Conductive Activation Carbon Monoliths Prepared Directly from Brown Coal

Applications in Gas and Liquid Adsorption

Mehrdad Parsa, Emma Qi, Alan. L. Chaffee
School of Chemistry

12th ECCRIA
5-7 Sept, Cardiff

Activated Carbon

Activated carbons: usually powder or granulated

Bed reactors issues:

- agglomeration
- particle entrainment
- maldistribution
- plugging
- high pressure drop

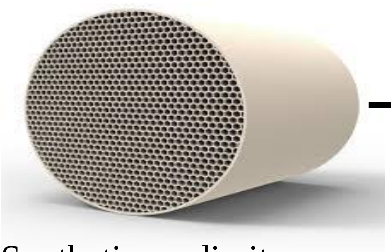
Carbon honeycomb monolith :

a structured activated carbon

MONASH University

Carbon honeycomb monolith

- Coated monoliths



Synthetic cordierite

Carbon coated cordierite

- Integral monoliths

Uniform structure throughout

Features :

✓ high void fraction (reduces the pressure drop)
✓ large surface area
✓ high mass transfer rate
✓ regenerable

MONASH University

Integral Carbon Honeycomb Monoliths

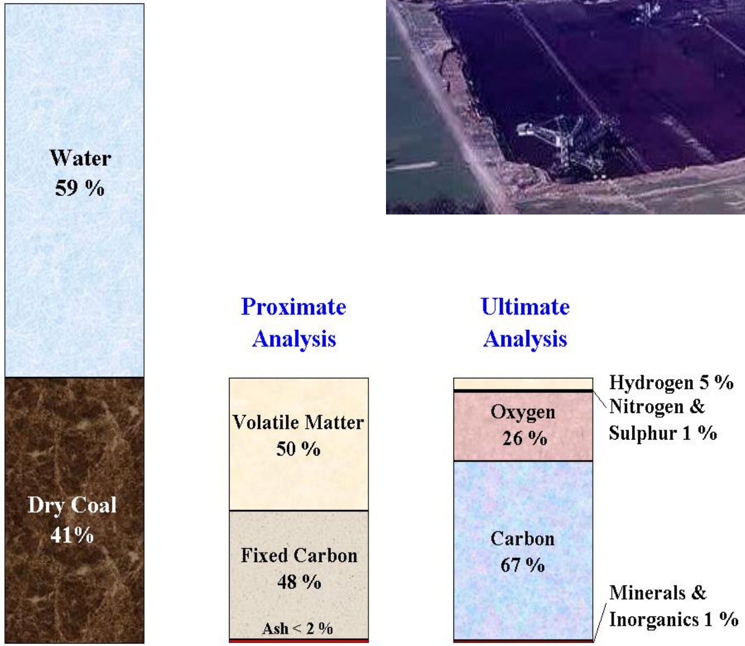
Finding suitable precursors:

- Furanic resins
- Acetone resin
- Phenolic (resole and novolac) resins
- Furfuryl alcohol resins

Reducing production cost

MONASH University

Victorian Brown Coal as Carbon Precursor



Advantages

- Soft texture
- Low inorganic & mineral content
  (very low non-functional inorganic fraction)
- Low nitrogen and sulfur contents
- **Significantly Cheaper**,
  relative to resin precursors & high-rank coals.

Patented Honeycomb Carbon Monoliths from Brown Coal

Prepared by extrusion

Carbonisation
Activation

MONASH University

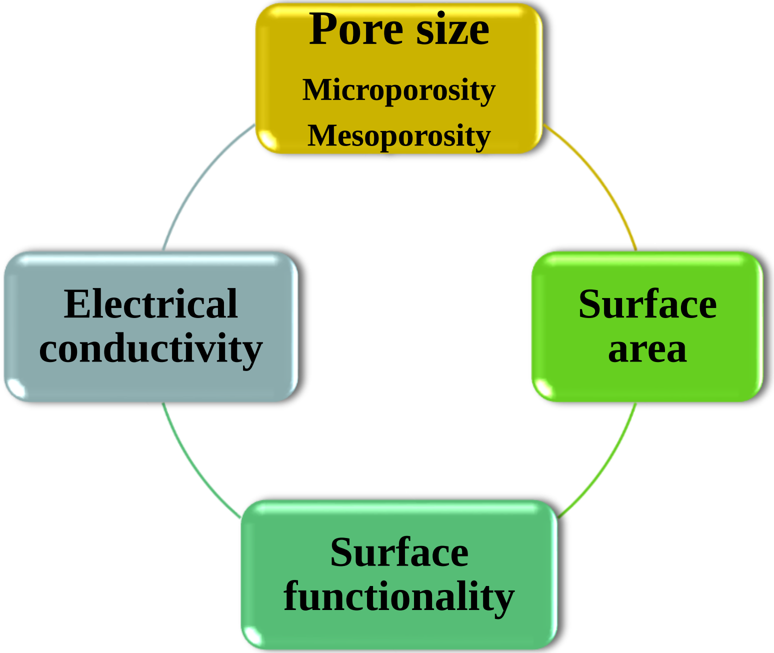
Australian Provisional Patent AU2016901978

