

Absorption Technology Laboratory

- at NTNU Chemical Engineering and SINTEF Materials and Chemistry

Reactor Technology Group

Activities on CO₂ removal

The Reactor Technology group in collaboration with SINTEF Materials and Chemistry has a substantial activity in the field of CO₂ (and also other acid gases) removal from exhaust gas, process gases and natural gas. We study mainly technologies associated with absorption of CO₂ into physical and chemical solvents using conventional absorption towers or new membrane contactors. Our work comprises both experimental work and rigorous modelling of the absorption processes.

In the following is given a short description of our experimental facilities. It is important to note that design and modelling of absorption processes necessitates knowledge and experimental work within a large spectrum of fields such as hydraulics, mass transfer, chemical and physical equilibrium, kinetics, and thermal and transport properties. We do not cover all these fields, but have activities in many.

Equilibrium measurements

For absorption processes we rely on measurements of binary and ternary equilibrium. The binary equilibrium relates the pressure of the liquid mixture to the composition and temperature and is performed in a simple pressure cell with good temperature control and accurate pressure monitoring. For the ternary measurements we need to cover a large range of temperatures and compositions. The partial pressure (or fugacity) of CO₂ is measured as function of liquid phase composition and temperature. In order to cover the whole range of conditions met in an absorption process, from say 20 to 120°C and with CO₂ partial pressures ranging from 0.01 kPa to 20 bar, it is necessary to operate several equilibrium cells. For the low temperatures and low CO₂ partial pressures a circulation system is used, see figure 1. The gas is circulated through three bottles of solvent, in a thermostat box, until equilibrium is reached. The gas and liquid phases are both analysed. The operating range is 0.01 – 20 kPa of CO₂ partial pressure and 20 - 70°C.

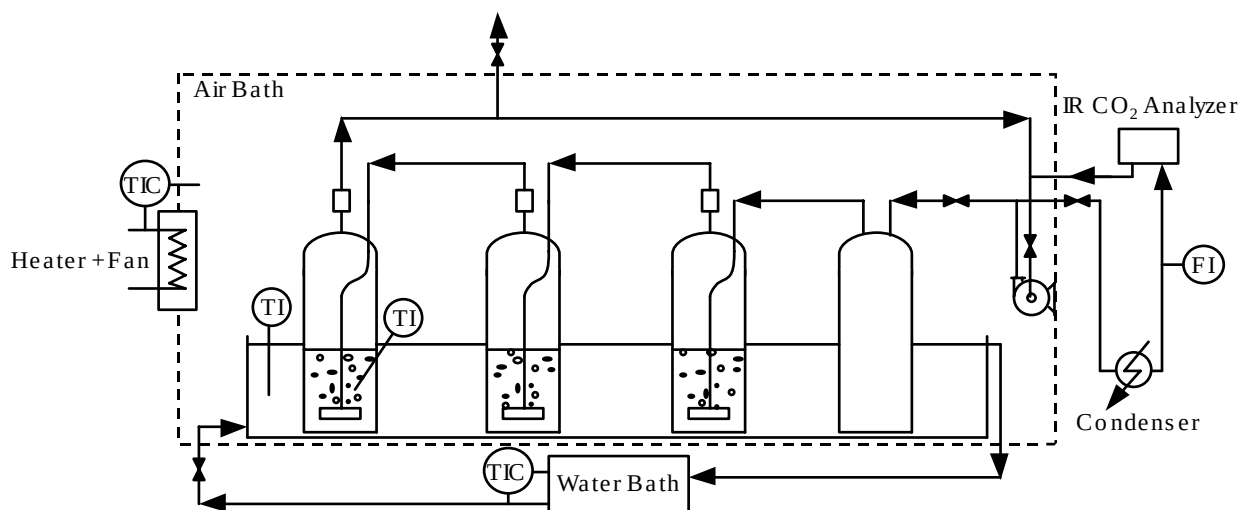


Figure 1. Vapor-liquid equilibrium apparatus for atmospheric pressure

A similar apparatus based on the same principles is used for the high temperature measurements. Here the cells need to be operated at about 7 bars in order to obtain data that can be used for desorber/regeneration conditions. The apparatus is shown in figure 2. This apparatus can operate up to 7 bars and a temperature of 135°C



Figure 2: This apparatus can operate up to 7 bars and a temperature of 130°C

For higher pressures, mostly encountered for natural gas in the absorber, we have a third apparatus where the contact between gas and liquid is enhanced by gentle shaking.



