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How to maximize the value of mature HC fields?

Workshop

Budapest, 18. November 2010.

Society of Petroleum Engineers

Improving CO_2 Flooding Efficiency to Maximize the Value of Mature HC Fields

How to maximize the value of mature HC field?

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Why should apply CO_2 flooding?

- Advantage of CO_2 flooding
  - Available in large amount from natural reservoir
  - Inexpensive
  - Non-flammable, non-toxic
  - Reduced oil viscosity
  - Oil swelling
  - Pressure maintenance

Why should not apply CO_2 flooding?

- Disadvantage of CO_2 flooding
  - Corrosion
  - Recirculation (environment protection)
  - CO_2 low viscosity
    - CO_2 viscosity 0,04-0,06 cP
    - Oil viscosity 0,6-1,0 cP

      ⇓

    - High mobility ratio

      ⇓

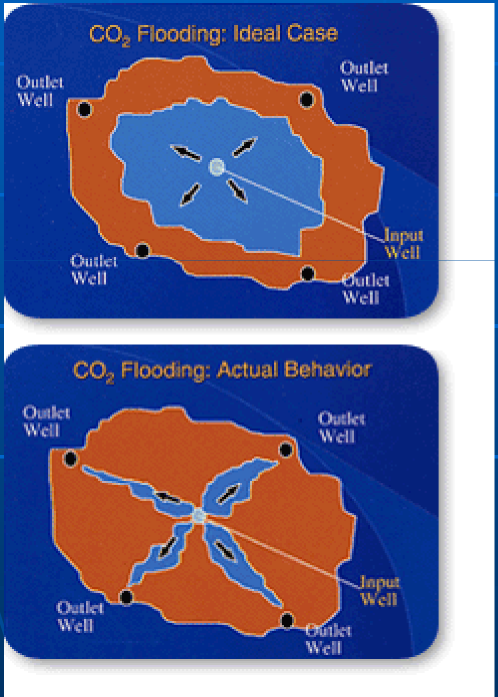
    - Low sweep efficiency

Mobility ratio

$$M = \frac{K_{CO2}}{\mu_{CO2}} \Big/ \frac{K_{oil}}{\mu_{oil}}$$

- The viscosity ratio leads to the mobility ratio.
- Unfavorable mobility ratio contributes to miscible fingering and reducing the aerial sweep efficiency.
- Low viscosity of CO_2 contributes to the low vertical efficiency, especially in stratified reservoir.

