_2O \rightarrow H_2+CO$ (Water gas reaction)

$CO+H_2O \rightarrow H_2+CO_2$ (Water gas shift reaction)

Carbon is mainly consumed as a form of K_2CO_3

$K_2O+CO_2 \rightarrow K_2CO_3$

$K_2O+H_2 \rightarrow 2K+H_2O$

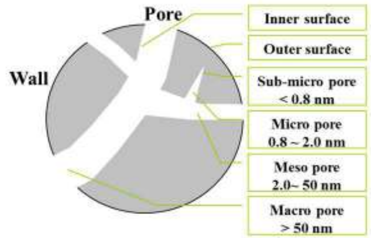
$K_2O+C \rightarrow 2K+CO$

K compounds are reduces as a metal

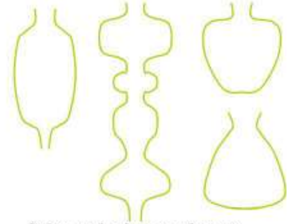
- Higher surface area compared to the steam activation
- Almost no productions of CO and CO_2
- K metal intercalation: higher diffusivity than steam molecule

KOH	K_2O	K_2CO_3	K
MP: 380℃ BP: 1324℃	MP: 490℃ (350℃, KO and K)	MP: 891℃	MP: 64℃ BP: 774℃

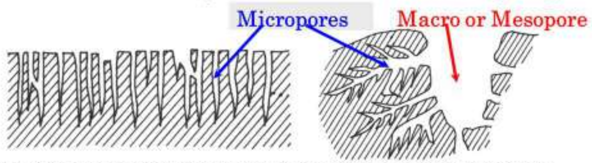
Conventional concept of activated carbons



Classification of surface and pores

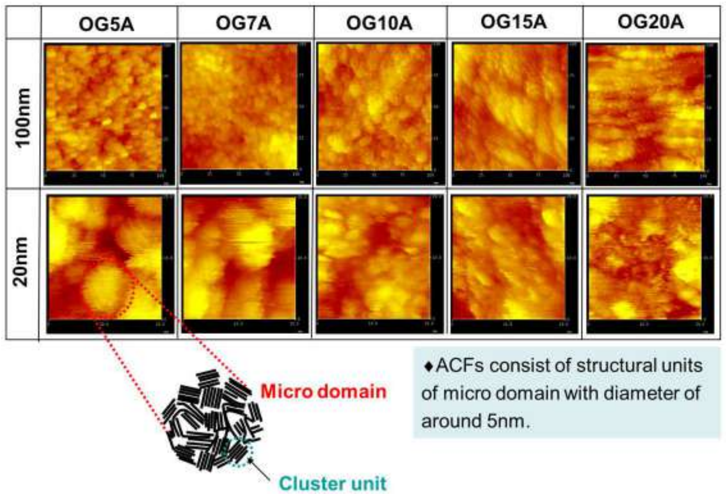


Schematic shapes of pores



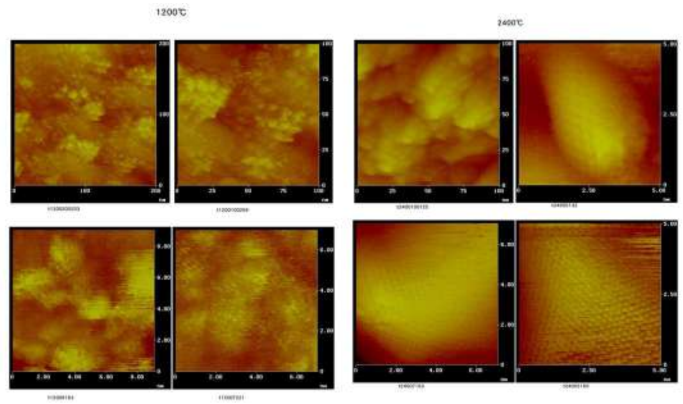
Schematic pore images of activated carbon fiber and activated carbon

STM images of ACFs



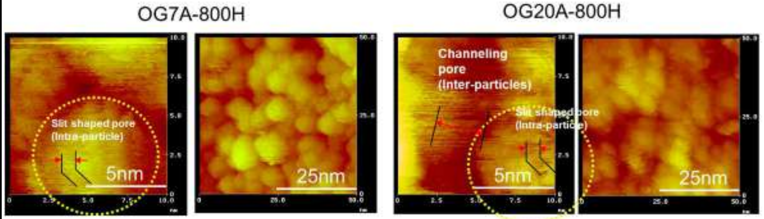
♦ACFs consist of structural units of micro domain with diameter of around 5nm.

Structure of glassy carbon



Pore nucleation in activated carbon

In order to remove oxygen containing functional groups for removing the heterogeneous effect of STM, OG7A and OG20A were heat-treated at 800°C in a hydrogen atmosphere (H_2 / He =1/4).



- ♣Vacant spaces between the two domains of OG20A are larger than that of OG7A.
- ♣Domain size of OG20A is a little smaller than that of OG7A.
- ♣Slit type pores were observed in domains of OG7A and OG20A.
- ♣It can be presumed that almost pores larger than 2nm nucleated by the inter-particle mechanism.

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Novel concept of activated carbon

Surface Area, Pore: *Depth & Volume*

Surface Structure

Surface Chemistry

Based and Edge Plane, Substituents

Hetero Atoms in Hexagon

Carbon Structure of Wall

Micro, Nano, Macro Structure of Carbon Wall

-Graphitization Extent

-Domain Structure

Density, Reactivity (Activated Surface)

→ *Precursor : Structure and Reactivity*

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Novel concept of activation

Precursor of ACF has been composed of nano-structural primary units

Structural factor should be ... the better understanding of activated ... heir applications.

Size and arrangement of BSU
Etching and diffusion of oxidative agent against BSU

Pores from intraparticles (Slit shaped? Micropores less than 2 nm)

Pores from interparticles (Channeled shaped having wider pore size distributions (0.2 ~ 50 nm)

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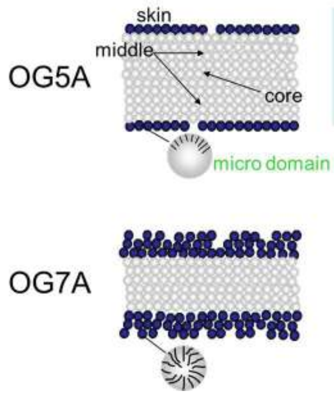
Novel understanding of activation mechanism

A model for cross section of ACFs



- ♣Only skin is activated, homogeneous narrow pore exist on the surface of domains.
- ♣The activation does not reach to the middle and core parts.

↓

OG5A has smallest surface area but homogeneous pores.

- ♣Skin and middle parts are activated.
- ♣Pores in domain become wider and longer than that of OG5A because of the pores formed by inter-domain mechanism.
- ♣Pores are formed by the intra-domain and inter-domain mechanisms.

↓

Heterogeneous pores exist.

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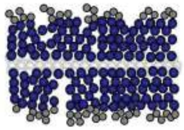
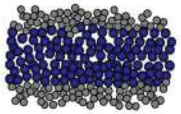
OG10A



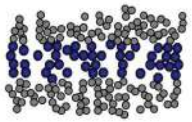
♣The activation proceeds to near the core.
♣Domains in the surface become smaller by activation.
↓
OG10A have various size pores.