VBC Honeycomb Carbon Monoliths

Samples	Cell density (cells/in^2)	CO_2 Surface area (m^2/g)			Conductivity ($\Omega^{-1}cm^{-1}$)		Compressive strength (MPa)
		Dried	Carbonized	Activated	Carbonized	Activated	
Formulation A	470	206	707	1150	135.9	148	130
Formulation B	470	123	700	1200	227.5	171	142
Formulation D	470	118	695	726	220	180	144
Polymer coated cordierite HM [1]	232			680		0.035	
Integral HM from powdered coal [2]	50						17

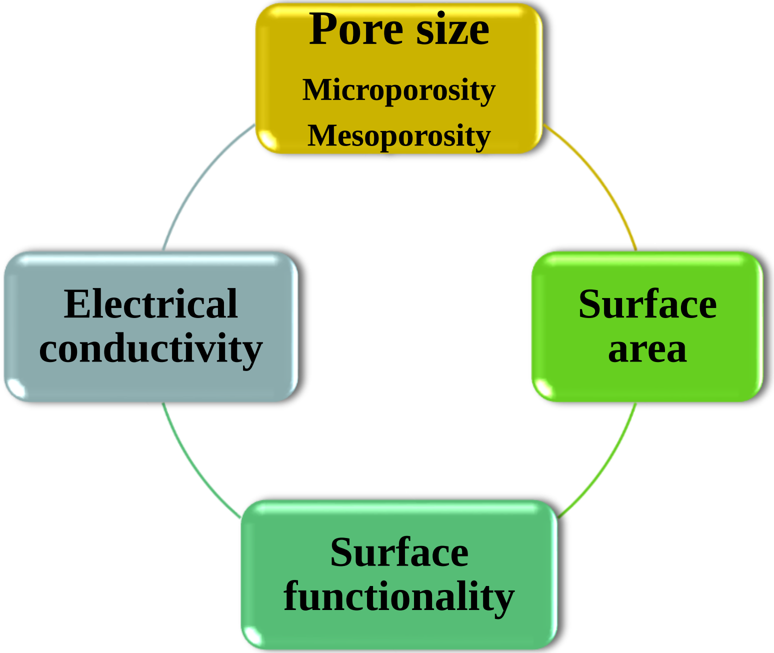
1. Vergunst, T., F. Kapteijn, and J.A. Moulijn, *Preparation of carbon-coated monolithic supports.* Carbon, 2002. **40**(11): p. 1891-1902.
2. Liu, L., et al., *Preparation of activated carbon honeycomb monolith directly from coal.* Carbon, 2006. **44**(8): p. 1598-1601.

Tuning the Monolith Properties



Electrical conductive
High surface area
Easy to fabricate
Light weight and high-strength
Regenerable

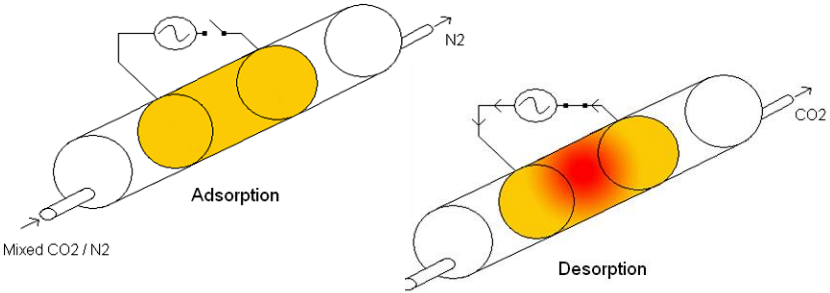
Facilitates Electrical Swing Adsorption (ESA)



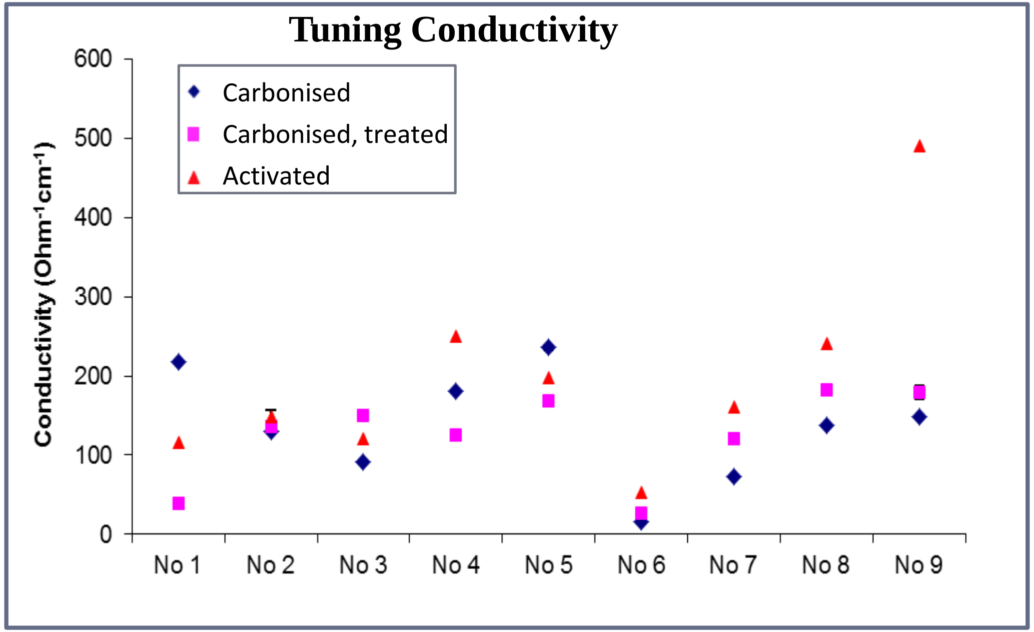
Electrical conductive
High surface area
Easy to fabricate
Light weight and high-strength
Regenerable