Figure 3: High pressure turning cell

The turning cell can operate up to 20 bar total pressure, and therefore also 20 bar CO₂ partial pressure. The maximum operating temperature is 85°C.

A fourth equilibrium cell is under construction. This is made for high temperature and high pressure measurements, specially aimed at high pressure desorption operation.

Screening

One activity we have is on selection of new absorbents. For this we need to be able to screen a large number of solvents in a reasonable time. This apparatus consists of 6 identical gas bottles where gas, at a constant CO₂ concentration, is passed through. The bottles are filled with an exact amount of liquid with predefined amounts of solvent. The apparatus is shown in figure 4.

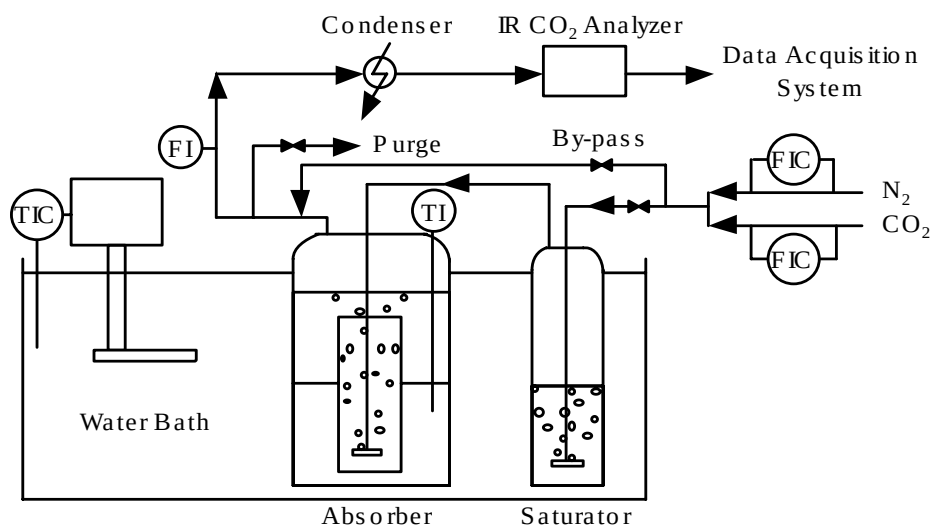


Figure 4. Screening apparatus for CO₂ capture solvent selection

The absorption rate is highest initially, and reduces as the solvent CO₂ loading increases. Typical results are shown in figure 5.

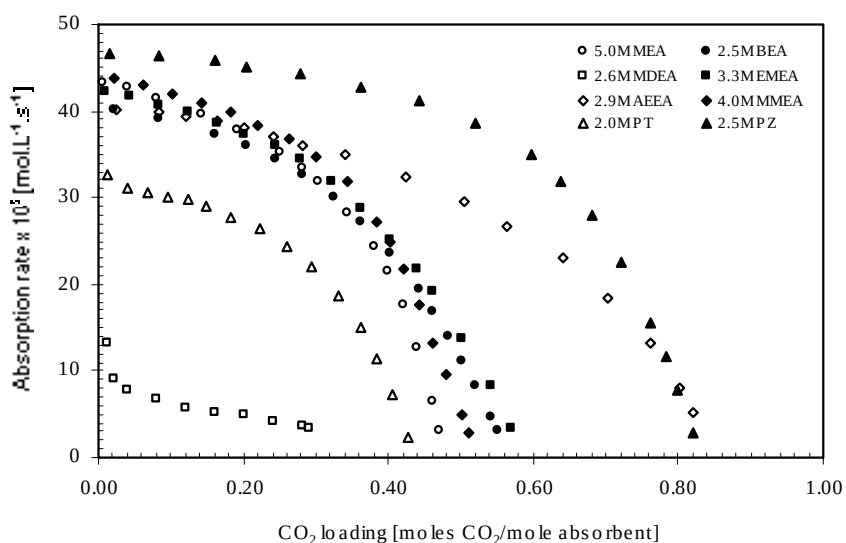


Figure 5. Typical absorption curves for various solvents in the screening apparatus.

