FLUIDISATION – SOME CONCEPTS FOR CARBON CAPTURE AND POWER PLANT COOLING WATER USE MIMINISATION

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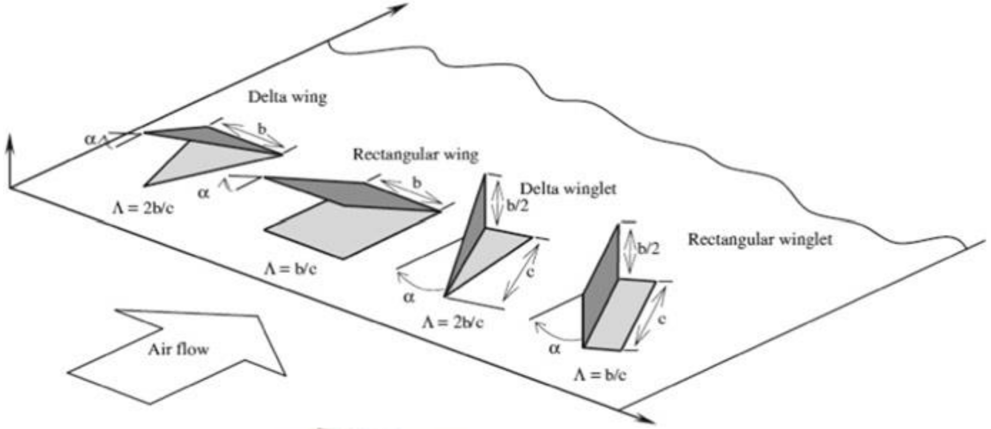
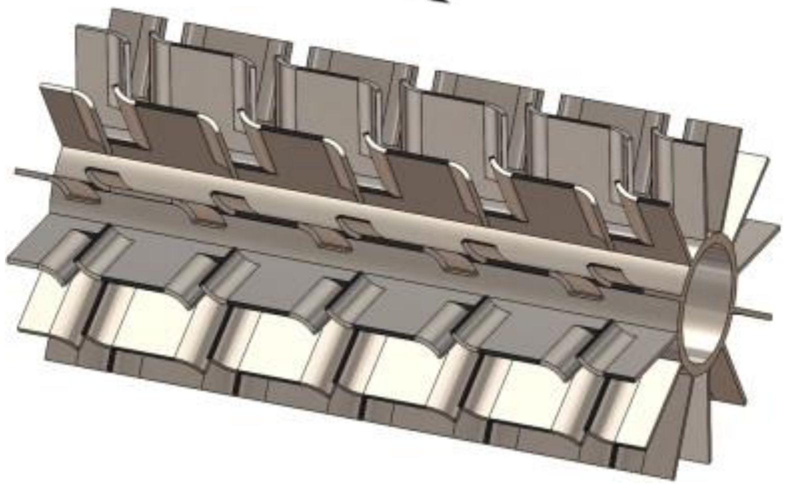
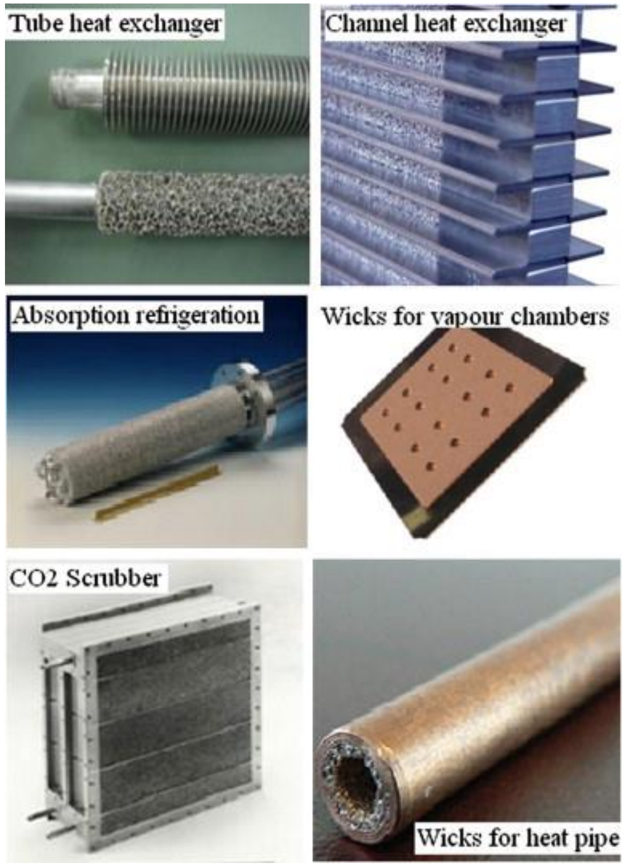
Scope of the Talk

- We are discussing two areas of current interest and importance:
  - Reducing cooling water use in power station condensers by ‘dry cooling’
  - Carbon capture, in particular post-combustion capture
- Both can involve fluidised bed technologies as methods for improving heat and mass transfer
- The carbon capture aspects will feature in an EPSRC project with Heriot-Watt and Hull, to start in September
- The Air-cooled condenser work is an area in which we invite collaboration for an HORIZON 2020 potential opportunity