Electrical swing adsorption (ESA)

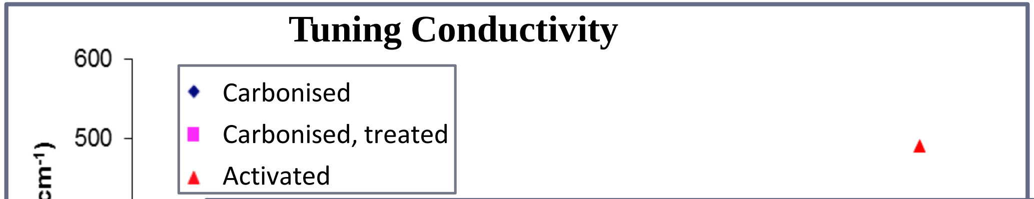
- resembles thermal swing adsorption (TSA)
- faster heating/cooling cycles
- higher productivity
- concentration &quick recovery of adsorbates

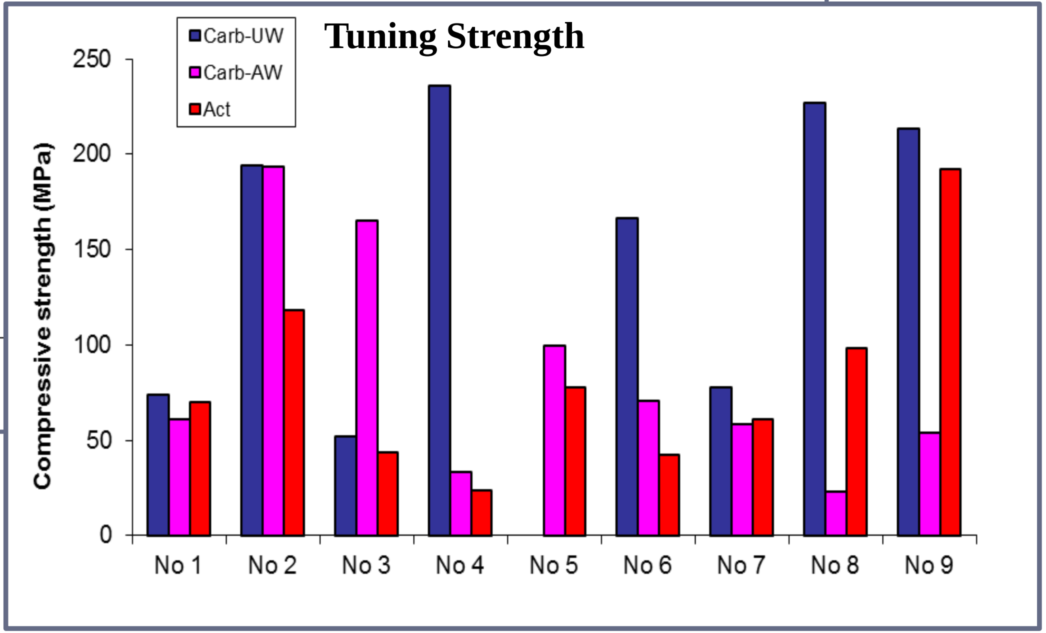


Tuning the Monolith Properties

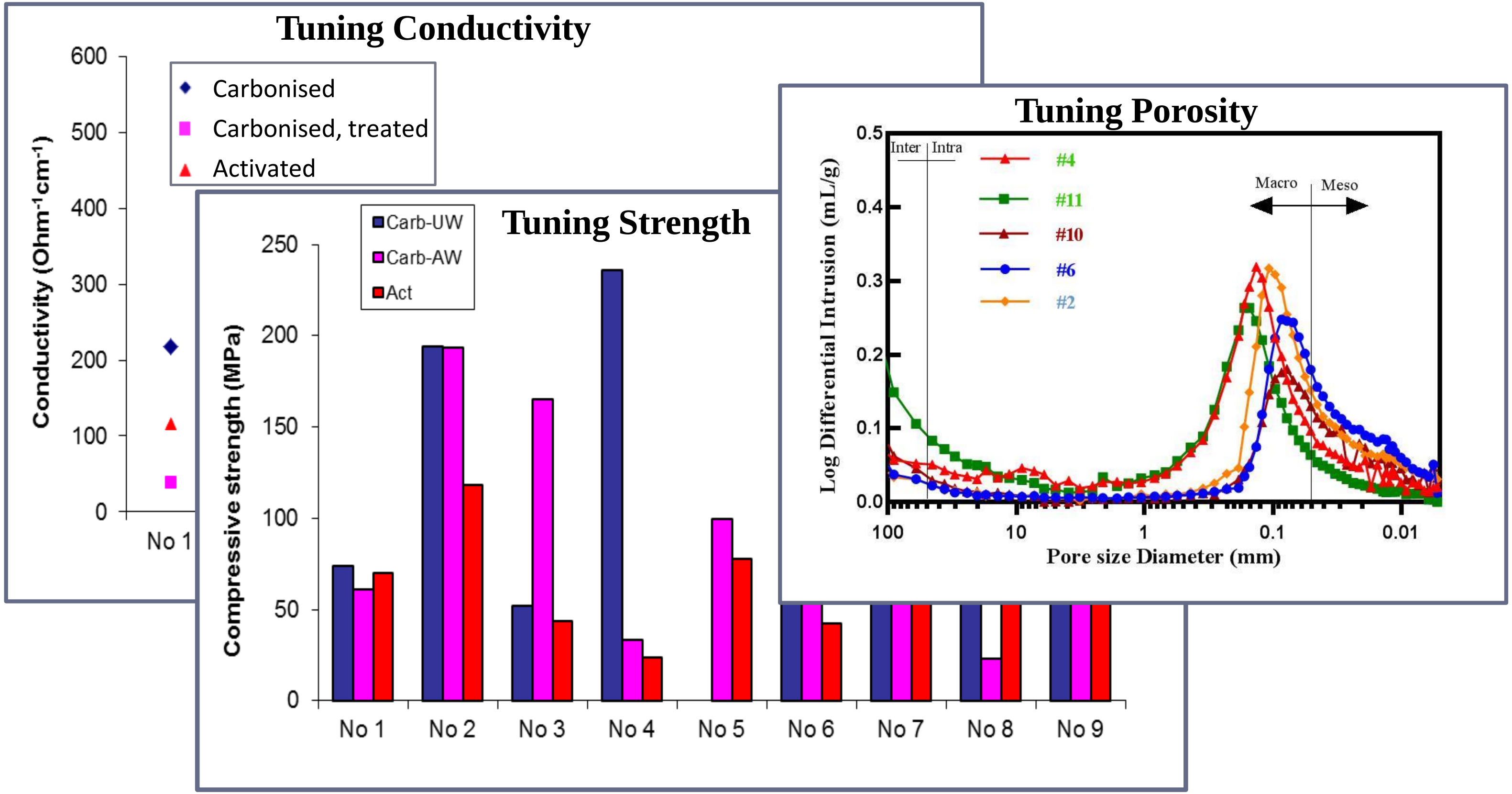