OG15A



♣Whole parts of skin, middle and core are activated.
♣The pores from the intra-domain become larger by activation.
♣Owing to some domains burning, fiber diameter becomes smaller than OG5A, 7A and 10A.
↓
More homogeneous pore distribution than that of OG10A

OG20A



♣Over 70% of domains are burned-off.
♣Pore portions from interparticle nucleation becomes larger
↓
♣OG20A diameter become smaller than OG15A.
OG20A have largest surface area but heterogeneous pores.

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Novel recognition of the structure of ACs

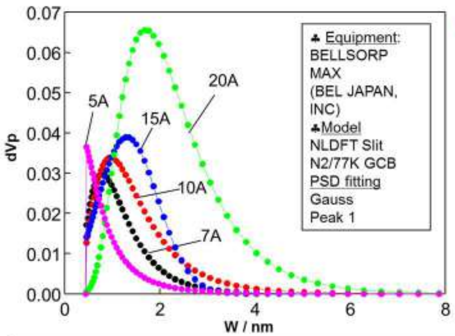
多孔性炭素材料:乾燥・精製・分離・貯蔵などに利用

効果的な性能向上のために
詳しい細孔発達 メカニズムの解明が必要

マイクロドメインモデル

N.Shiratori, et al., *Langmuir* 2009, 25(13), 7631-7637. 1

Pore size distribution（NLDFT）



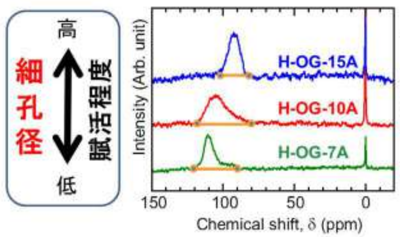
♣**Advantage of DFT method**
Determination of a pore size distribution in the wide range of pore size from micro pore to meso pore.

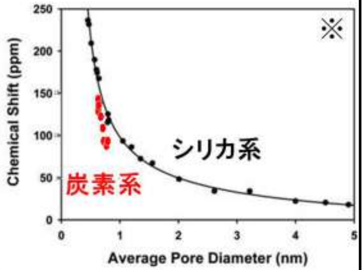
♣Disadvantage
This method needs
>measurement in low pressure
>assumption of pore structure
>homogeneity of adsorbent surface

	OG5A	OG7A	OG10A	OG15A	OG20A
pore size at peaks (nm)	Less than 0.44	0.72	0.98	1.28	1.86
Pore distribution range in this DFT profile (nm)	~2.8	~3.0	~5.0	~3.0	0.44~7.0

♦The pore size at peak increased in the order of OG5A<7A< 10A < 15A < 20A.

Pore size distribution (Xe-NMR)





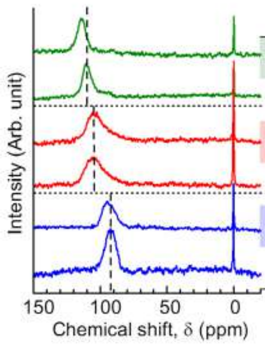
細孔径・細孔径分布解析結果

sample	^{129}Xe-NMR		N_2 adsorption		
	Avg.	range	αs	NLDFT	range.;@NLDFT
H-OG-7A	0.96	0.88~1.27	0.65	1.18	0.47~1.35
H-OG-10A	0.99	0.87~1.27	0.73	1.02	0.45~4.97
H-OG-15A	1.11	1.00~1.29	0.80	1.11	0.45~5.13

※N.Shiratori, et al., *Langmuir* 2009, 25(13), 7631-7637. 20

Effect of functional groups (Xe-NMR)

OG-XA (X=7,10,15) ⟷ 官能基 ⟷ HOG-XA (X=7,10,15)



sample	$w_{-\alpha s}$ (nm)	$O_{(diff.)}$ (wt%)
OG-7A	0.68	6.1
H-OG-7A	0.65	4.4
OG-10A	0.72	6.4
H-OG-10A	0.73	2.9
OG-15A	0.78	5.2
H-OG-15A	0.80	2.5

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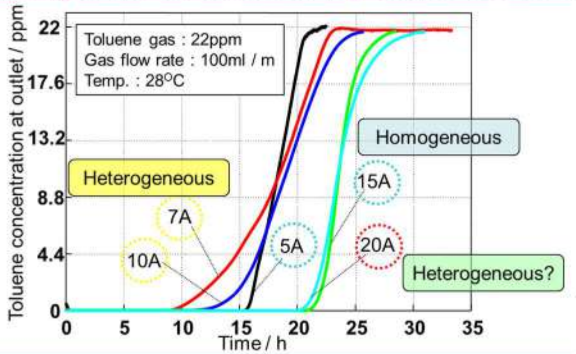
Adsorption of toluene by various ACs



- The slopes of breakthrough curves for 5A and 15A were steeper than those of curves for 7A and 10A.
- ACFs with homogeneous pores (5A and 15A) showed rapid toluene adsorption and larger capacity per unit area and longer breakthrough time, whereas ACFs with heterogeneous pores (7A and 10A) showed slow toluene adsorption and smaller capacity per unit area.

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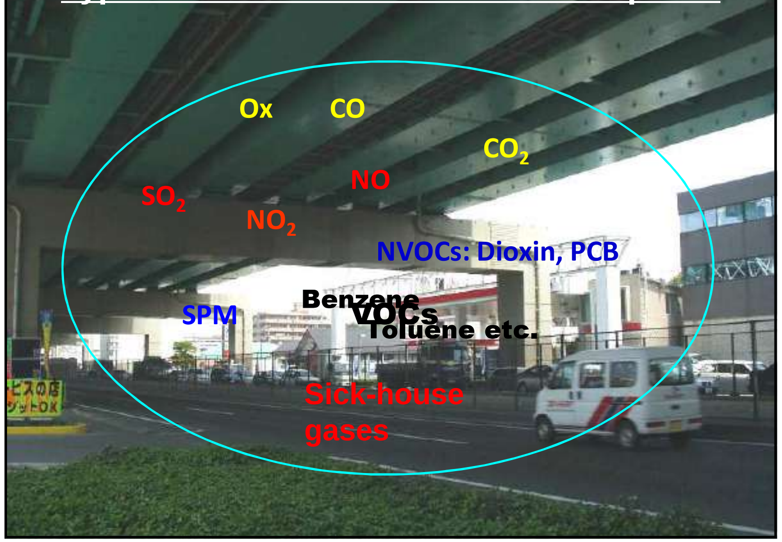
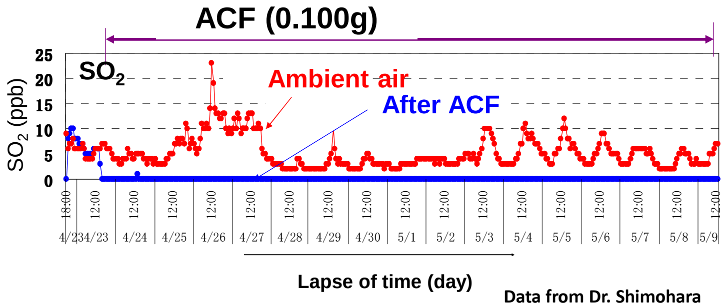
Removal of SOx and NOx Using ACFs

Typical Hazard Gases in the Atmosphere



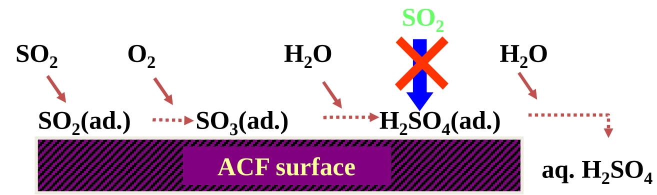
ACF

SO_2 → SO_4^{2-}



Data from Dr. Shimohara
Of Fukuoka H & E Institute

DeSOx mechanism using ACF



SO_2+ad.→SO_2ad.