Air-cooled Condensers (ACC's) use several enhancement methods





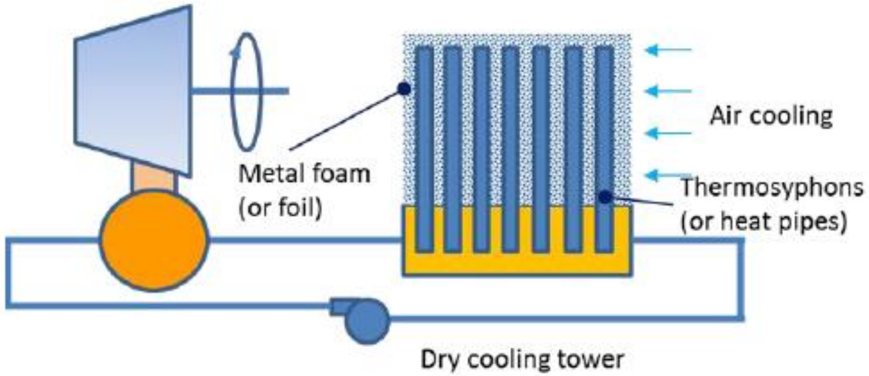


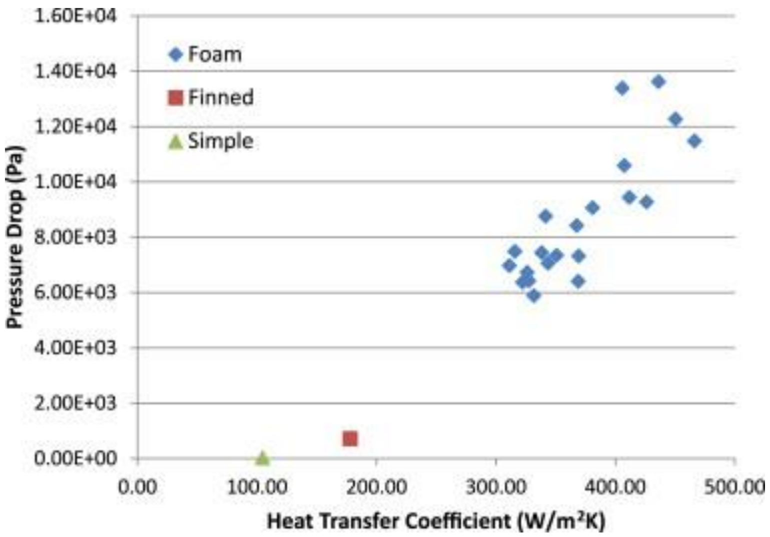
EPRI-NSF Power Plant Dry Cooling R&D

Project Title	Orgnization	Funder
Direct Contact Liquid on String Heat Exchangers for Dry Cooling of Power Plants	UCLA	NSF
On-demand Sweating-Boosted Air Cooled Heat-Pipe Condensers for Green Power Plants	U of S Carolina	NSF
Ejector Cooling Systems with Evaporation/Condensation Compact Condensers	Univ of Missouri Columbia/SPX	NSF
Novel Thermosyphon/Heat Pipe Heat Exchangers with Low Air-Side Thermal Resistance	Univ of Kansas /Univ of Connecticut	NSF
Auto Flutter Enhanced Air Cooled Condensers	GaTech/Johns Hopkins/Southern Company/SPX	NSF-EPRI
Advanced Air Cooled Condensers with Vortex-Generator Arrays between Fins	UIUC	NSF-EPRI
Indirect Dry Cooling Towers with Phase-Change Materials as Intermediate Coolants	Drexel/ACT/Worley Parsons	NSF-EPRI
Novel Heat-driven Microemulsion-based Adsorption Green Chillers for Steam Condensation	UMD/Worley Parsons	EPRI
Nanostructure Enhanced Air-Cooled Steam Condensers	MIT/HTRI	EPRI
Porous Structures With 3D Manifolds For Ultra-Compact Air Side Dry Cooling	Stanford	EPRI

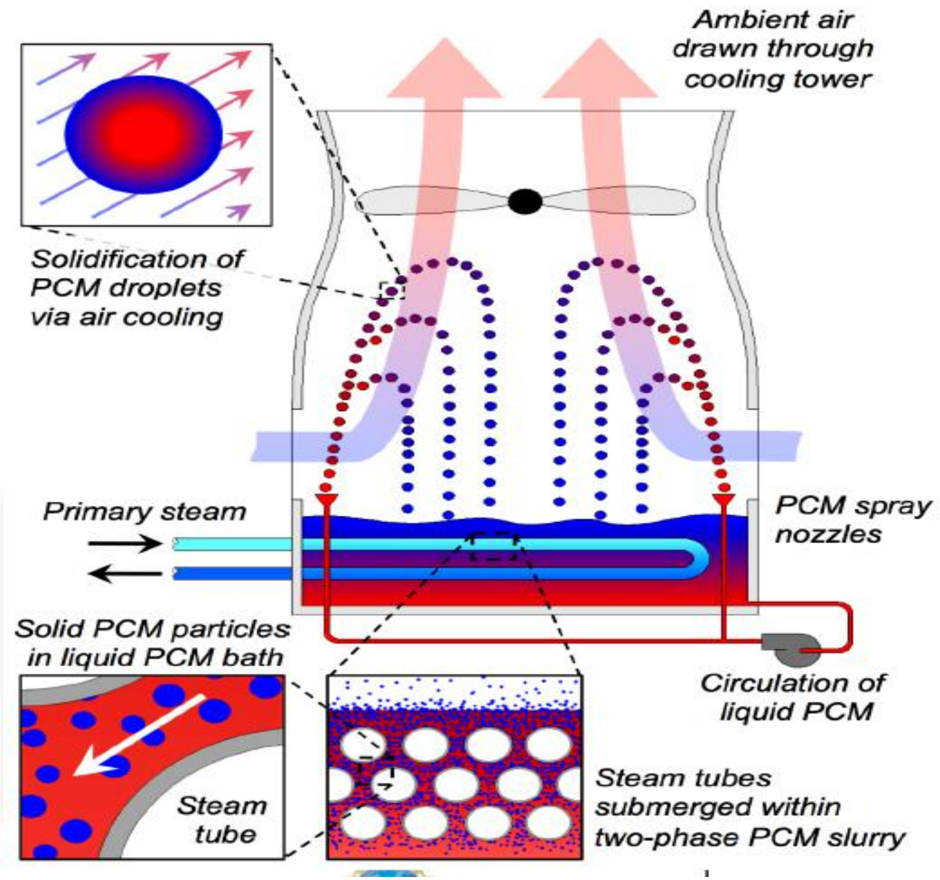
US Concepts funded by EPRI & NSF

This one uses heat pipes/thermosyphons with metal foam as the condenser extended surface.
?Expensive & liable to act as a fly-catcher.
At HEXAG Brunel Univ. presented other heat pipe options.





Use of Phase Change Materials (PCMs)

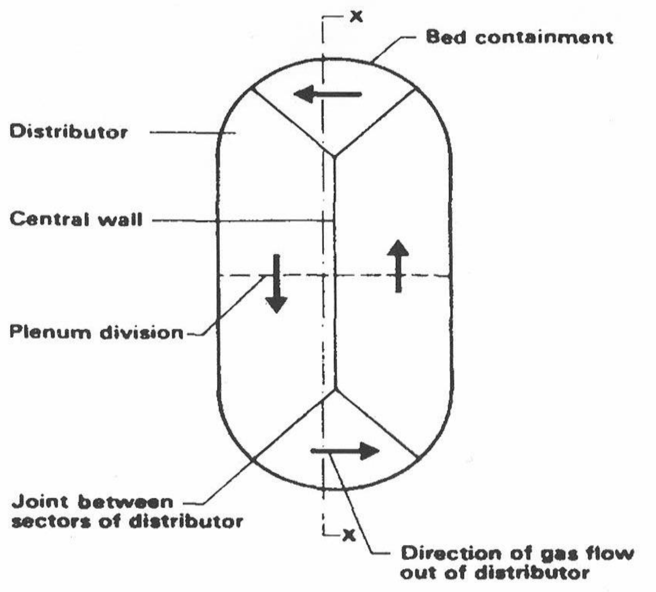


Indirect Dry Cooling Towers with Phase-Change Materials as Intermediate Coolants (Drexel University/ACT)

In this version the condenser tubes are immersed in a PCM slurry.
An alternative design that we feel would be better would be fluidisation of the encapsulated PCM micro-spheres and use of the race-track type heat exchanger for regeneration. The Torbed would be an option – hear Dan Groszek in the next talk.