Tuning the Monolith Properties

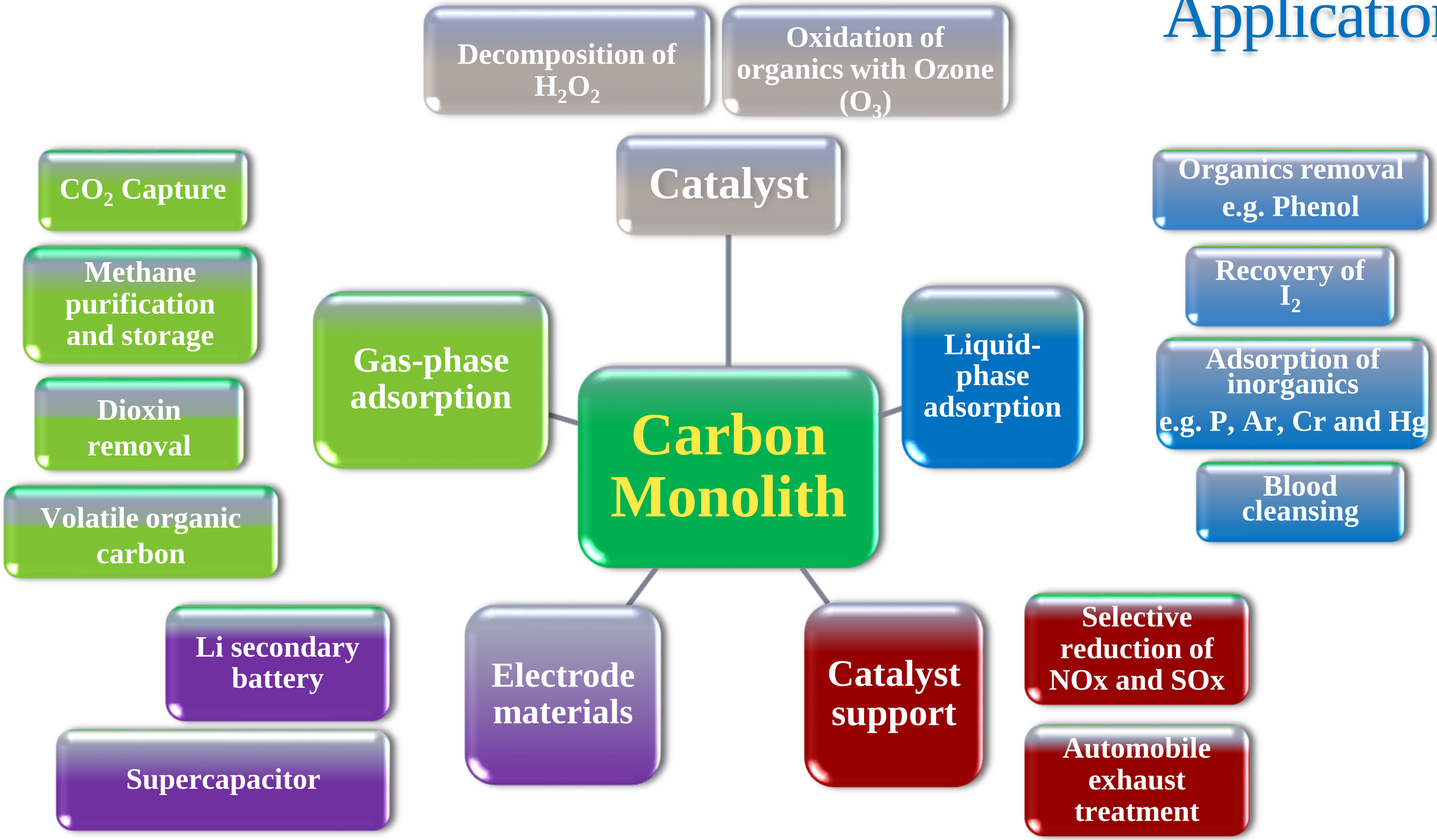




Tuning the Monolith Properties

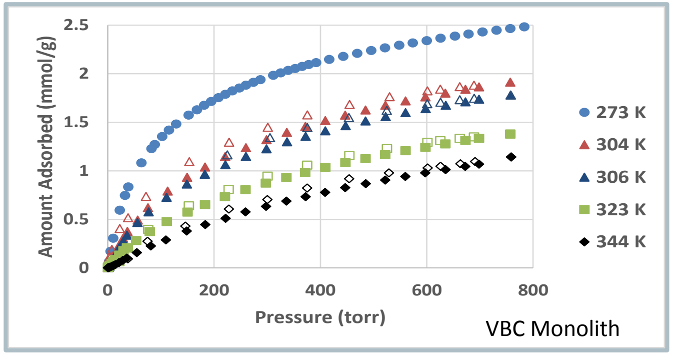


Applications

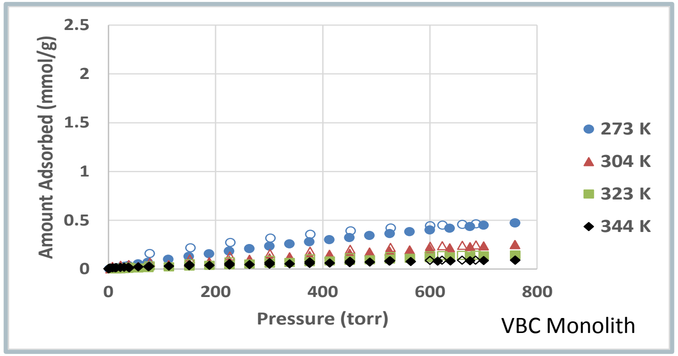


Active Carbon Monoliths from VBC for CO_2 Capture

CO_2 adsorption isotherms



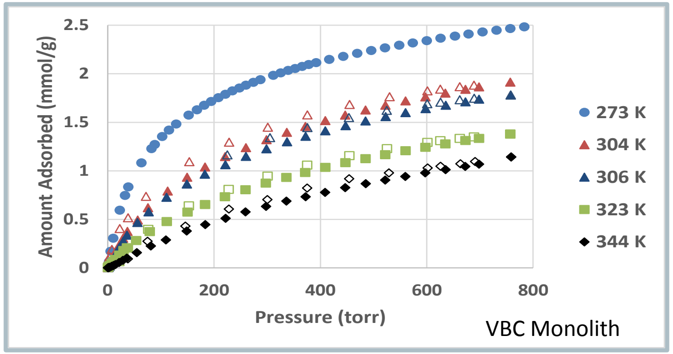
N_2 adsorption isotherms