SO_2ad.+1/2O_2→SO_3ad.

SO_3ad.+H_2O→H_2SO_4ad.

H_2SO_4ad.+H_2O→aq.H_2SO_4

Active Sites on Carbon Surface

Oxygen functional group	Acidic nature: Oxidative Basic nature: Reductive
Free valence	
Benzyne bonds on edge	Oxygen activation
Hetero-atoms in edge	Zigzag or Armchair

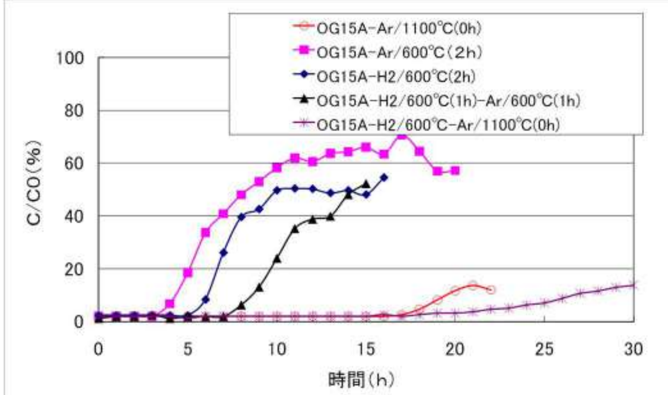
Hexagon stacking height

Hydrophilic/Hydrophobic
Small surface energy

How to control ?

Breakthrough of SO_2 Removal

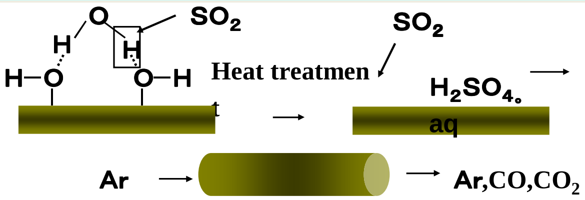
Optimum Post-Heat treatment with Reductive Oxygen Removal



SO_2 1000ppm,O_2 5vol.% H_2O 10vol.%,N_2 balance, Flow rate: 100ml/min, Temperature: 50℃

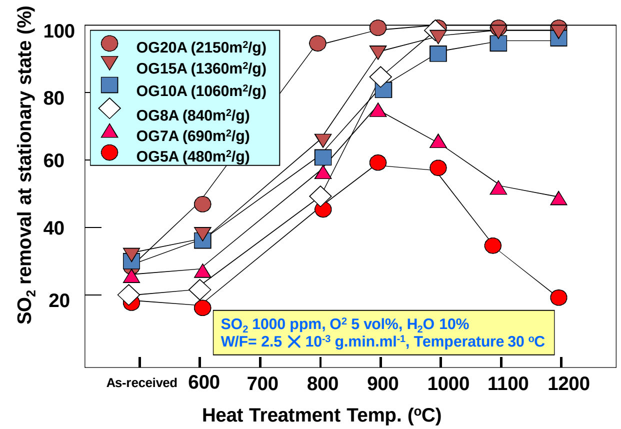
Effect of Heat Treatment

Removal of Functional Groups
with Least Changes of Carbon Structure
Surface Area and Hexagon Stacking



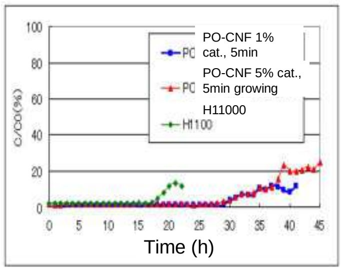
Carbon	C	H	N	O	Ash (%)
	(wt.%, dry)				
OG-15A	93.5	0.6	0.5	5.5	0.0
OG15A-H1100(0min)	97.0	0.4	0.5	2.2	0.0
OG-15A-H1100(1h)	96.8	0.2	0.3	2.7	0.1

The Effect of Heat Treatment for SO_2 Removal



DeSOx by ACF and CNF-ACF Composite

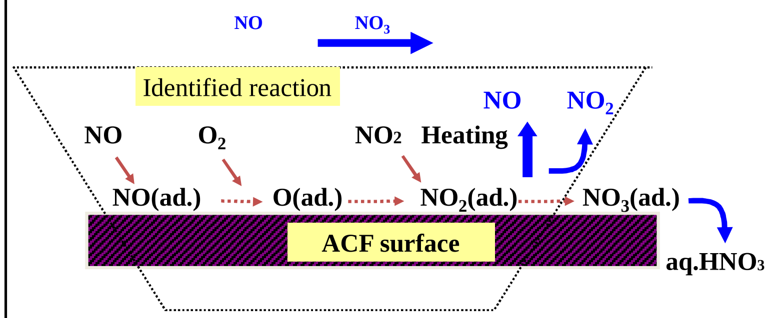
DeSOx Properties of ACF and ACF-CNF



DeSOx condition: SO_2 1000ppm, O_2 5vol%, H_2O 10vol%,
N_2 balance、Total flow rate: 100 ml/min
Reaction Temperature: 50 ℃

PDU for SOx Removal by ACF

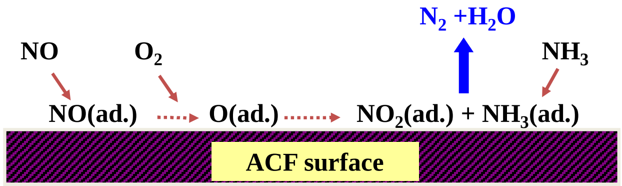
NO & NO_2 Oxidation over ACF



Strong Inhibition of H_2O

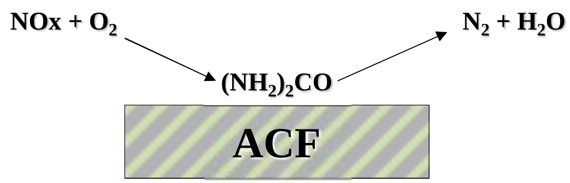
The oxidation of NO_2 always produces NO And NO_3^- through the disproportionation.