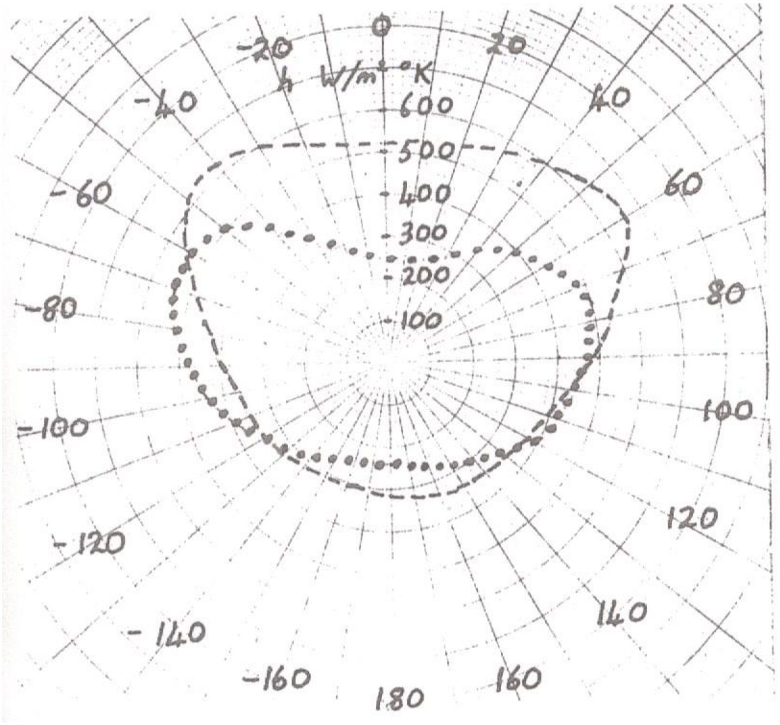
Regeneration of the PCM

- Effective ACC's are of greatest importance in areas where solar Rankine cycle power plant exist – Australia, southern Europe, the Middle East etc.
- High ambients necessitate working with close approach temperatures (air-steam)
- Also if use can be made of cooler overnight temperatures for PCM regeneration, this could facilitate the fluid bed concept
- The race-track fluid bed may not be appropriate for PCM regeneration where overnight cooling is available
- Its application may be more effective where a continuous cool source such as a ground tunnel is constructed.



Plan view of the race track – fluidising air will come out of the board at an angle, the particles circulating as shown.

Enhancement of air-side HTC using a fluid bed



As identified by Prof. Colin Ramshaw, the heat transfer coefficient around a tube in a gas stream can be increased by an order of magnitude using a fluidised bed.

Local Heat Transfer around a 3.5 cm Diameter Tube in a Fluid Bed

Minimising fluid velocity = 0.11 m/s

---------------- u = 0.89 m/s

…………………u = 0.23 m/s

Data obtained by Colin with Sand

Heat Transfer Results – Sand - see Ramshaw, C. et al (1987), ”Process Optimisation” pp41 *et seq*, IChemE Symposium Series 100.

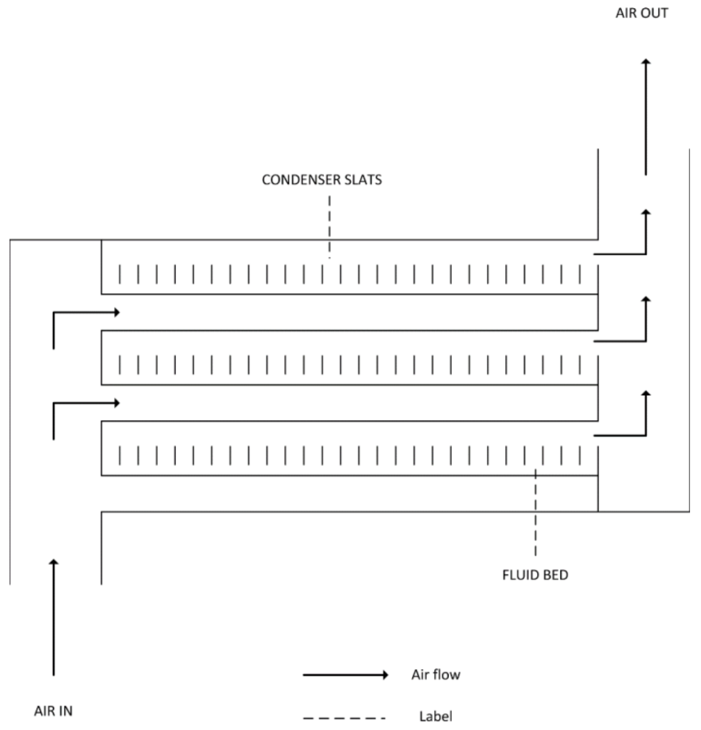
(Mean sand particle size 184 microns; sand minimising fluid velocity = 0.06 m/s)

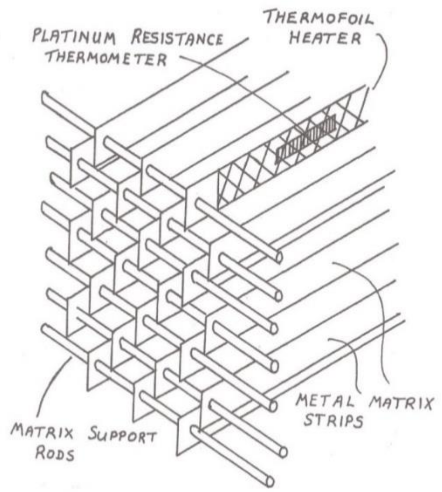
Matrix Type	Superficial gas velocity (m/s)	Heat transfer coeff. W/m^2K	Bed material
A	0.16 0.33 0.49	37 37 40	None
B	0.16 0.33 0.49	35 39 40	None
A (repeat)	0.16 0.33 0.49	35 38 42	None
B (repeat)	0.16 0.33 0.49	37 39 44	None
B	0.16 0.33 0.49	593 606 670	Sand
A	0.16 0.33 0.49	663 676 670	Sand
A (repeat)	0.16 0.33 0.49	600 633 638	Sand
A (repeat)	0.16 0.33 0.49	622 615 622	Sand
B (repeat)	0.16 0.33 0.49	563 595 591	Sand

A fluid bed concept using slats to carry the condensate

A structure comprising narrow hollow slats within a shallow fluidised bed may be a feasible option for an ACC.
In view of the high gas side heat transfer no fins will be needed, resulting in a considerable simplification and hopefully cost reduction. This will also help to reduce the overall pressure drop, which will be largely determined by the bed height and the particle characteristics.

Shallow beds will allow a low pressure drop. The concept does offer the prospect of achieving heat transfer coefficients in the range of 600 W/m^2K and above without using a multiplicity of fins. This **may** lead to significant capital cost reductions. A 50% reduction in footprint has also been calculated.