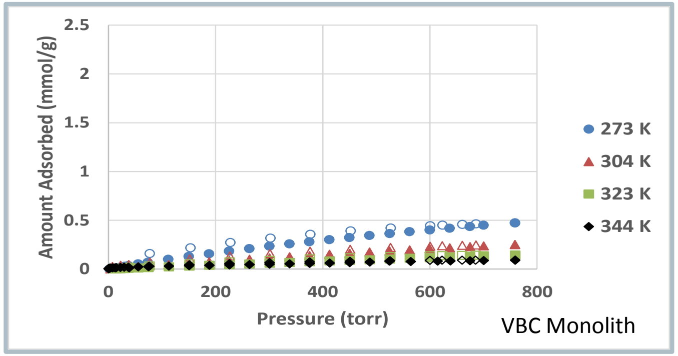
Australian Patent Application AU2016901978

Active Carbon Monoliths from VBC for CO_2 Capture

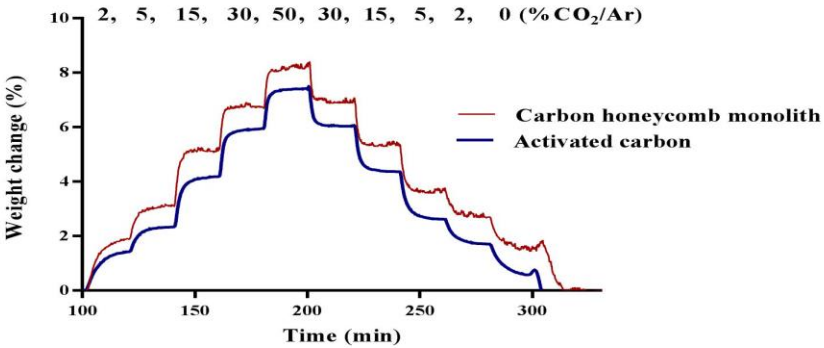
CO_2 adsorption isotherms



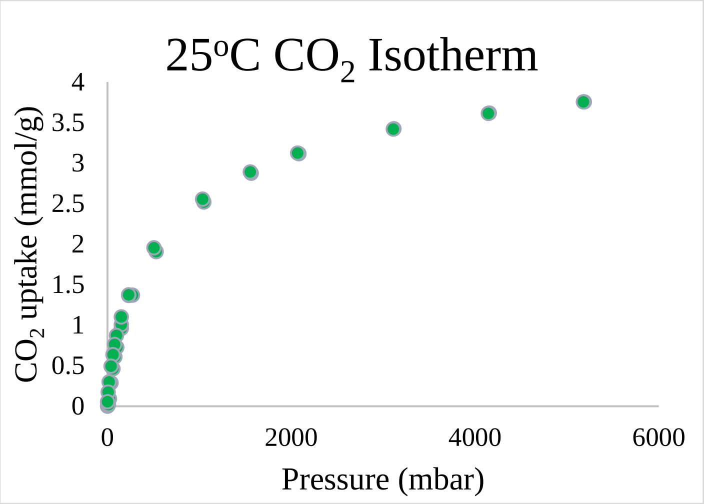
N_2 adsorption isotherms



CO_2 Partial pressure swing adsorption (PPSA), 20 °C



CO_2 Adsorption (IGA system)