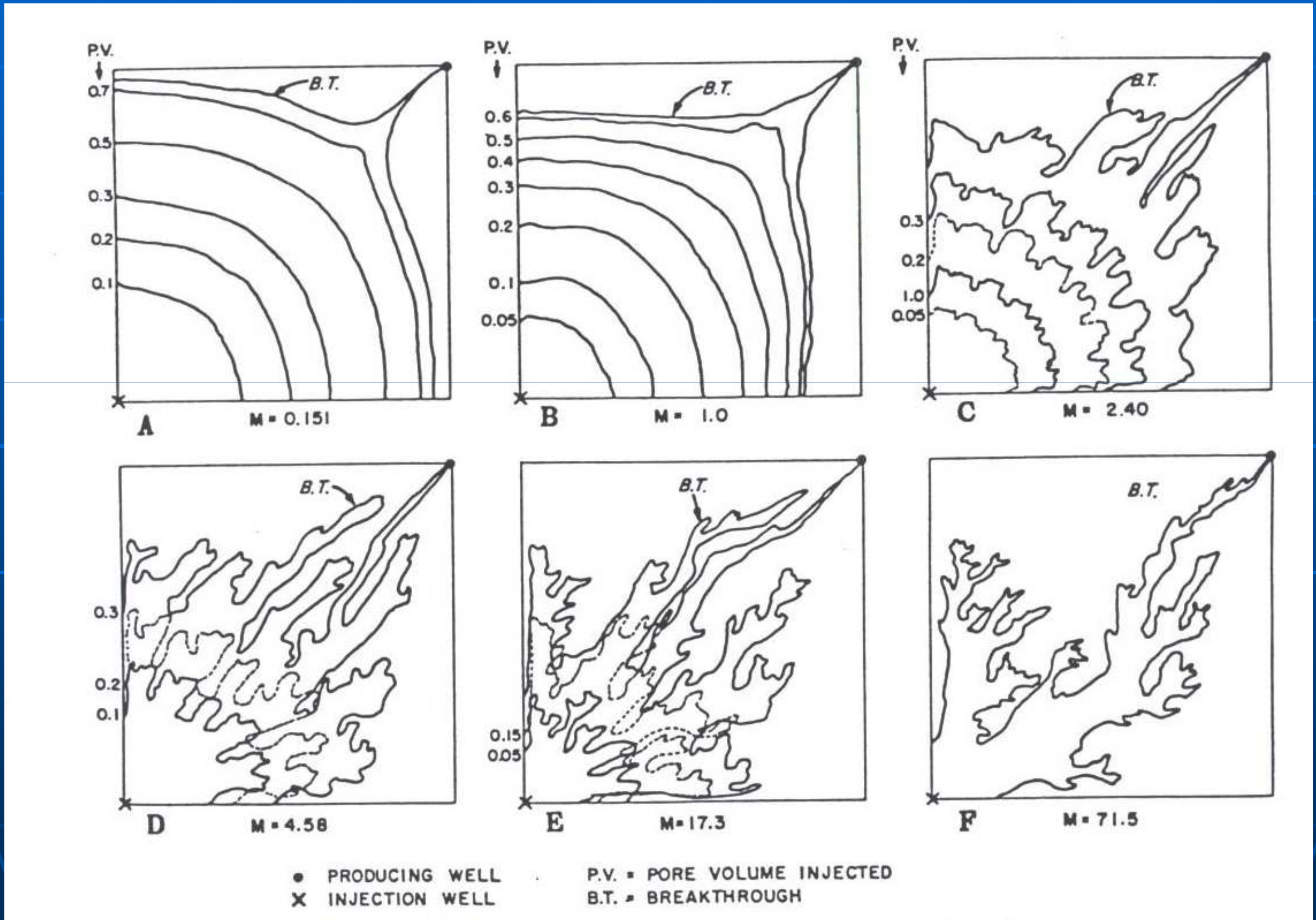
Displacement fronts



In case of $1 \leq M$

In case of 10~M

Viscous miscible fingering



Increase the sweep efficiency

- CO_2 mobility reduction
  - WAG decrease the relative permeability of CO_2 by increasing the water saturation
    - Advantage: water prolongs the duration of the CO_2 flood.
    - Disadvantage: water shield the residual oil from CO_2 and reduces the displacement.
  - Generation of CO_2 foam,
    - Advantage: foam blocks preferential flow channels.
    - Disadvantage: the surfactant adsorbs and the foam breaks down.
  - Increasing viscosity of CO_2 via addition of a “thickening agent”