Summary on Air-Cooled Condensers

In some ways more radical is the suggestion to introduce phase change materials (PCMs) into the fluid bed. Gains on pressure drop and the opportunity to 'store' energy at times when high ambients were present might be of benefit. With regard to the EPRI/NSF concept proposed and being studied at Drexel University in the USA, it is felt that the PCM slurry they have suggested would be rather difficult to handle and a fluid bed of micro-encapsulated PCMs would be better. **Data on these and micro-fluid beds are discussed next by Dr. Vladimir Zivkovic.**

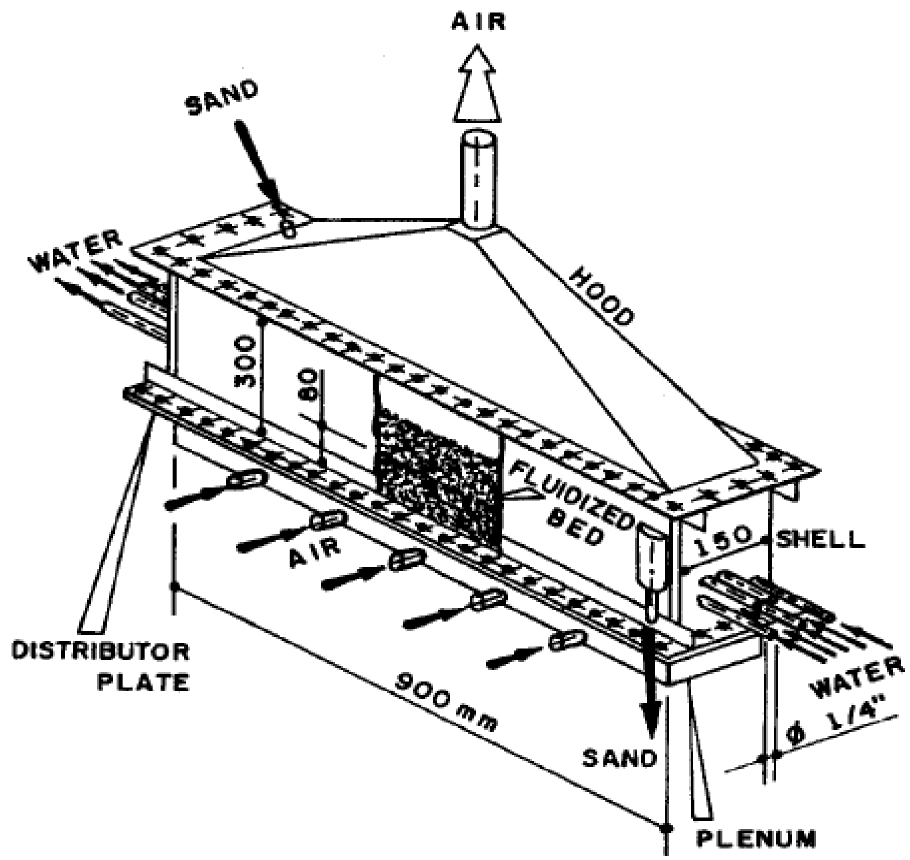
A further improvement on the Drexel design would of course be to use the slat concept of Professor Ramshaw – an interesting challenge indeed.

It would be fair to conclude that if one wants to significantly improve the performance of ACCs – and the principal aim is to reduce plot area while maintaining performance – it is necessary to go for a radical solution.

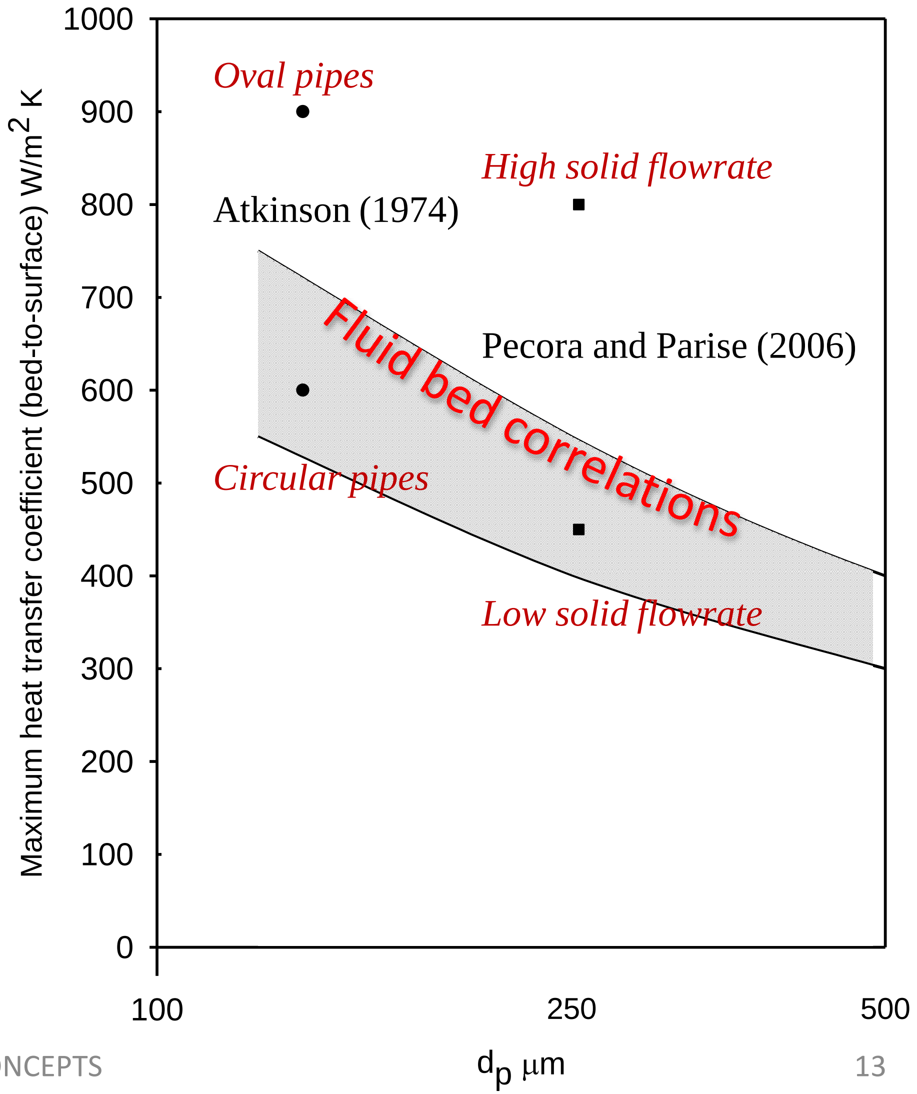
PCM Particles in Fluid Beds and Carbon Capture based upon Adsorption

- Work at Newcastle University has analysed PCM particles in fluid beds – confirming the data of Colin Ramshaw on heat transfer enhancement.
- Concurrently a study of micro-fluidised beds has allowed 3D printing to be employed in their manufacture.
- This will be extended to the EPSRC Carbon Capture project starting in September, where 3D printed (polymer material) small scale bed geometries will be explored for sorption experiments.
- In conjunction with Hull University (modelling) and Heriot-Watt University (adsorption characterisation of materials), Newcastle University plan in the later stages of the three-year project to carry out experiments on the Torftech Torbed pilot plant.

