Carbon-Based Adsorbents for CO_2 & VAM Capture

PCC Science & Technology Seminar
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Shi Su

ENERGY FLAGSHIP/EARTH SCIENCE AND RESOURCE TECHNOLOGY
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Carbon-Based Adsorbent Research Program

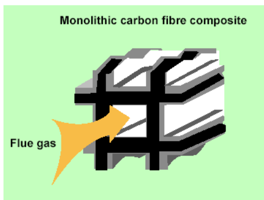
- Fundamental study on high-performance carbon-based adsorbent development
  - Carbon fibre (CF) composite
  - Carbon nanotube (CNT) composite
  - CF\CNT composite
  - Biomass (macadamia nut shell) carbon composite
- Various applications of carbon-based adsorbents
  - Post-combustion CO_2capture (PCC)
  - Ventilation air methane (VAM) capture
  - Flue gas cleaning
  - Industrial purification processes
- Process & equipment development
  - Lab scale and large scale test units for CO_2 and VAM capture
  - Site trials and demonstration of prototype units
  - Data & experience for scaling up

Why carbon-based adsorbents

- Chemically stable against steam, SO_x and NO_x
  - ✓ Avoid flue gas pre-treatment prior to CO_2 capture (this is important as no FGD and SCR $DeNO_x$ for coal fired power plants in Australia)
  - ✓ More suitable for PCC applications compared to moisture sensitive zeolites and other SO_x/NO_x intolerable adsorbents e.g. supported amine
- No degradation issue → secondary environmental impact
- Lower heat capacity of solid adsorbent than liquid absorbent of conventional solvent technologies thus requiring lower energy for thermal regeneration
- Physical adsorption
  - ✓ Low heat of CO_2 desorption
  - ✓ Potential to reduce the cost of LECT by using the waste heat of flue gas for adsorbent regeneration
- Low cost of adsorbent materials

Novel CO_2 Capture Technology

- CO_2 adsorption using honeycomb carbon fibre composite monoliths
  - ✓ Enable CO_2 capture in a dry process
  - ✓ Suit high dust environment with low pressure drop
  - ✓ Low energy consumption (lower heat capacity of solid than liquid in conventional solvent technologies thus requiring lower energy for regeneration; flue gas waste heat for desorption)
  - ✓ Stable with SOx and NOx, no degradation issue

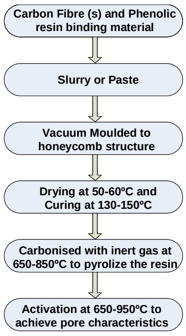


Lab Scale Study

Fabrication and Testing of Lab Size Honeycomb Carbon Fibre Composite Monoliths

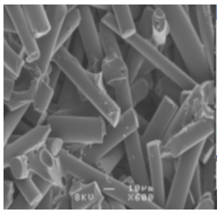

Molding equipment


3 processing furnaces



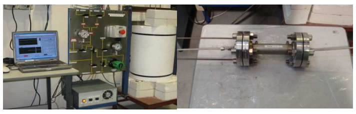
Length: 80mm, Dia: 30mm, Number of Channels: 17,


Fabricated (HMCFC)


Microscopic morphology

Adsorbent Testing Equipments

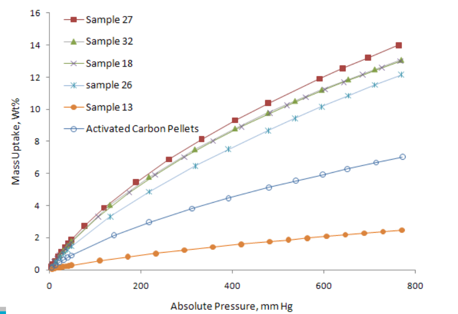

Adsorbent Characterisation


Breakthrough Test Rig with Lab Scale Adsorption Chamber

Lab Scale Study (continued)

Characteristics of monoliths from different carbon fibres

Carbon Fibre Monolith Types as Sample Numbers	Burn-off, %	BET - N_2 Surface area, m^2/g	DA- Method		CO_2 Mass Uptake, %	
			Pore width, nm	Pore volume, cm^3/g	0ºC	25ºC
27	37	1305	1.8	0.6828	20.87	13.8
18	28.8	855.3	1.61	0.4685	19.36	13
32	24.6	1017.2	2.14	0.6078	19.46	13.2
26	68.4	1873.9	1.93	1.588	19.18	12.2
13	21.7	347.74	1.81	0.1905	4.2	2.5