Samples	Adsorption capacity at 25°C (mmol/g),			Surface area (m^2/g)	Ref
	0.15 bar	1 bar	5 bar		
Brown coal derived activated carbon monolith	1.0	2.6	3.8	1150	
Poly(benzoxazine-co-resol)-based activated carbon monoliths	1.0	2.5	-	2200	[1]
Phenolic resin derived activated carbon monoliths	0.91	2.7	-	625	[2]
Polypyrrole-derived activated carbons	-	2.3	8	3500	[3]
Nanoporous benzimidazole-linked nanofibers	1.6	4.0	4.4	787	[4]

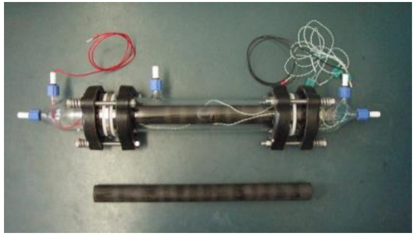
[1] G.-P. Hao, W.-C. Li, D. Qian, G.-H. Wang, W.-P. Zhang, T. Zhang, A.-Q. Wang, F. Schüth, H.-J. Bongard, A.-H. Lu, Structurally Designed Synthesis of Mechanically Stable Poly(benzoxazine-co-resol)-Based Porous Carbon Monoliths and Their Application as High-Performance CO_2 Capture Sorbents, Journal of the American Chemical Society, 133 (2011) 11378-11388.

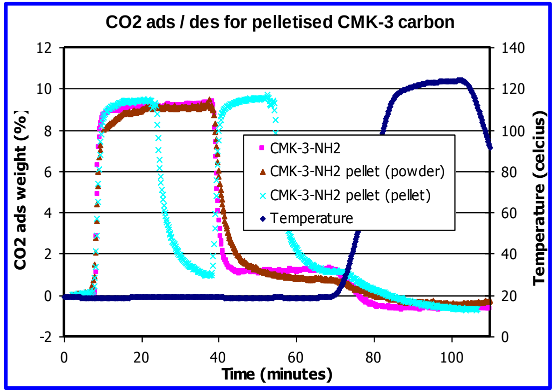
[2] Y. Jin, S.C. Hawkins, C.P. Huynh, S. Su, Carbon nanotube modified carbon composite monoliths as superior adsorbents for carbon dioxide capture, Energy & Environmental Science, 6 (2013) 2591-2596.

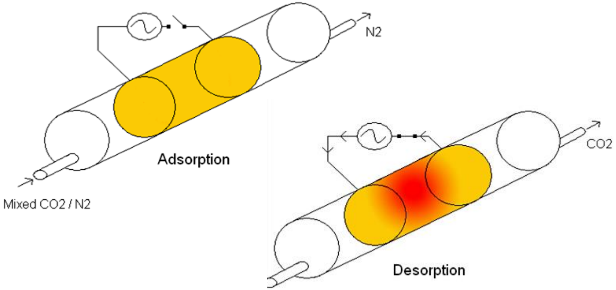
[3] M. Cox, R. Mokaya, Ultra-high surface area mesoporous carbons for colossal pre combustion CO_2 capture and storage as materials for hydrogen purification, Sustainable Energy & Fuels, 1 (2017) 1414-1424.

[4] M.G. Rabbani, A.K. Sekizkardes, O.M. El-Kadri, B.R. Kaafarani, H.M. El-Kaderi, Pyrene-directed growth of nanoporous benzimidazole-linked nanofibers and their application to selective CO_2 capture and separation, Journal of Materials Chemistry, 22 (2012) 25409-25417.

Active Carbon Monoliths and ESA



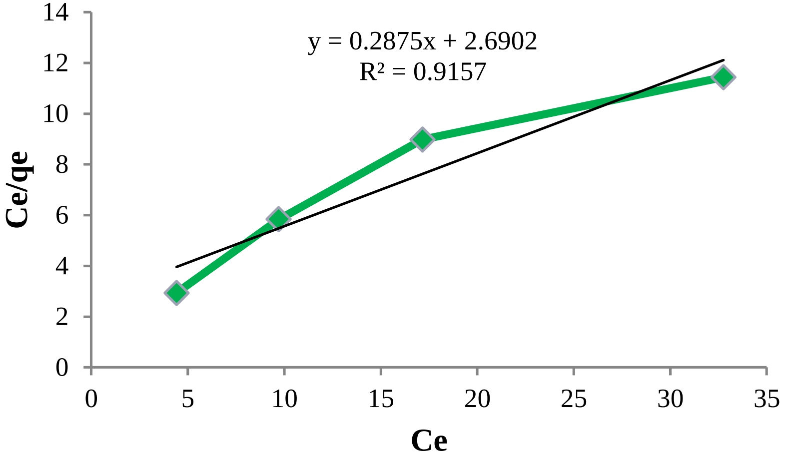




- Monolithic carbons can capture CO_2 and then be regenerated by **Electrical Swing Adsorption (ESA)**
- This previous work involved expensive precursor materials and/or processing methods
- VBC derived adsorbents are now prospective for CO_2 capture and many other applications.
- Heat is not wasted in regeneration