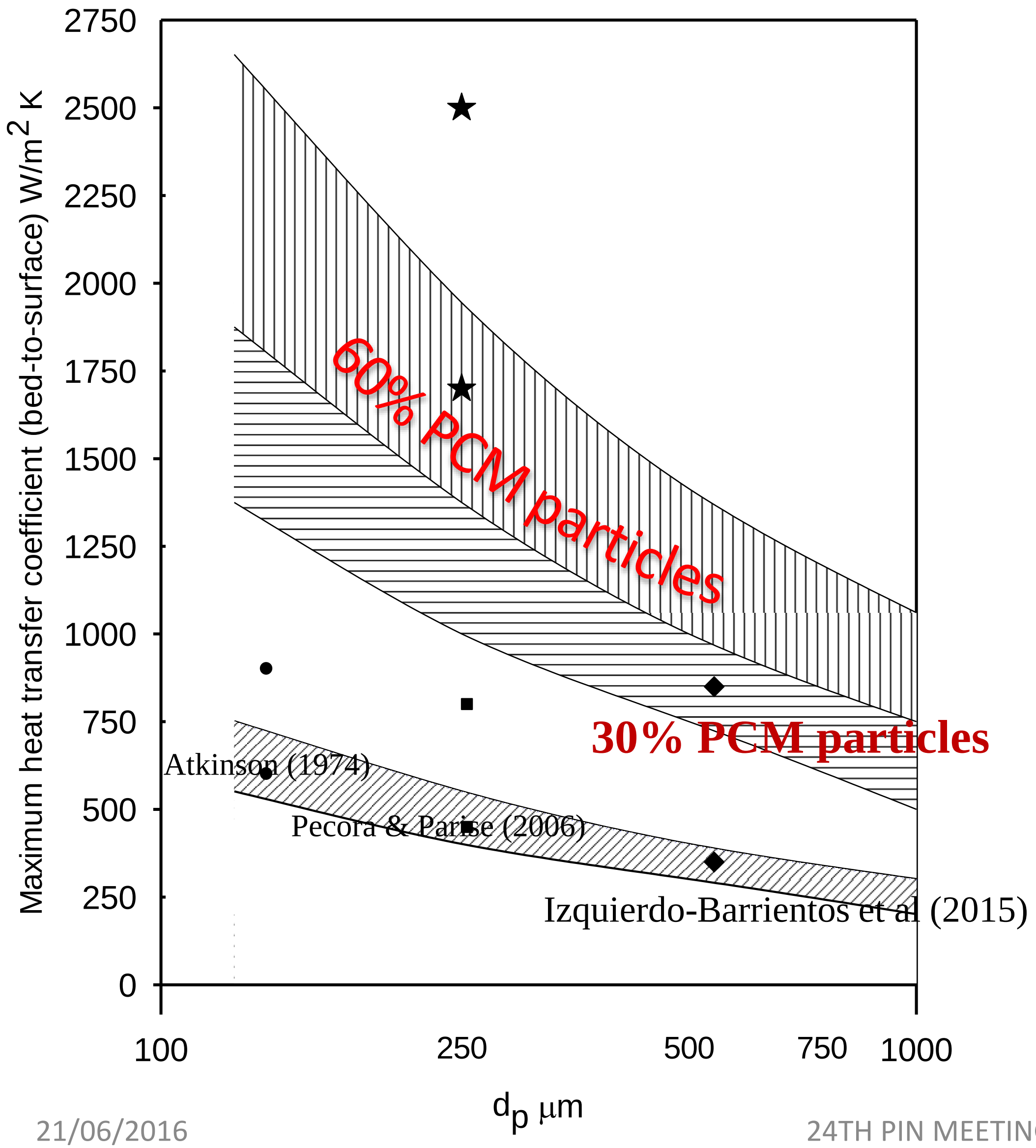
Schematic of shallow fluidized bed

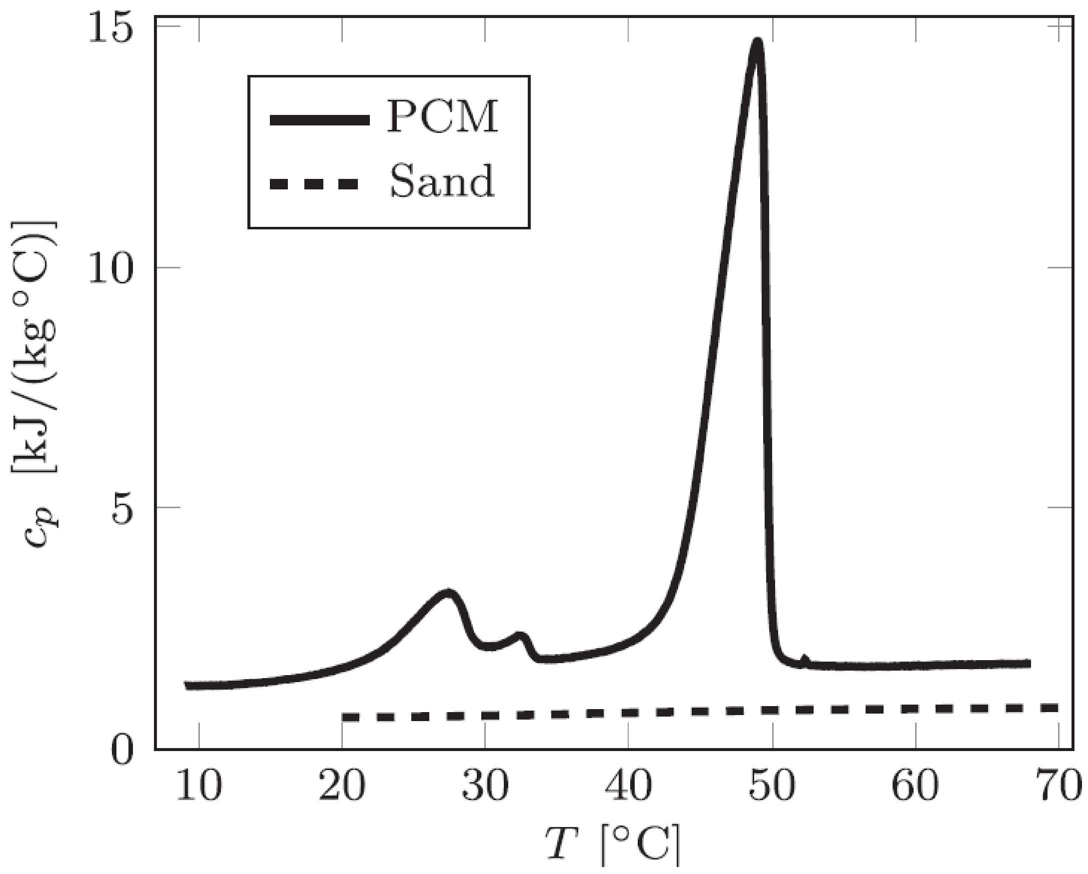


A.A.B. Pécora, M.R. Parise, Brazilian Journal of Chemical Engineering, 23 (2006) 497-506.