Criteria of thickening agents

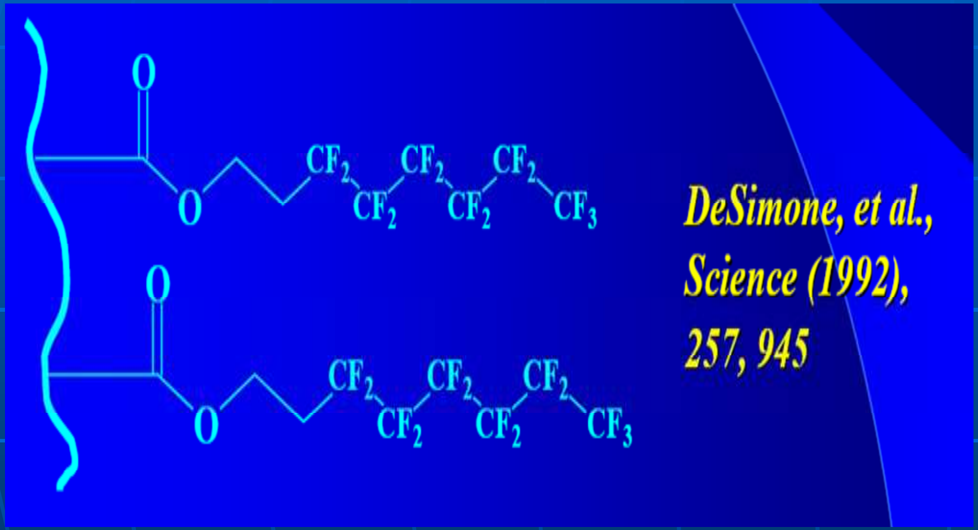
- Will be soluble in CO_2 without co-solvent
- Generally it is necessary to increase the viscosity a 2-10 fold in concentration as low as 0.1~3 wt%, as determined Darcy's Law for flow of through porous media,
- Will be inexpensive,
- Safety handle,
- Stable at reservoir conditions.
- Distribution coefficients will be low.

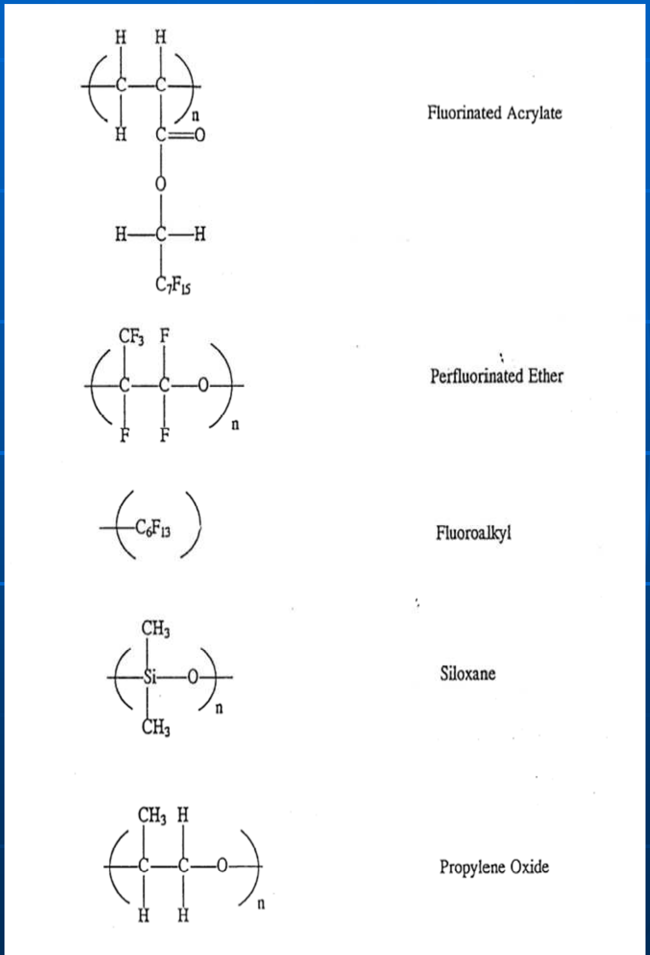
Design of thickening agent candidates

1. The thickener should not be tested in organic liquid an initial screening. The most CO_2 soluble surfactant have been identified as low solubility in alkenes.
2. Polymers should design specifically for use CO_2. This is achieved by incorporating CO_2-philic tails because CO_2 is a feeble solvent.
3. Viscosity must be measured in the appropriate apparatus and flow range because of non-Newtonian nature of the thickened carbon dioxide solution.
4. The thickener will work lower concentrations if it is a end functionalized polymer forms associative or H-bonded aggregates in solution.