Kinetics

Measurements of the chemical kinetics of the various solvent systems are important in order to calculate the mass transfer rates and thereby correctly design both a conventional absorption tower and a membrane absorber. We have three apparatuses that can measure kinetics.

Membrane contactor

The laboratory membrane contactor can be used to measure reaction kinetics by measuring the absorption rate and then deducing the kinetics from the membrane contactor model. Membrane with varying contact times can be used. In figure 6, a module with relatively long contact time is shown. We also have two other modules.



Figure 6. Laboratory membrane absorber module. (Range 25 - 70oC, < 1.5 bars CO2 pressure)

Wetted sphere contactor.

A thermostated wetted sphere contactor has been operated on slow systems.



Figure 7. Wetted sphere contactor

String of discs contactor

A string of discs contactor has been built and calibrated for both the MDEA (slow) and the MEA (fast) system. Kinetic data can be extracted at least within this range of solvents. Analyses have shown that we can use this for both evaluation of column performance, as a direct scale-up tool, and for deducing kinetic data.

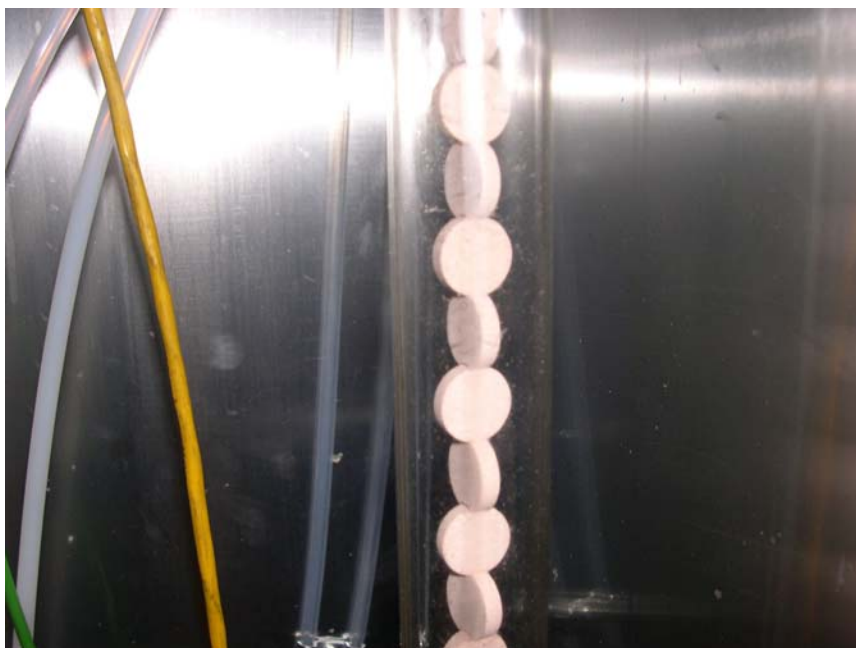


Figure 8. String of discs contactor

Thermal data

For the measurement of heat of absorption we have a flow calorimeter of type Chemisens. There is one 250 ml and one 2 l calorimeter. The 2 l calorimeter is now in a renovation phase and will be fully established with flow lines and infrastructure by September 2004.

This will enable both measurements of heat of reaction for new solvents and mixtures, and specific heat for the unloaded solutions.

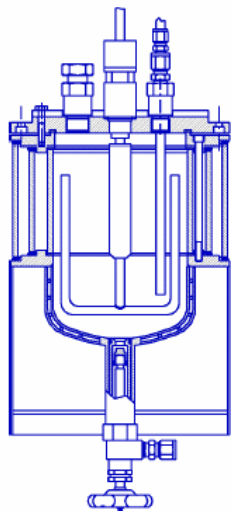


Figure 9. Chemisens flow calorimeter.

Transport properties

Viscosity

We have a high pressure viscometer, Physica MCR 100, where we can measure the rheology of both loaded and unloaded solutions.



Figure 10. Physica MCR 100 Rheometer

The operating ranges are -20 - 150°C and 1 – 150bar.