Expected heat transfer coefficient with PCM particles





$$h \propto c_p^n \text{ ; usually n= 0.5}$$

$$h \propto \sqrt{c_p}$$

Sorbent behaviour in a fluid bed

From preliminary testing of the fluidization behaviour of PMMA based sorbent particles, it was found that, at high desorber temperatures, these sorbent particles formed aggregates plugging the reactor. **This underlines the importance of not only evaluating sorbent capacity but also fluidization behaviour in an early stage of process development.**

Quote from: Veneman, R., Li, Z.S., Hogendoorn, J.A., Kersten, S.R.A., Brilman, D.W.F., 2012. Continuous CO2 capture in a circulating fluidized bed using supported amine sorbents. Chemical Engineering Journal 207–208, 18-26.

The miniaturized FB system for adsorbent screening and testing

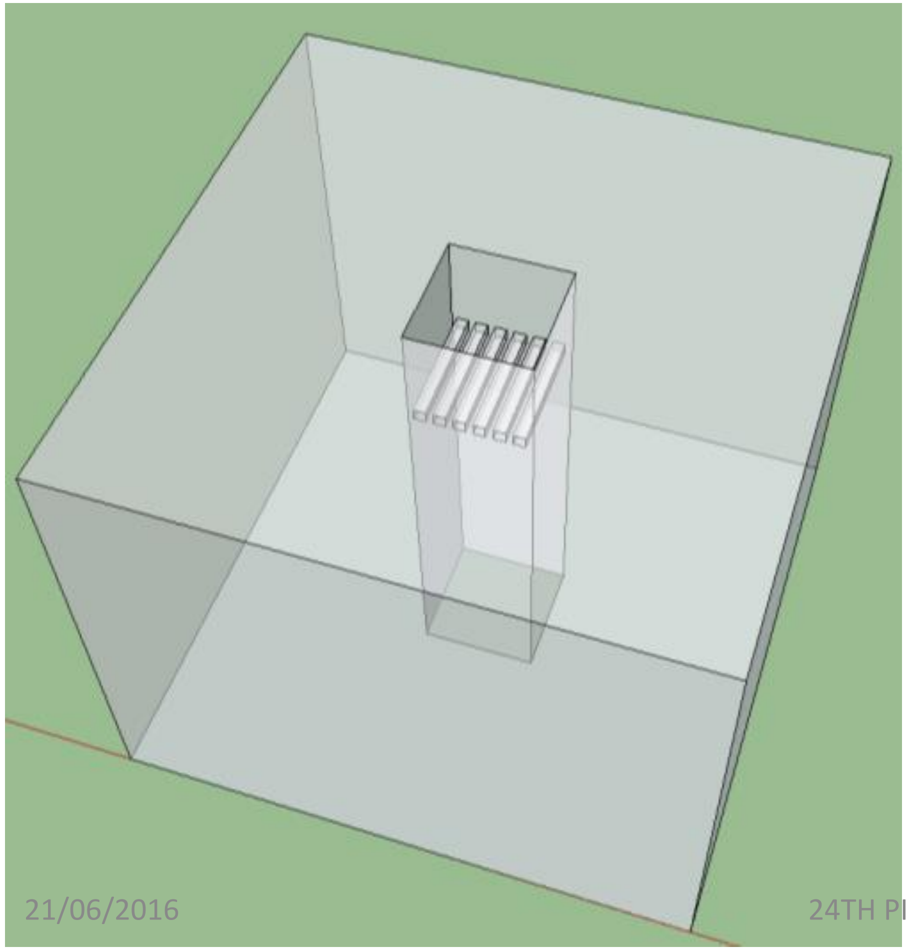
- A more realistic hydrodynamic conditions relevant to large fluidized bed systems
  - Need to be aware of difference between macro and mini-FB systems such as wall effects
- Defluidization can also be assessed (e.g. due to particle agglomeration)
- Attrition can be assessed (size degradation and material loss)
- Larger pellets sample can be used than used in a TGA experiments allowing the recovery of materials after each experiments to perform various analytical techniques (e.g. Brunauer-Emmet-Teller (BET) surface area)
- Cycling experiments can be investigated to assess all parameters (capture efficiency, attrition) under more realistic condition using small amount of adsorbents

3D printing of miniaturized fluidized beds

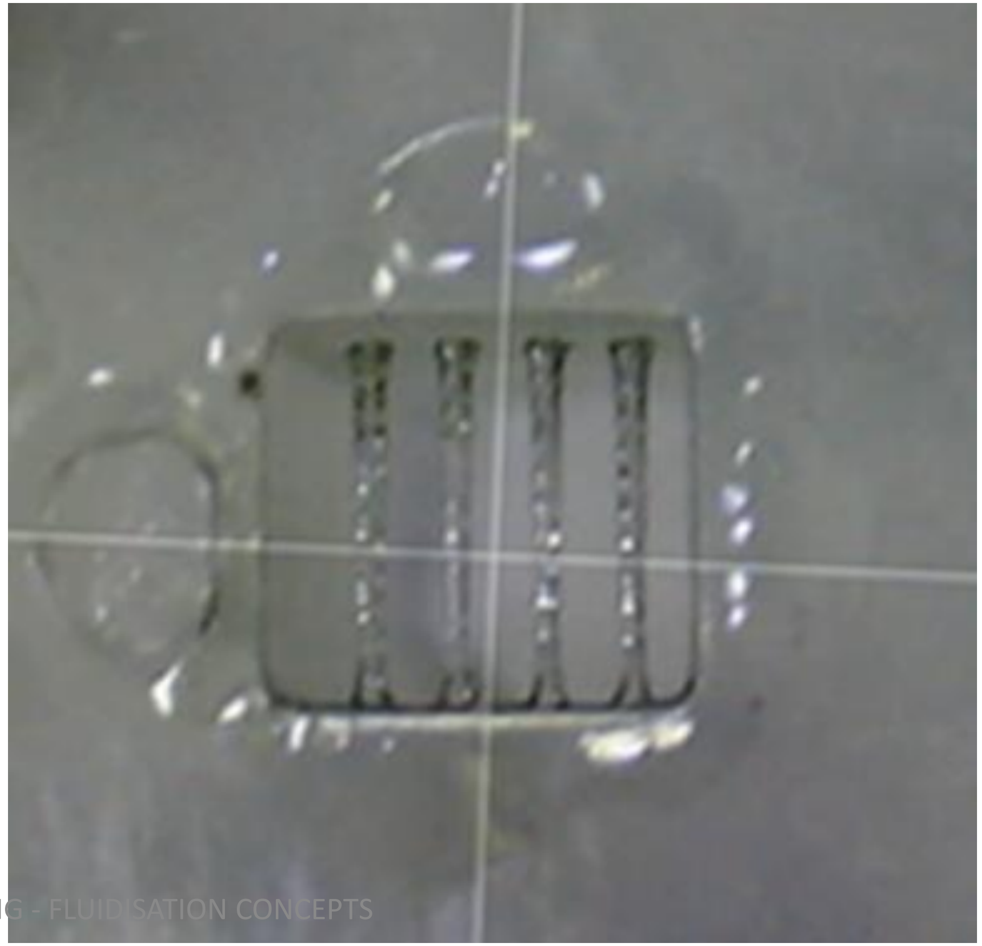
3D printing will be used to enable fast design-fabrication cycles for testing and optimization a micro circulating fluidized bed, but also to study the possibility of other intensified fluidization systems like rotating fluidized beds, the ‘racetrack’ and the Torbed which would be the first study of these systems at the micro-scale.