S Delaney, PhD Thesis, Monash University, 2009

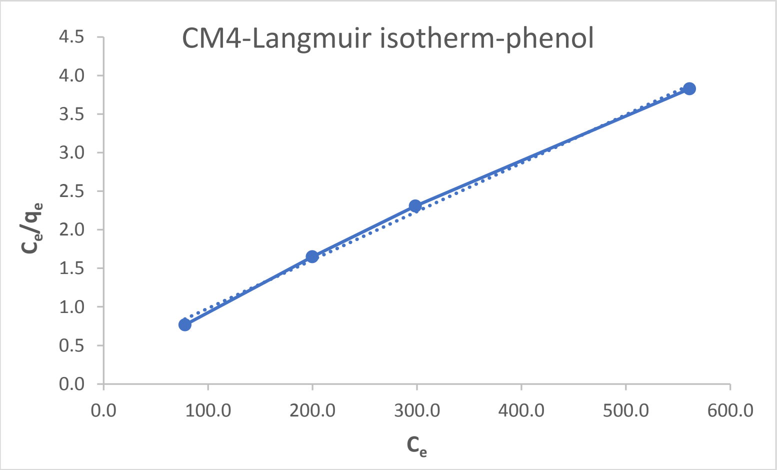
Phosphorous adsorption



Samples	Adsorption capacity (mg/g)	Ref
Brown coal derived activated carbon monolith	3.48	
Activated carbon (made from soaking sugarcane bagasse)	1.19	[1]
Commercial Activated carbons	1.56	[2]
	3	
	18	

[1]. Liang, M.N., et al., *Adsorption Removal of Phosphorus from Aqueous Solution by the Activated Carbon Prepared from Sugarcane Bagasse.* Advanced Materials Research, 2011. **183-185**: p. 1046-1050.
[2]. Boki, K., et al., *Phosphate Removal by Adsorption to Activated Carbon.* Nippon Eiseigaku Zasshi (Japanese Journal of Hygiene), 1987. **42**(3): p. 710-720.

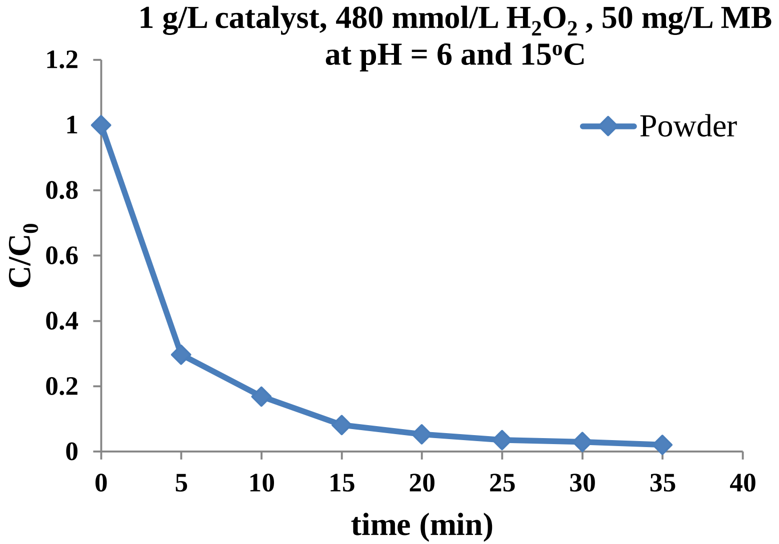
Phenol adsorption



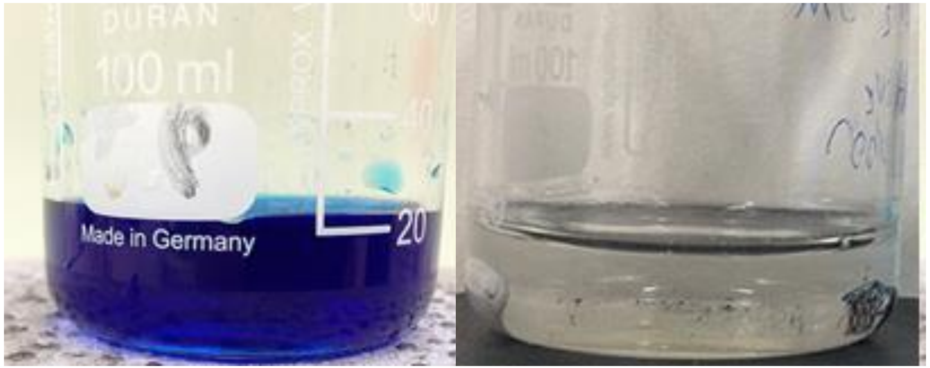
Code	HM type	Activation	Adsorption capacity Q_m (mg/g)	Source
CM1	1	Condition A	20	Present study
CM2	2	Condition A	48	
CM3	1	Condition B	128	
CM4	2	Condition B	159	
MAST AC	Commercial		114	
HM AC		Gomes (Appl. Surf. Sci., 2016. 380)	17-24	Literature
		Yam (Desalin. Water Treat., 2016. 57)	54-56	
		Teoh (Desalin. Water Treat., 2015. 54)	65-67	
		Yoshida (Adsorption 2016 Preprint)	20-132	