Adsorption isotherms at 25ºC

Large Scale Capture-Regeneration Studies

Fabrication of large scale adsorbents

Large scale moulding unit for composite fabrication

Large size adsorbents (Ø 123 mm), 267 small gas channels, 13 big channels for heating/cooling

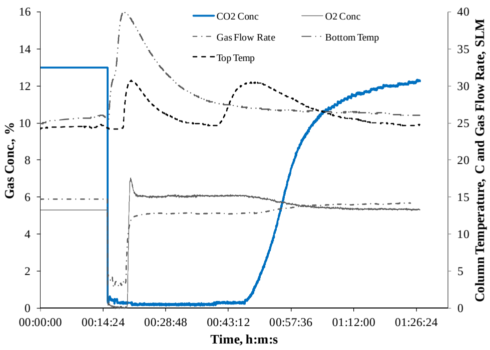
Test Unit Coupled with regeneration

Large scale CO_2 capture –regeneration unit and process schematic

- Two 2 meter long columns stacked with adsorbents
- Designed for higher gas throughputs up to 200SLM
- Repetitive capture & discharge capability
- Thermal and vacuum swing regeneration

Summary of Large Scale Study Results

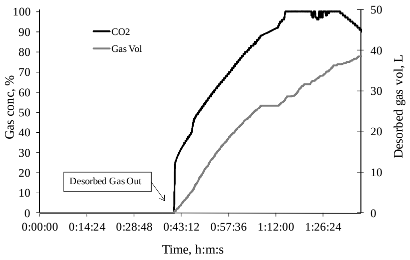
Adsorption Breakthrough Profile Showing CO_2 capture at Real Time



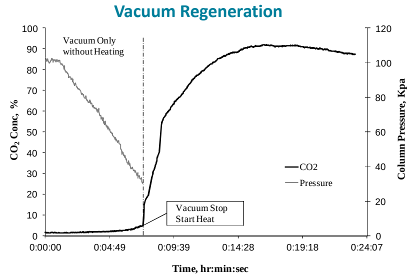
- CO_2 capture carried out at ambient temperature and pressure
- Simulated flue gas consisting of 13% CO_2, 5.5% O_2 and balance N_2
- CO_2 capture efficiency > 97% from adsorption breakthrough

Thermal and Vacuum Regeneration

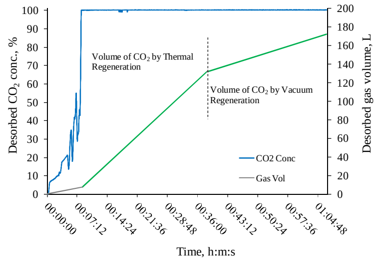
Individual Thermal Regeneration



Vacuum Regeneration



Combined Thermal and Vacuum Regeneration



- Residual CO_2 inside column after thermal regeneration
- Vacuum regeneration alone ineffective
- Heating is essential to desorb CO_2
- Combined thermal and vacuum regeneration with pure product purge most effective
- Very high purity of Recovered CO_2
- CO_2 recovery > 95%

Site Trials of Prototype CO_2 Capture Unit at Vales Point Power Station

- Objective: to conduct site trial of CO_2 Capture technology at Vales Point Power station to evaluate the performance of novel HMCFC solid sorbent using real flue gas
- Unit currently being commissioned and to be tested

Development of New-Generation Carbon Composite Adsorbents

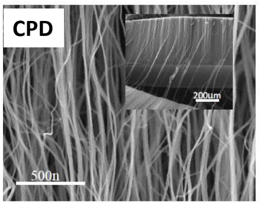
- **Objective**
  - Enhance CO_2 adsorption capacities (smaller footprint, lower capital and operating costs)
  - Lower the cost of sorbents

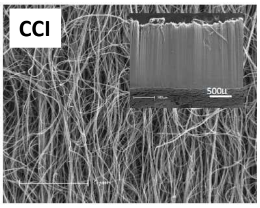
- **New-generation carbon composite adsorbents**
  - Carbon nanotube (CNT) modified carbon composite monoliths
  - Macadamia nut shell biomass carbon

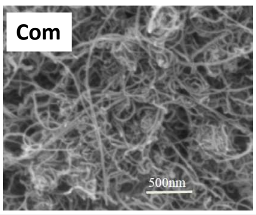
Preparation of CNT Composites

Source of CNTs

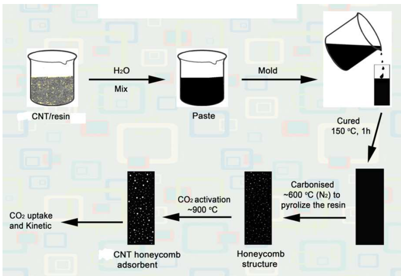
Three types of multi-wall CNTs were used for adsorbent fabrication.