Preliminary results of MEng project: distributor

Distributor design: series of pillars
CAD drawing

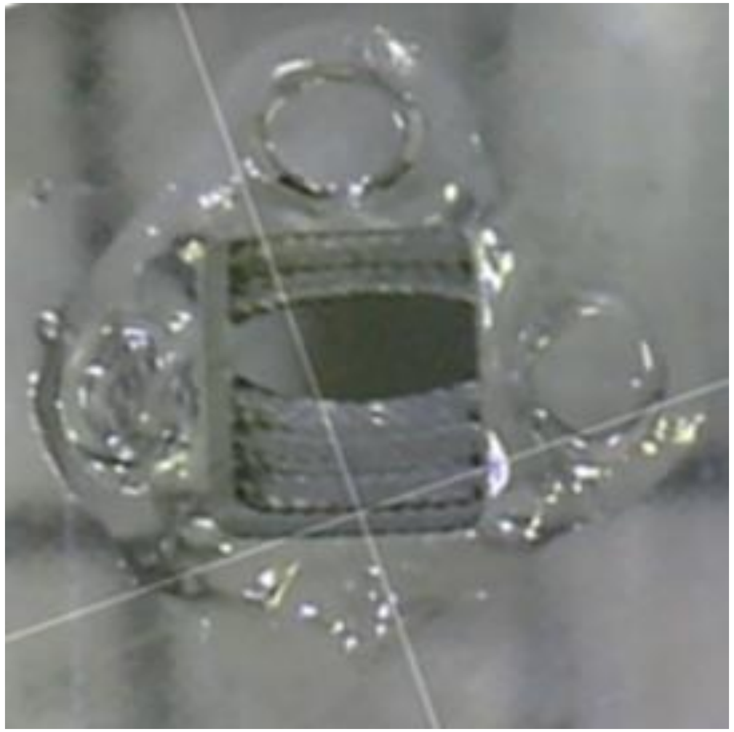


Successfully printed distributor, the pillars are 100 µm in diameter with 100 µm spacing.