The Mechanism of NO Reductive Removal



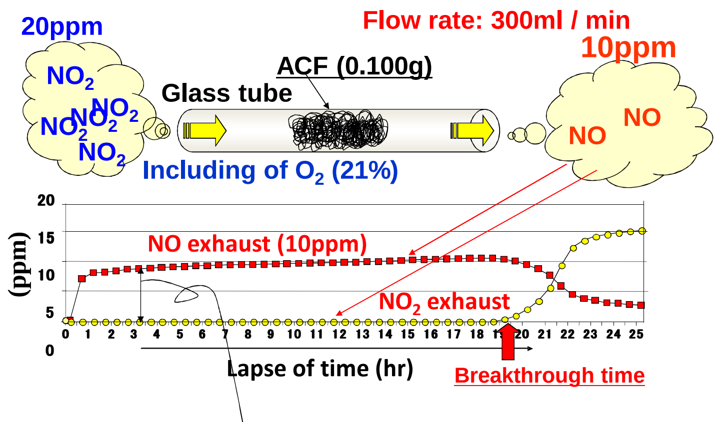
The mechanism of NO removal consists of adsorption and oxidation of NO into NO_2 which is reduced with NH_3

NOx Reduction at Room Temperature



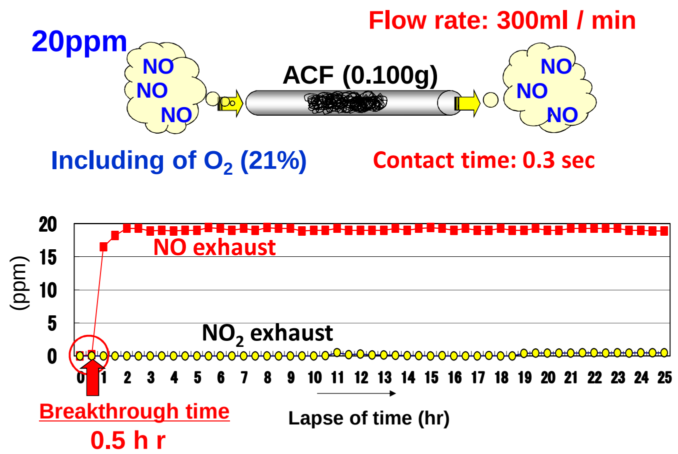
- NOx oxidation
- Urea Activation
- NOx in Environment
- Roles of ACF : More variety of ACF

Adsorption of NO_2 in ACF

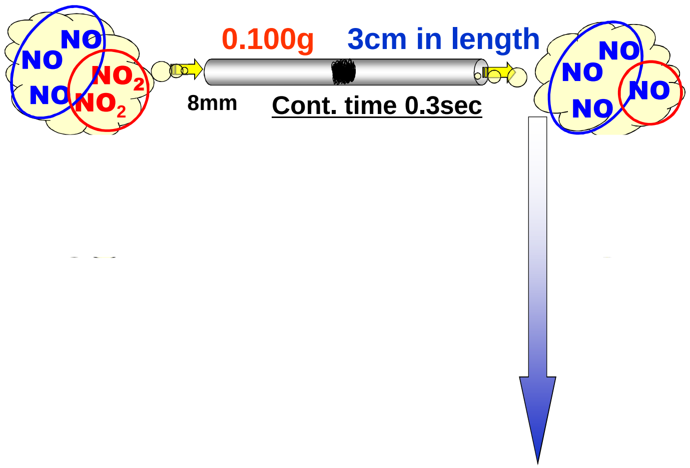


Half amount of adsorbed NO_2 is exhausted as NO.

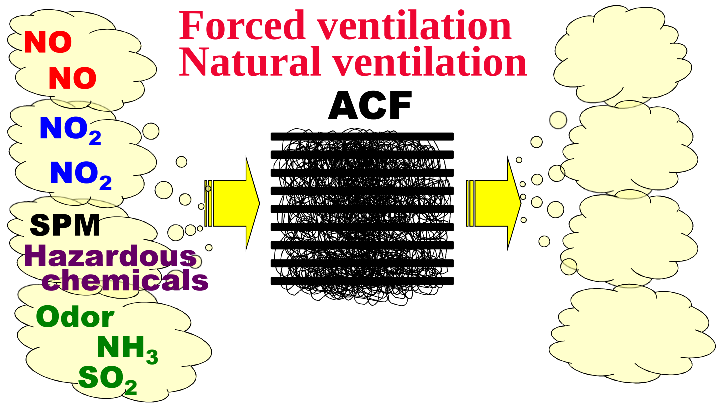
Scavenging activities against NO



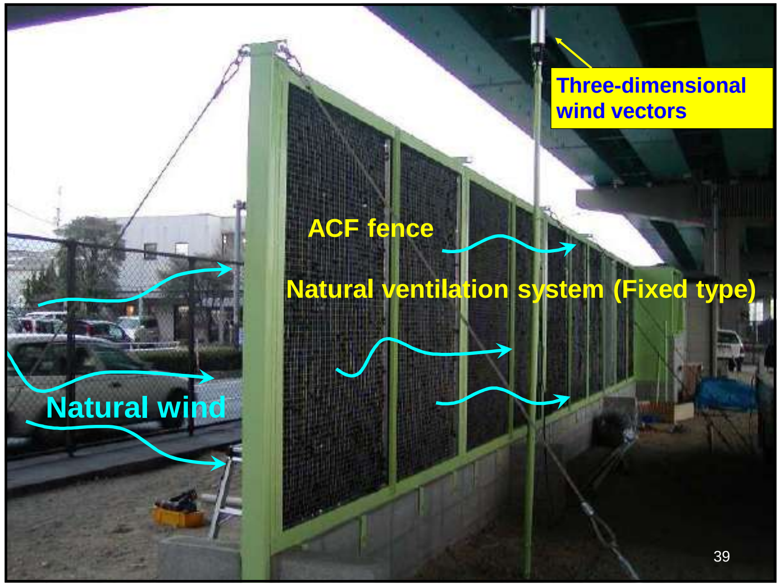
The characteristics of NOx purification



Characterization of ACF purification



Room temperature, ozonizer is no need, no light irradiation, compact design



Novel applications of ACs

1. HCHO(Removal of sick-house gases)
2. Super capacitor
3. Medicine
4. Capacitive De-ionization (CDI)
5. Heat Pump (adsorptive heat pump)

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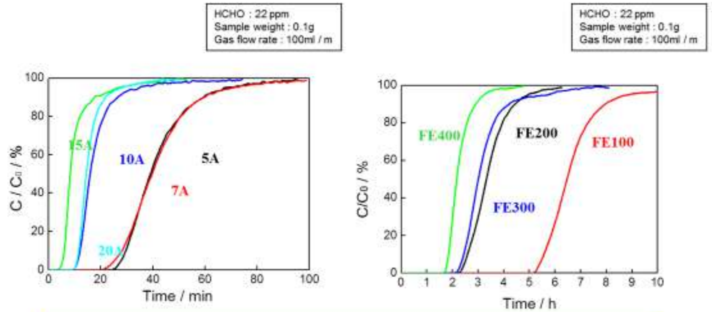
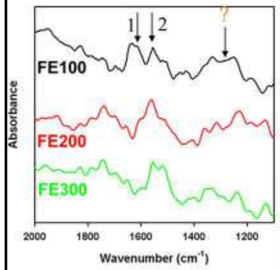
1. HCHO & Toluene （Sickhouse gases）

Removal of HCHO using ACs



Break through time
◆Pitch-based ACF : 15A < 20A < 10A < 7A < 5A
◆PAN-base ACF : FE400 < FE300 < FE200 < FE100

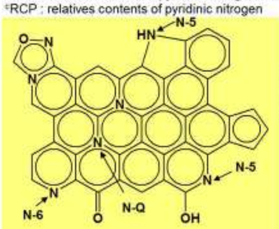
Micro ATR-FTIR analysis of ACs



1) *Pyridinic nitrogen band*
2) *Internal standard*

	Micro-ATR FTIR analysis			EA and XPS analysis		
	I.S[a]	Pyridinic N[b]	RCP[c]	N / C ratio	Pyridinic N[b]	RCP[c]
FE100	279	134	0.48	0.118	0.737	0.087
FE200	276	108	0.39	0.066	1.050	0.069
FE300	332	70	0.21	0.044	0.734	0.032

[a] I.S : Internal standard (1560cm⁻¹)
[b] Wavenumber related with pyridinic nitrogen : 1610~1600cm⁻¹
[c] RCP : relatives contents of pyridinic nitrogen