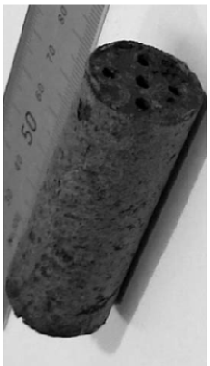
Preparation process of CNT composites



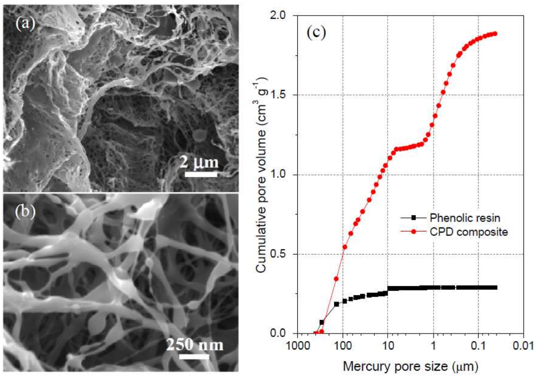
Specifications of as-produced/as-received CNTs

CNT samples	Diameter, *D* (nm)	Length, *L* (µm)	Alignment	Purity (%)	Aspect ratio, *L/D*
CPD	10	300	highly aligned	99.8	30,000
CCI	80	1500	aligned, some branching	97	18,750
Com	10-20	5-15	very tangled	95	400-1,500

Morphology of CNT composites



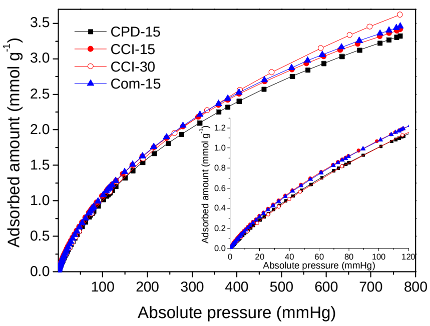
Prepared CNT carbon composite monolith



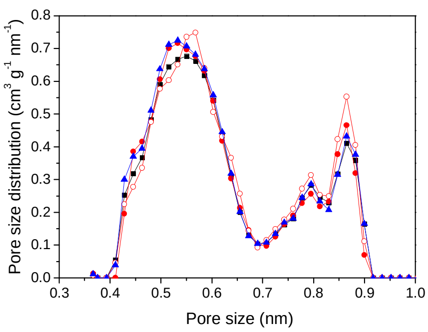
Morphology and macropore size distributions

CO_2 Adsorption Capacities of CNT Composites

CO_2 uptake at 25 °C



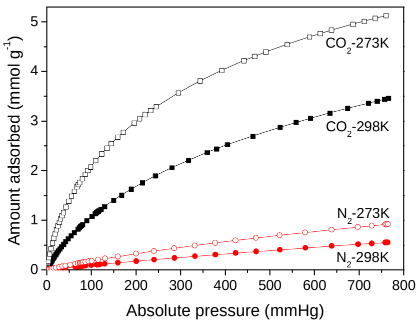
Narrow micropore size distributions



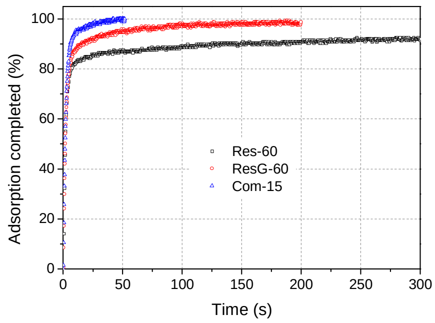
- 159 mg CO_2 g^{-1} at 25 °C and 1 atm
- 52 mg CO_2 g^{-1} at 25 °C and 114 mmHg