Diaphragm cell

We have a diaphragm cell under reconstruction that hopefully will be in operation during the autumn of 2004.

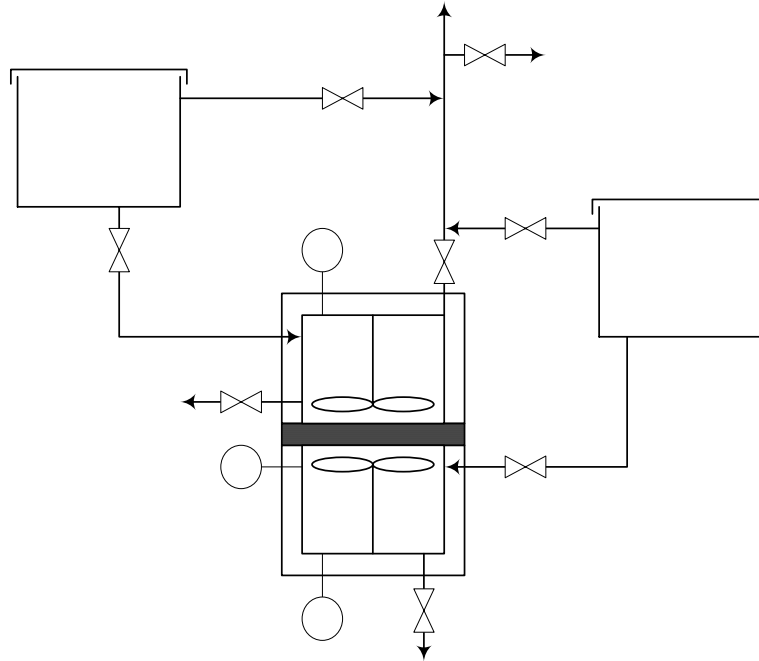


Figure 11. Diaphragm cell for diffusivity measurements.

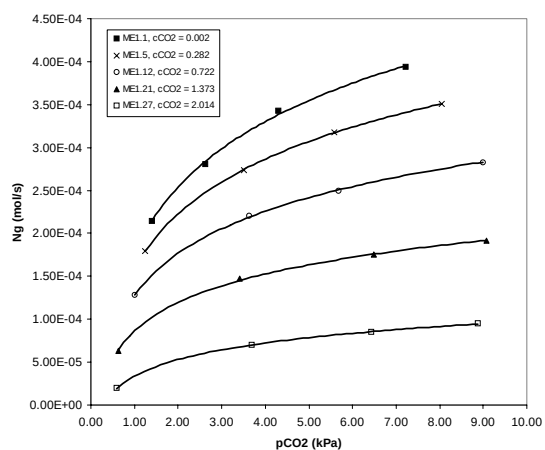
Pilot plant

The laboratory pilot plant as shown in figure 11 is a fully fledged absorption plant instrumented to run around the clock. It is a combined column and membrane absorber set-up where one may run the two columns or with the absorber or desorber column exchanged with a membrane contactor unit. The absorber inner diameter is 15 cm and the desorber is 10 cm. The absorber packing height is 4.5m.



Figure 11 Pilot absorption plant

Laboratory unit



Pilot plant 15 wt%

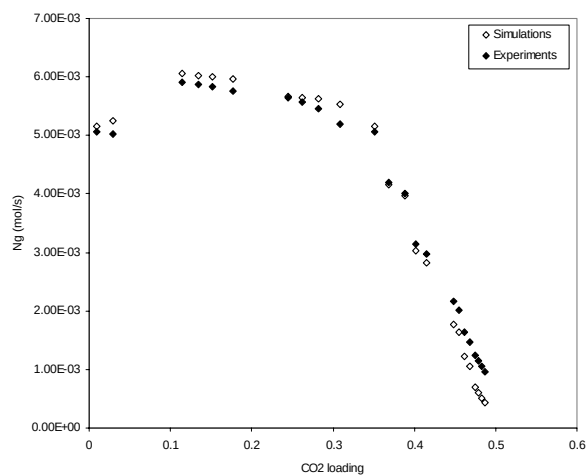


Figure 12. Sample results showing agreement between model and experiments