Pyridinic N (N-6)
Pyrrolic or Pyridinic N (N-5)
Quaternary N (N-Q)

Micro-ATR FTIR

Relative amount of pyridinic nitrogen functional groups for PAN based ACFs by micro-ATR FTIR analysis

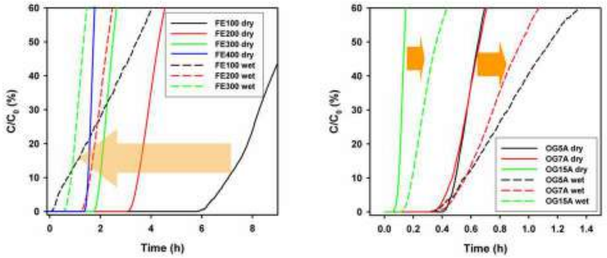
Sample	Internal Standard	Pyridinic N [a]	Internal Standard /Pyridinic N
FE100	279	134	0.48
FE200	276	108	0.39
FE300	332	70	0.21
FE400	330	64	0.19

[a] Wavenumber related with pyridinic nitrogen: 1610 ~ 1600 cm⁻¹

Effect of humidity

WATER Competitive adsorption decreases the adsorption amount of HCHO.

Dry condition (solid line) and wet condition (dashed line) for the different kinds of a) FE series and b) OG series



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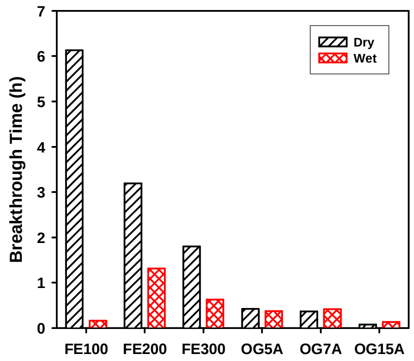

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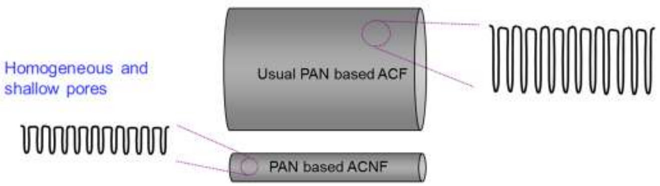
Novel concept of pore (shallow pore)

♦ Electrospun PAN based nanofiber (100% PAN)
Diameter: 800 nm, Nanotechnics (Korea)

100 times surface area compared to usual PAN fiber
→Can be expected very shallow and homogenous pores。



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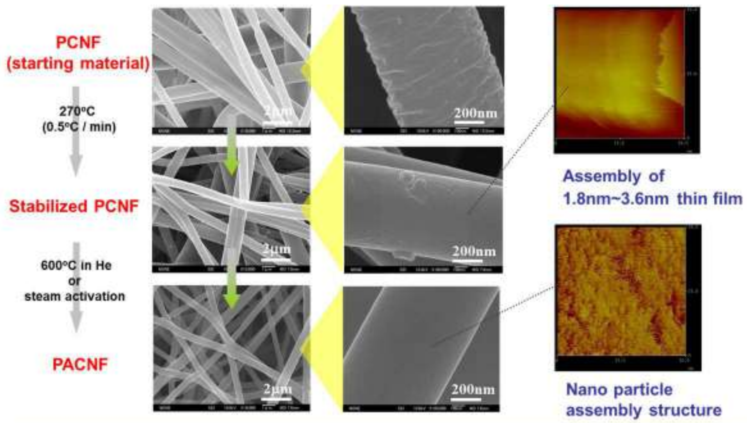
PAN based activated carbon nanofiber



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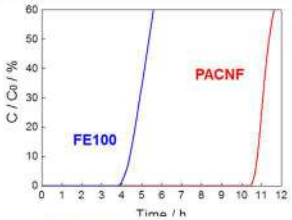
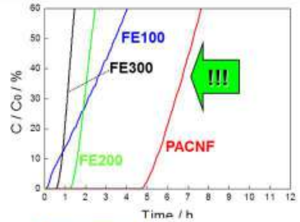
Removal of HCHO using PAN-ACNF

RH	BET (m2 / g)	Elemental analysis (wt%)					N / O	Microporous ratio (%)
		C	H	*N*	*Odiff*	ash		
90%	375	68.06	1.19	*18.02*	*11.41*	1.32	1.80	94.7%



Experimental
HCHO : 11 ppm
Sample weight : 0.05g
Gas flow rate : 100ml / ml
Humidity of condition : 0%



Experimental
HCHO : 11 ppm
Sample weight : 0.05g
Gas flow rate : 100ml / ml
Humidity of condition : 50%

Under the circumstances of humidity (RH=50%), PACNF shows specific prominent adsorption characteristics for formaldehyde.

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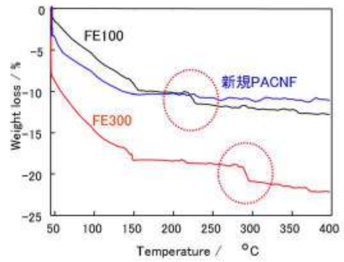
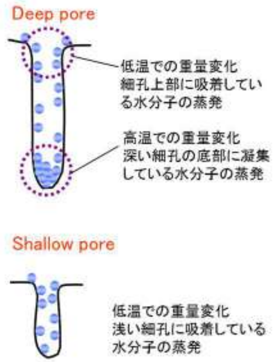
Shallow pore (?)

水分を飽和吸着させたサンプルを
アルゴン中で400℃まで昇温させ、
重量変化を観察





Carbon, 48, 4248-4255 (2010).

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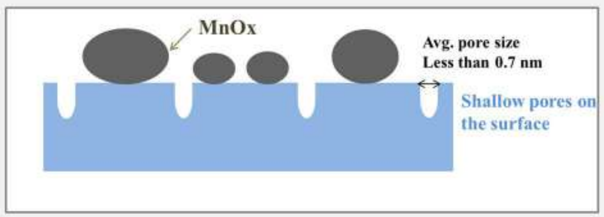
Complete removal of HCHO using MnOx/ACNF

① Activated nano carbon fiber

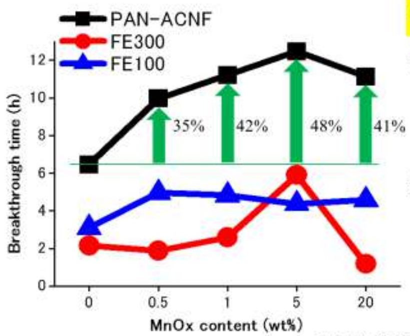
② Catalytic decomposition of HCHO by MnOx into water and carbon dioxide

③
- Clean removal into Water and Carbon dioxide
- Lifetime prolonged

The conceptual model of MnOx-carbon catalyst



Catalysis Today, in press (2012).

