Future developments

- New amine based absorbents – new formulations and new molecules
- Increasing mass transfer using enzymes (carbonic anhydrase)
- Other catalysts: borate and arsenite
- Amine functionalised ionic liquids
- Amine functionalised hyperbranched polymers
- Phase change absorbents

Future developments

- The ultimate goal of PCC is the cost and energy efficient separation of CO_2 from the gas stream of a fossil fuel based power station.

- Any evolutionary or revolutionary technique that potentially results in improved performance should be investigated.

- Revolutionary ideas are difficult to generate. In the following a few evolutionary ideas:

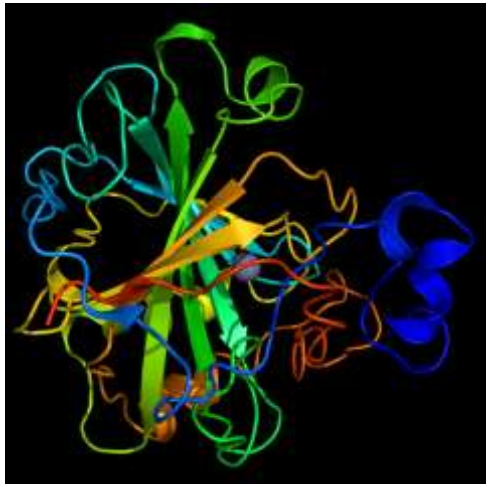
New amines formulations and new molecules

- Very promising and already commercially exploited are mixed amine solutions.
- As discussed previously, the idea is to combine the strengths of different amines in one absorber solvent:
- A ‘fast amine’, e.g. piperazine, mixed with a ‘high capacity amine’, e.g. a tertiary amine.

- At this stage a substantial number of amines have been comprehensively investigated; many more mixtures that are possible and will be analysed in the future.

Increasing mass transfer using enzymes (carbonic anhydrase)

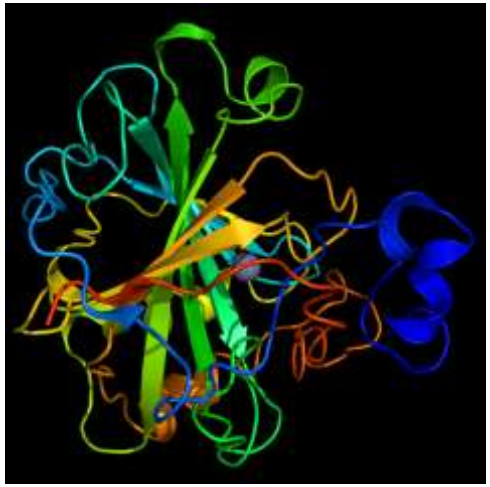
- Enzymes, and more generally catalysts, do not affect the equilibrium nor the net energy requirements of a process; however they can dramatically improve the rate of a particular reaction.
- Carbonic anhydrases catalyse the reaction between CO_2 and H_2O to form carbonic acid and this rate improvement potentially allows the usage of a smaller, cheaper absorber and possibly also stripper columns.
- Very importantly, catalysts could enable to usage of carbonate absorbers, they are chemically completely stable but suffer from slow absorption kinetics.



Ribbon diagram of human carbonic anhydrase II

Increasing mass transfer using enzymes (carbonic anhydrase)

- Carbonic anhydrases are very large naturally occurring enzymes; they are very efficient but also very fragile.
- Most naturally occurring carbonic anhydrases, are not robust enough to survive the harsh conditions prevalent in absorber and particularly stripper columns.
- Research is directed at identifying naturally occurring carbonic anhydrases that are sufficiently robust.
- Genetic modification of existing enzymes is an alternative approach.



Ribbon diagram of human carbonic anhydrase II

Other catalysts: borate and arsenate

- Simple inorganic compounds act as catalysts , similar to but much less efficient than carbonic anhydrases. Most prominent are:

- borate, $B(OH)_4^-$
- arsenite, AsO_2^-

- Both compounds are known to catalyse the reaction of CO_2 with water. They are investigated as potential catalysts in PCC solvents that do not contain reactive amines, e.g. carbonate or tertiary/sterically hindered amine absorbers.

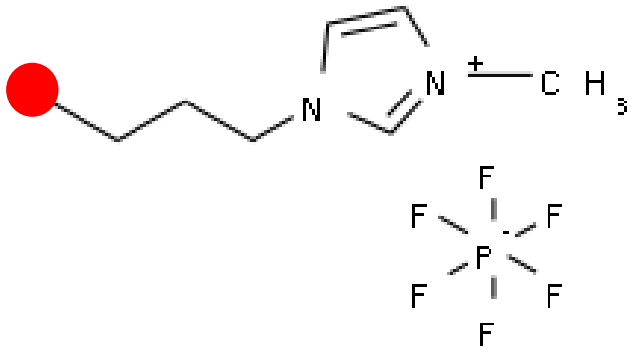
Amine functionalised ionic liquids

- Ionic liquids have interesting properties that can be very interesting for PCC applications:
  - They can be very stable
  - They are completely non-volatile
  - They can be very good solvents for polar compounds

- Disadvantages include:
  - They are very viscous
  - They accumulate water
  - They tend to be very expensive

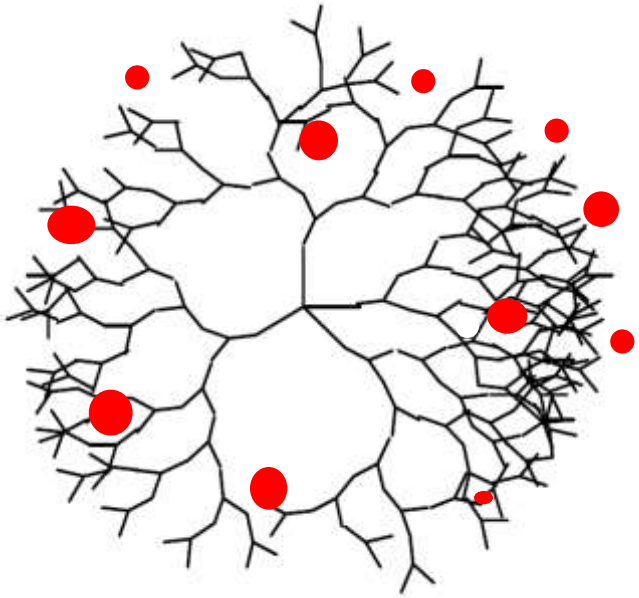
Amine functionalised ionic liquids

- Ionic liquids will not just replace the aqueous solvent; it is possible to incorporate the amine functionality into the components of the ionic liquid.
- A typical example of an ionic liquid is
- 1-butyl-3-methylimidazolium hexafluorophosphate;
- For this ionic liquid, the potential of functionalisation (•) at the butyl group is almost obvious.



Amine functionalised hyperbranched polymers

- Hyperbranched polymers are a group of polymers with densely branched structures which can incorporate a large number of reactive groups (•), such as amines.
- Advantages such as minimal volatility and potentially high reactivity can be outweighed by high viscosity and potentially low solubility.
- Nevertheless, these molecules are quite novel and thus there is rather little known about their properties. Which also means there is hope.



Phase change absorbents

- Phase change undergo a phase separation upon absorption of CO_2. One phase contains chemically absorbed CO_2 and can be separated from the other phase, giving a concentrated CO_2 phase for regeneration.
- The overall effect is reduced energy requirement for the production of a unit of purified CO_2.

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