MONASH University

Methylene blue dye removal

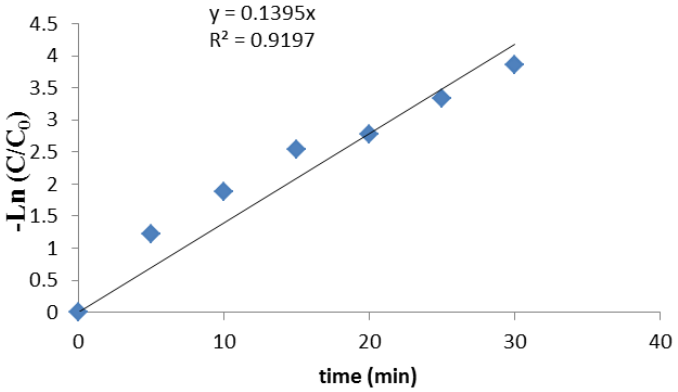


Rate constant = 0.14 min^{-1}



Decoloration efficiencies. 95%
after 20 min

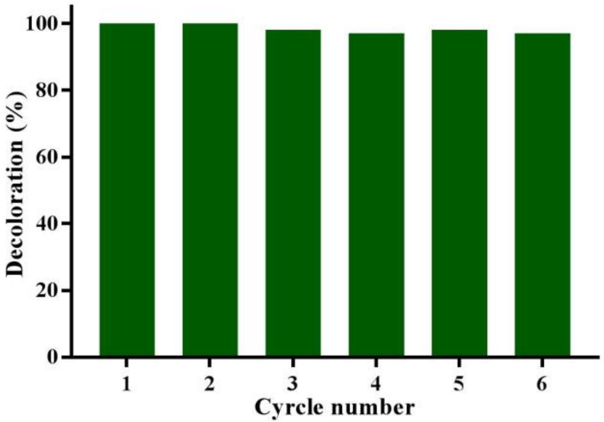
Methylene blue dye removal

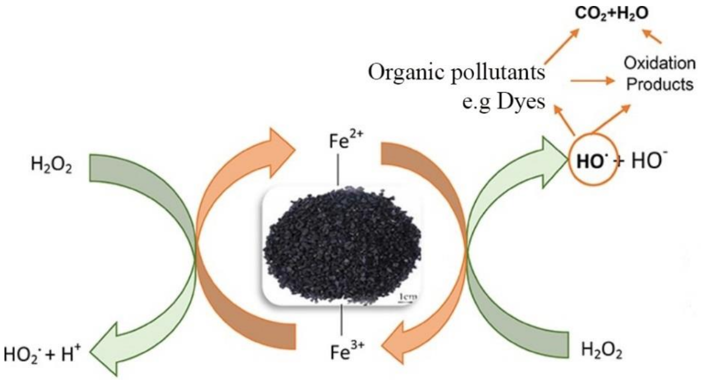


Rate constant = 0.14 min^{-1}

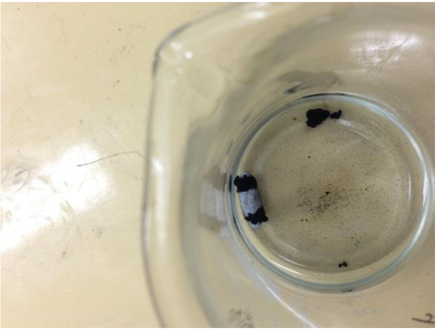
Catalyst	pH	Catalyst (g/L)	MB mg/L	H_2O_2 mmol/L	k min^{-1}	Ref
Fe_3O_4/carbon octahedra	3	0.5	10	90	0.085	1
Fe_3O_4/CeO_2	6	1	100	164	0.02	2
$CuFe_2O_4$/Cu@C	7	0.5	20	5.33	0.11	3
reduced $CuFe_2O_4$	3.2	0.1	50	500	0.055	4
$Fe_3O_4@SiO_2$	6	1	50	480	0.02	5
Fe_3O_4/SiO_2/C	6	1	50	480	0.126	6
Fe_3O_4/TiO_2/C	6	1	50	480	0.011	7
FNC	**6**	**1**	**50**	**480**	**0.14**	**This study**

Methylene blue dye removal





Monolith incorporates catalyst



Conclusions

- Victorian brown coal derived activated carbon honeycomb monoliths can be tuned/optimised for various application.
- Surface area and pore size distribution can be tuned
- Compressive strength and electrical conductivity of monoliths can be tuned
- Regeneration can be achieved by electrical swing adsorption (ESA)
- Activated carbon monoliths exhibit good performance for CO_2, H_2 and CH_4 adsorption relative to commercial and literature reported materials.
- Activated carbon monoliths showed exceptional phenol adsorption, good phosphorus adsorption, effective dye adsorption
- Activated carbon monoliths show exception organic removal by catalysed (Fenton-type) oxidation
- Looking to demonstrate other applications such as catalysis, electrode materials, etc

Thank you for listening!

Acknowledgements

Environmental Clean Technologies (ECT)\

Brown Coal Innovation Australia

MATESA (EU project)

IKTS Fraunhofer, Dresden, Germany

MONASH University