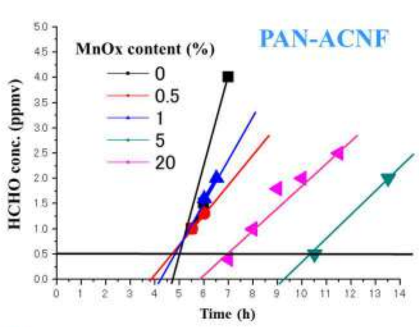


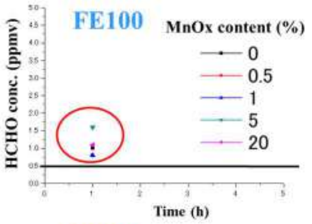
Weight-0.05g base

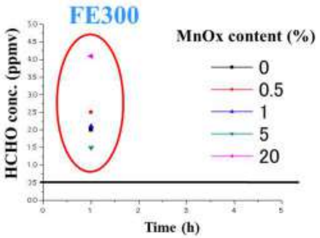
Dry condition

1. **MnOx combined with carbon support to enhance HCHO removal.**
2. **PAN-ACNF showing the highest synergy at 5% MnOx.**

Mn_3O_4 or MnO_2 alone breakthrough in less than an hour.
➡ Deposition on carbon support improves catalytic activity of MnOx.







※Breakthrough time: Time reaching 0.5 ppm

Test condition

- Temp: 30℃, Relative Humidity: 90%
- Flow rate: 100 mL/min (HCHO : N_2 : O_2 = 5:4:1)
- HCHO inlet concentration: 10 ppmv

2. Super capacitor

Study of super capacitor using NMR

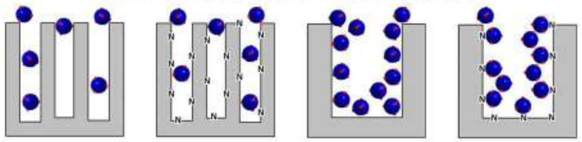
Pitch-based Activated Carbon Fibers (ACFs)

OG series : OG-5A, OG-7A, OG-10A, OG-15A, OG-20A (Osaka Gas Co., Japan)

PAN-based ACFs

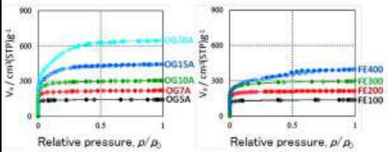
FE series : FE-100, FE-200, FE-300, FE-400 (Toho TENAX Co., Japan)

Model of micropores of OG and FE series



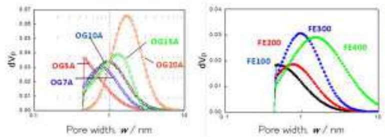
Aqueous and non-aqueous electrolytes with different ion sizes

N₂ adsorption/desorption isotherms @77K



Pore size distributions

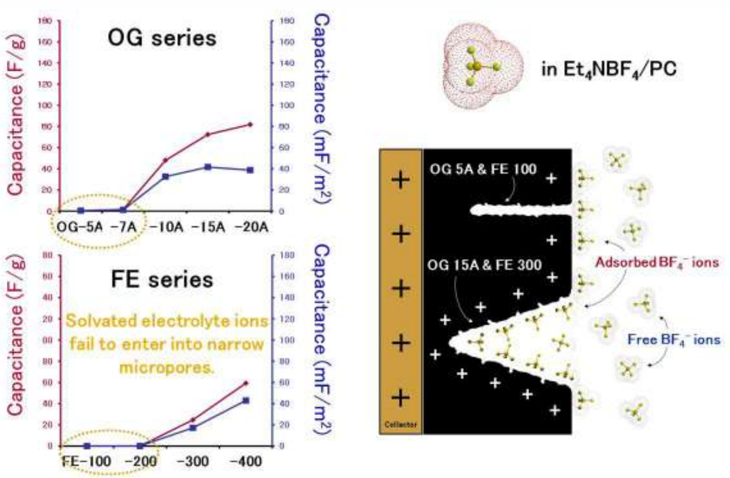
(*calculated by NL-DFT method*)

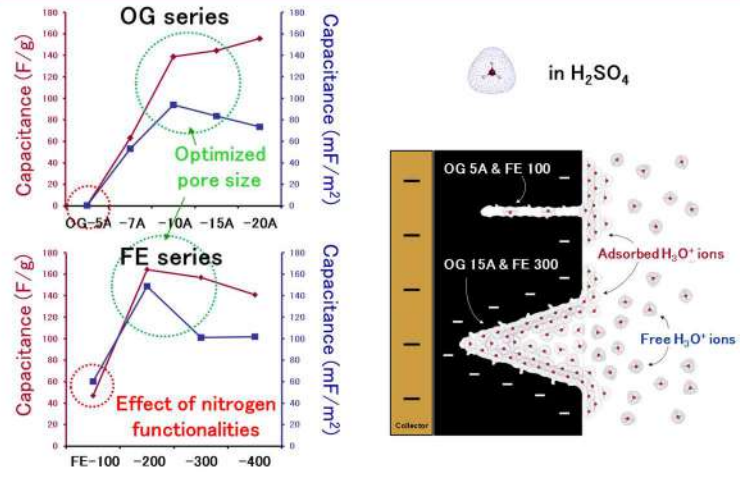


Pore structure parameters

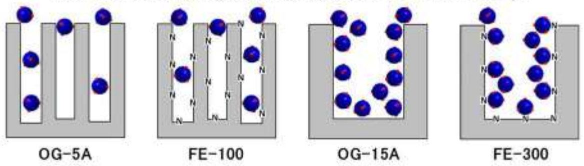
(*calculated from t-plot method*)

	Surface area (m^2/g)				Pore volume (cm^3/g)			Pore width (nm)	
	A_{total}	$A_{external}$	A_{micro}	A_{meso}	V_{total}	V_{micro}	V_{meso}	W_{micro}	W_{meso}
OG-5A	676.8	1.2	675.6	0	0.22	0.22	0	0.65	0.0
OG-7A	987.6	3.4	984.2	0	0.34	0.34	0	0.68	0.0
OG-10A	1211.7	5.4	1206.3	0	0.46	0.46	0	0.77	0.0
OG-15A	1488.0	13.9	1474.1	0	0.66	0.66	0	0.90	0.0
OG-20A	1817.4	15.9	1801.5	0	0.97	0.97	0	1.08	0.0
FE-100	636.9	1.2	635.7	0	0.21	0.21	0	0.67	0.0
FE-200	909.2	2.2	907.0	0	0.33	0.33	0	0.72	0.0
FE-300	1130.6	3.8	1099.7	27.1	0.45	0.43	0.02	0.78	1.82
FE-400	1187.1	5.2	931.2	250.7	0.60	0.38	0.22	0.82	1.73





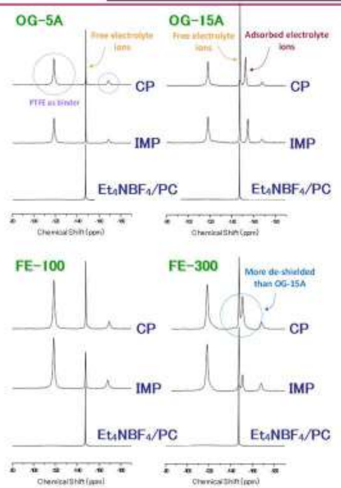
Model of adsorbed ions in micropores of OG and FE series