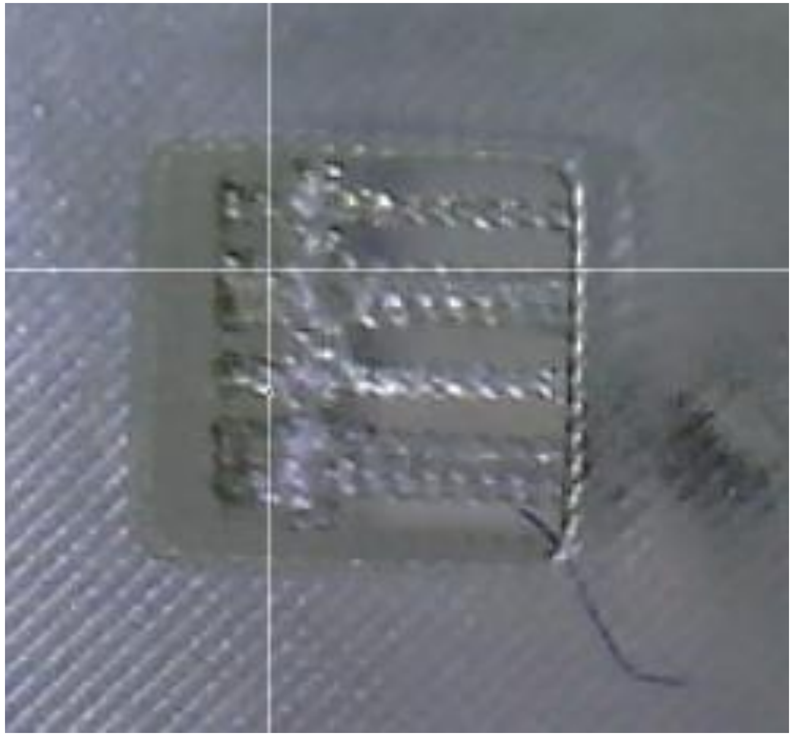


Failed 3D printed distributor structure

Warped pillars



Joined pillars



Final design

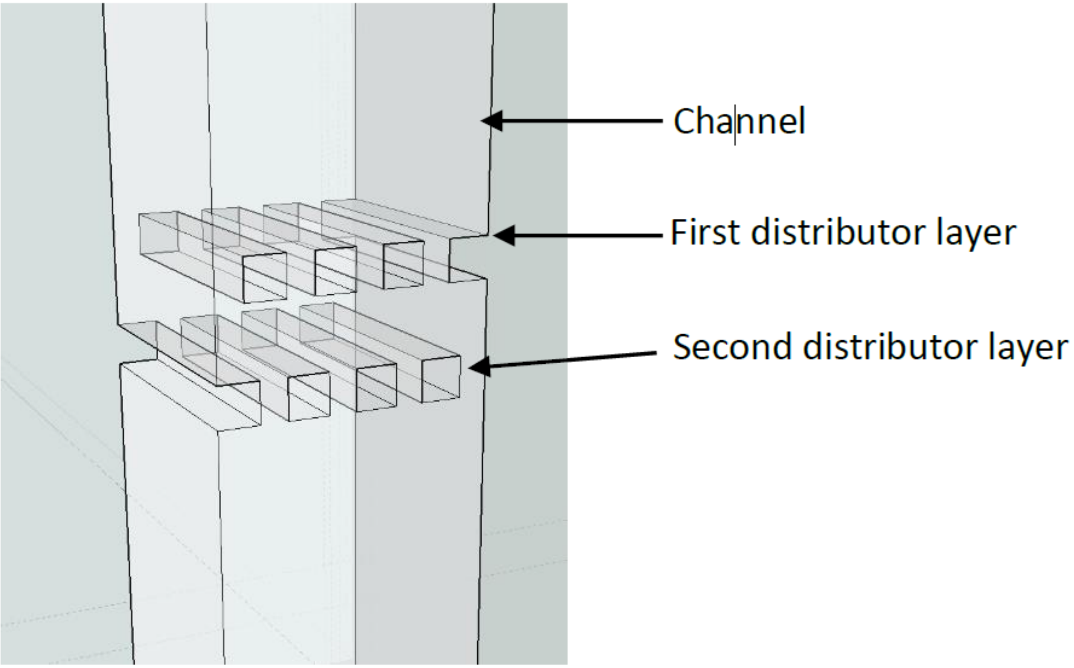
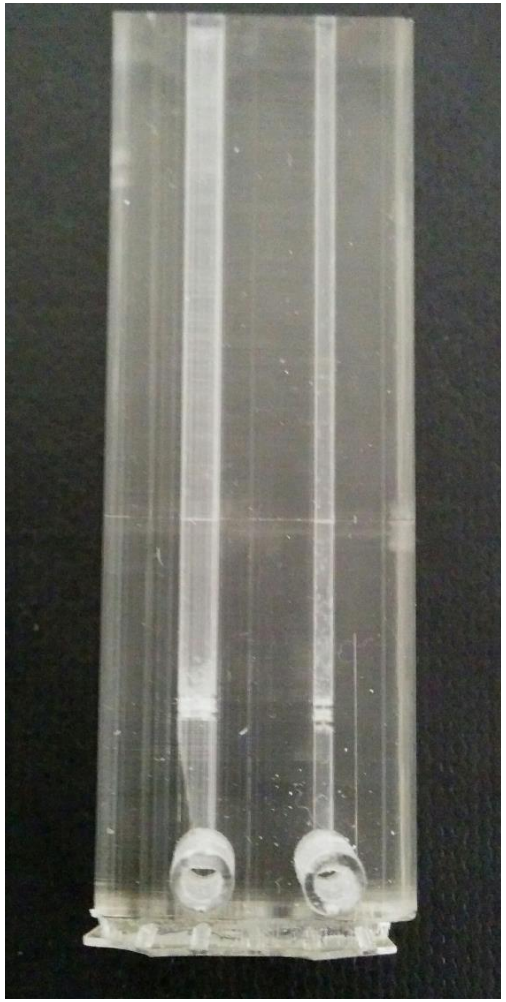
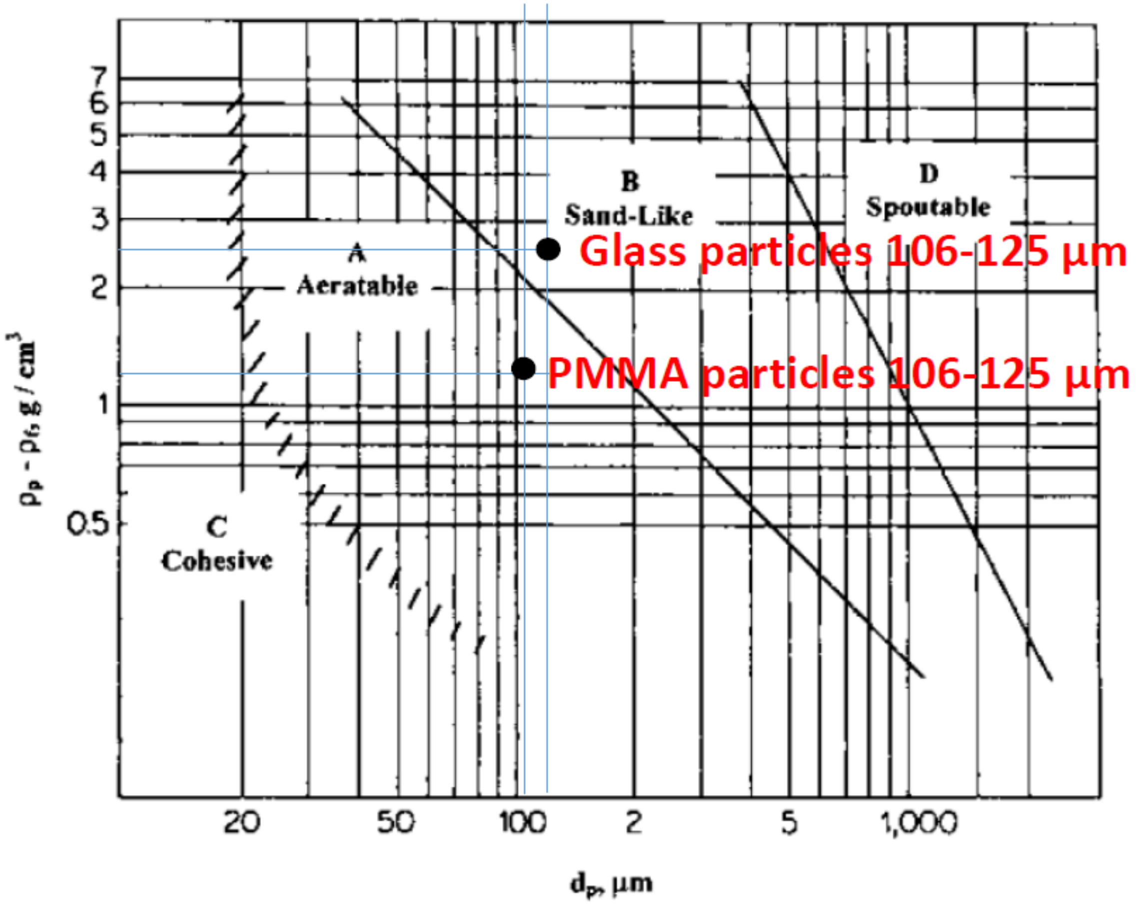


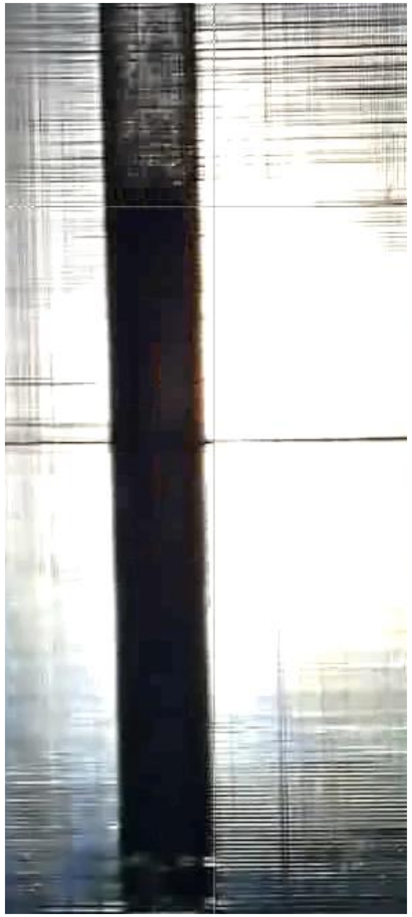
Figure 29 - Parallel double layer distributor array



Final FB design with 4 layer of pillars;
2mm channel on left and 1mm channel on right

Fluidization experiments: particles





Conclusions

- It appears that novel fluid bed concepts could be beneficial for air-cooled condenser designs in areas where water shortages necessitate cooling by other means.
- This may well feature in HORIZON 2020 calls and collaboration would be welcome with interested parties.
- Micro-fluidized beds are interesting as test-beds for scale-up in ACC uses or for Carbon Capture.
- The use of 3D printing gives experimenters the option to look at geometrical changes to beds in a cost-effective manner.