Adsorption Selectivity & Kinetics

CO_2 & N_2 uptake adsorption Isotherms at 0 and 25 ºC



Rates of CO_2 adsorption at 25 ºC and 25 mmHg



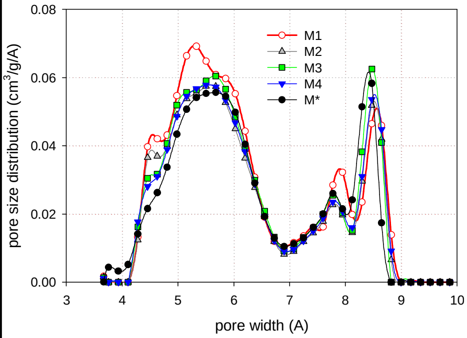
- CO_2/N_2 selectivity: 32.6 at 273 K and 19.8 at 298 K
- Fast adsorption kinetics observed in the CNT composites

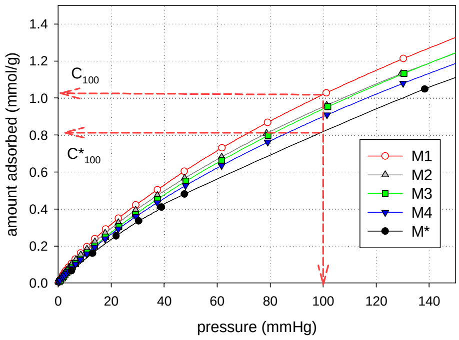
Macadamias around the World

- ❑ Only grow in tropical climates.
- ❑ Cultivated mainly in Australia, the USA and South Africa. The industries are expanding around the world
- ❑ In Australia, according to the Australian Macadamia Society:
- ➢ ~ 40 % of the world's production in 2009
- ➢ 35-40,000 tonnes nut in shell (NIS) yearly
- ➢ ~ 65 % are shell.

http://www.macadamias.org.uk/

Micropore Size Distribution (MPSD)

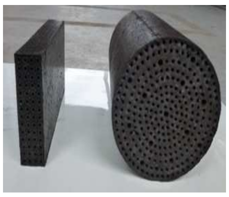


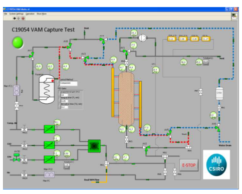


- M1 has the highest C_{100}, which is related to the MPSD in the range of 4-6 Å.
- Carbonized MNSs as a composite precursor are better than activated ones.
- Adding carbon fibre does not enhance the sorbent performance.

VAM capture technology

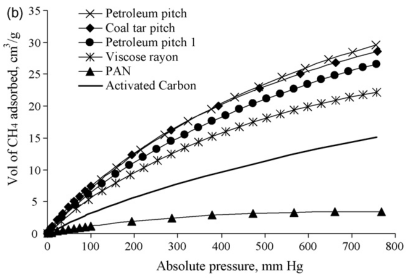
- Adsorbents
- Prototype test unit coupled with swings



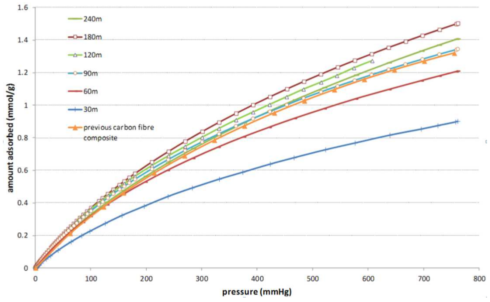


VAM capture technology (Continued)

- **Adsorption isotherms**
  - Petroleum pitch-based composite adsorbents: **more than twice** the adsorption capacity compared to conventional activated carbon



volume of gas adsorbed



CH_4 adsorption isotherms at 25°C - different carbon fibre monoliths

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Closing Remarks

- Porous carbon composite monoliths show great promise in CO_2 and VAM capture
- Development of high-performance adsorbents is highly important in the applications:
  - High CO_2 (or CH_4) loading capacity
  - High CO_2 (or CH_4)/N_2 selectivity
  - Fast adsorption kinetics
  - Suitable interaction for easy regeneration
  - Good mechanical, thermal and chemical stability

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Thank you

Dr Shi Su

t +61 7 3327 4679
e shi.su@csiro.au
w www.csiro.au