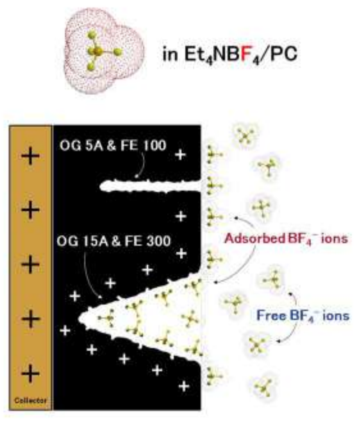


^{2}H or ^{19}F magic angle spinning (MAS) solid state NMR

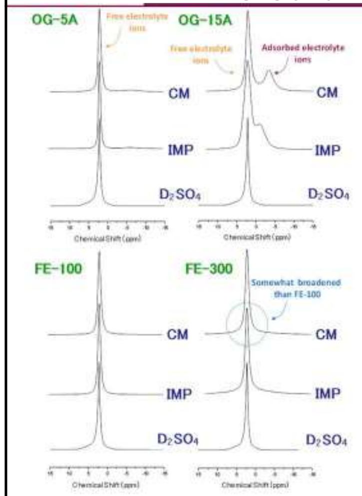
NMR equipment:	JEOL ECA400
Electrolytes:	0.5 M D_2SO_4 (aqueous)
	1 M Et_4NBF_4/PC (in-aqueous)
Electrode states:	Impregnated (IMP)
	Charged plus (CP)
	Charged minus (CM)

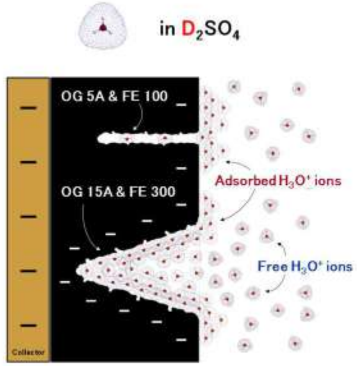
^{19}F MAS Solid-State NMR Spectra





^2H MAS Solid-State NMR Spectra





T_1 Values Measured from ^2H MAS Solid-State NMR

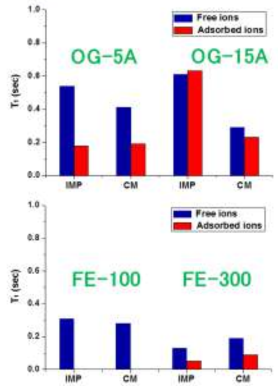
The shorter the T_1 value of relaxation time, the stronger the adsorption interaction between adsorbed electrolyte ions and carbon electrodes.

T_1 (sec) for OG series

OG-5A				OG-15A			
IMP		CM		IMP		CM	
Free	Adsorbed	Free	Adsorbed	Free	Adsorbed	Free	Adsorbed
0.54	0.18	0.41	0.19	0.61	0.63	0.29	0.23

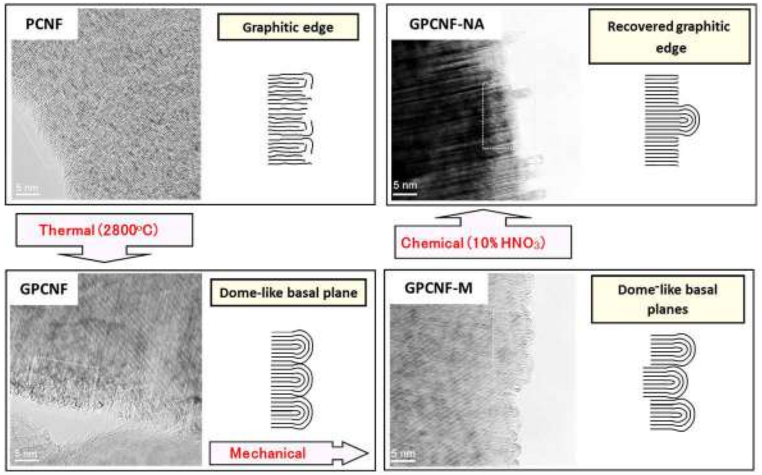
T_1 (sec) for FE series

FE-100				FE-300			
IMP		CM		IMP		CM	
Free	Adsorbed	Free	Adsorbed	Free	Adsorbed	Free	Adsorbed
0.31	-	0.28	-	0.13	0.05	0.19	0.09



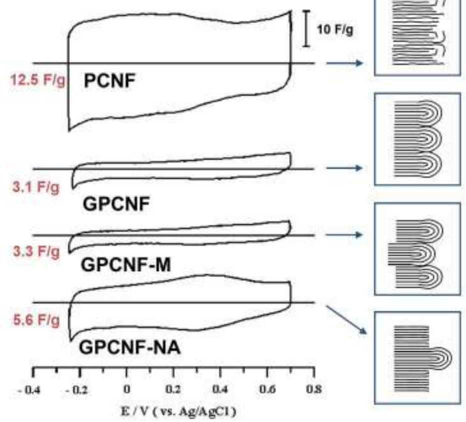
Surface modified PCNFs

Langmuir 2006, 22(22), 9086.



Capacitances of PCNF series

Langmuir 2006, 22(22), 9086.



PCNFs having edge surfaces Showed 3-5 times Higher capacitancs

AC- medicine

Characteristics of activated carbons for the selective adsorption behaviors for Indole and Amylase

Research background

Chronic Kidney Desease

Renal function decrease for removal poisons from body
⇒ **Artificial dialysis**

big burden to patient

To prolong the introduction of dialysis, AC medicine was developed

AC internal medicine

・To remove the entro-poisons like indole through the excretion with activated carbon.
・Very hard to take a dose (6g/day)

How to decrease the dosage amount

Factors for selective adsorption

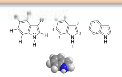
・Surface area and pore size

・Shape

・Surface property

Model adsorption materials

・To be removed



Indole (MW: 117.15)

⇒ a kind of poisons

・Not to be removed

Amylase (MW: about 46000)

⇒Digestive enzyme

Samples

OG series (Osaka Gas)

Relatively similar shapes of pores but different surface area and pore size distribution

・Surface area and pore
・Surface property

H_2-OG series

Hydrogenation of OG series to remove the oxygen functional groups(600℃, 1h)

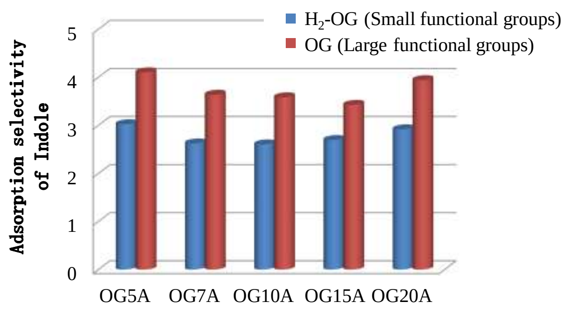
Ball type activated carbons

Ball type activated carbons with diameters of 100～300 μm

α_s analysis

		OG5A	OG7A	OG10A	OG15A	OG20A	H_2-OG 5A	H_2-OG 7A	H_2-OG 10A	H_2-OG 15A	H_2-OG 20A	SAC	OAC	Scmep	SACmip
SA (m^2/g)	A_{micro}	646	982	1283	1688	1928	728	1247	1305	1548	1802	1254	1585	570	1409
	A_{meso}	0	0	0	0	0	0	0	0	0	0	56	0	108	143
	$A_{external}$	0.3	0.3	0.1	0.3	0.3	0.4	0.1	0.3	0.3	0.5	6.6	1.4	0.2	0.4
Pore size (nm)	W_{micro}	0.65	0.68	0.74	0.90	1.11	0.65	0.70	0.75	0.91	1.11	0.69	0.96	0.64	0.74
	d_{meso}	0	0	0	0	0	0	0	0	0	0	12.0	0	5.85	3.24
Oxygen contents (%)		14.3	19.0	22.2	12.8	12.1	6.0	5.2	4.5	2.5	2.6	15.1	4.7	6.0	4.4

Effect of functional groups for binary solutions



Removal ratio of Indole (%)	OG5A	OG7A	OG10A	OG15A	OG20A
Small functional groups	49.9	70.1	69.3	70.9	72.1
Large functional groups	43.1	63.3	63.8	69.9	68.6
Removal ratio of amylase (%)	**OG5A**	**OG7A**	**OG10A**	**OG15A**	**OG20A**
Small functional groups	16.5	26.7	26.6	26.3	24.7
Large functional groups	10.5	17.4	17.8	20.4	17.4

Capacitive De-ionization (CDI)

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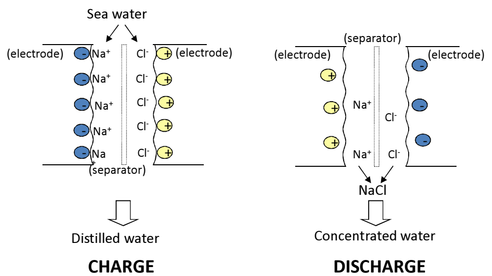
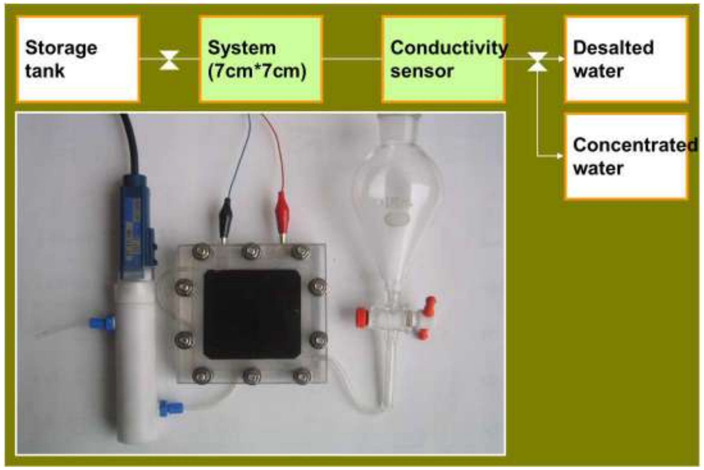
Principle of electrical desalination



- Diffusion of ions inside of pores
  - Rapid electrochemical adsorption and desorption

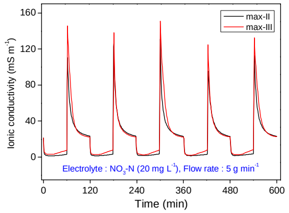
Experimental setup



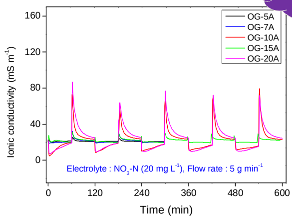
Nitric ion removal behaviors

Up to 1.0V

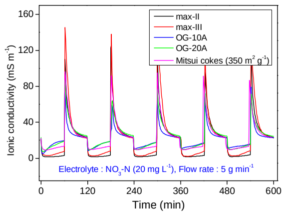
Maxsorb series



OG series



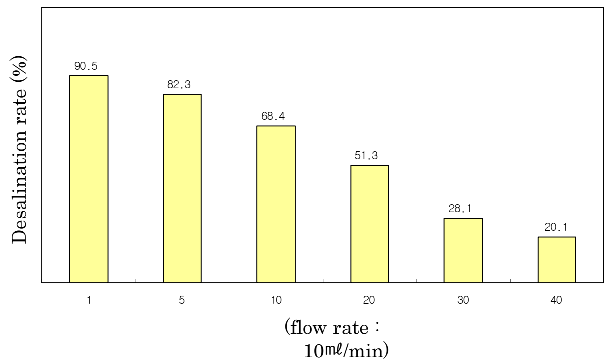
Total



- 硝酸性窒素イオンにおける脱塩特性は **Max−Ⅲが最大特性**を示した。
- 三井鉱産のコークスがOGシリーズより良かった。
- **Maxsorb > Mitsui cokes > OG series**

Cl^- ions in the city water

Effect of flow rate



Points

- How to increase lifetime
- How to increase adsorption selectivity and amount of ions

⇒

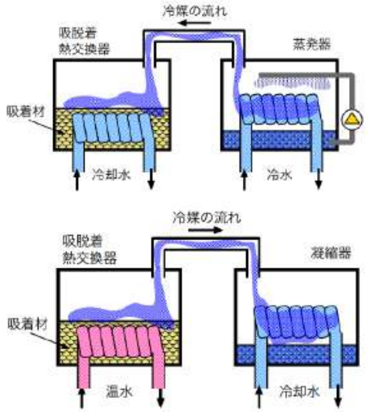
- ☐ Optimization of pore and its distribution
- ☐ How to increase molecular diffusivity
- ☐ Preparation of high electric conductive AC

Application of activated carbons to Heatpump for energy-free operation

Principle of Heat Pump

Adsorption

Desorption



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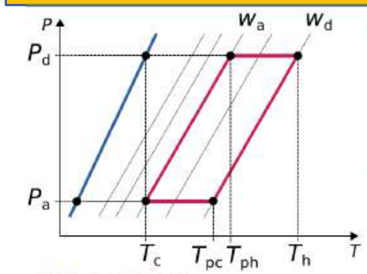
Static analysis of adsorptive HP



Heat input

$$Q_{in} = M_s C(T_h - T_c) + M_s q_s (w_a - w_d)$$

$$C = \begin{cases} c_s + c_r w_a & (T_c \le T \le T_{ph}) \\ c_s + c_r (w_a + w_d)/2 & (T_{ph} \le T \le T_h) \end{cases}$$

Cooling effect

$$Q_{chil} = M_s L_r (w_a - w_d)$$

COP

$$COP = Q_{chil}/Q_{in}$$

How to increase power
- Increasing effective adsorption

How to increase COP
- Making temperature change smaller

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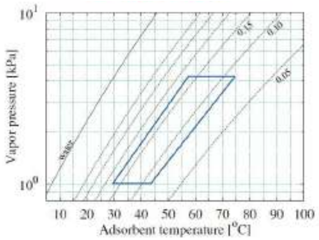
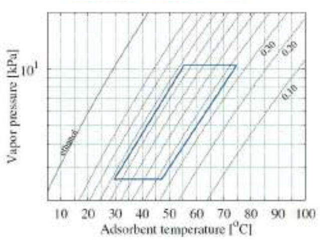
Performance test results

Silica gel- water



COP 0.69
冷凍効果 210 kJ/cycle

Activated carbon - ethanol



COP 0.66
冷凍効果 360 kJ/cycle

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Points

- How to increase adsorption amount of molecules such as water, methanol and ethanol

⇒

- ☐ Optimization of pore and its distribution
- ☐ How to increase molecular diffusivity
- ☐ Preparation of high thermal conductive AC

Carbons from now

Era of **nano-carbons** are almost finished. Only special applications are promising!

Era of **GOOD Raw material to GOOD Product** are almost finished. China and other developing countries will take over whole markets!

Era of **BAD Raw material to GOOD Product** are coming. Developed countries only have chances on such materials

Novel carbon, if it can be found, still has a chance to change the paradigm. But what is that?

Nano-carbons (Concept, methodology) — Fusion — **Conventional carbons (Waste Materials)**

New carbon materials, New processes for manufacturing, New markets for carbon applications