Classical CO_2 -philic functional groups

The first true CO_2-phile





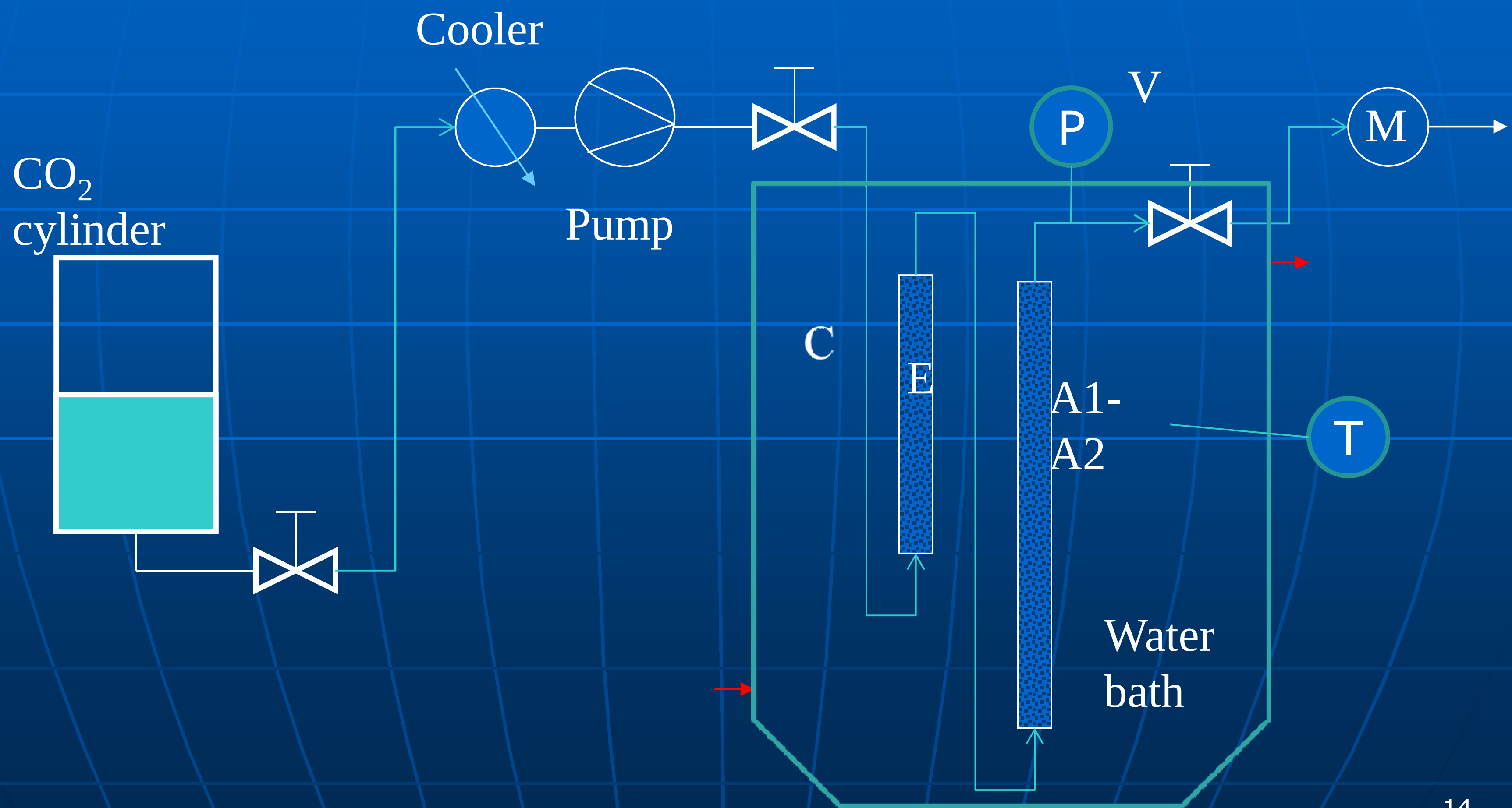
Compounds studied

- Commercial, non-halogenated oligomers and polymers
- Commercial surfactants
- Peracilated sugars and their derivatives
- Terc-butyl-phenols and their derivatives
- Dendrimers
- Iso-octanol derivatives

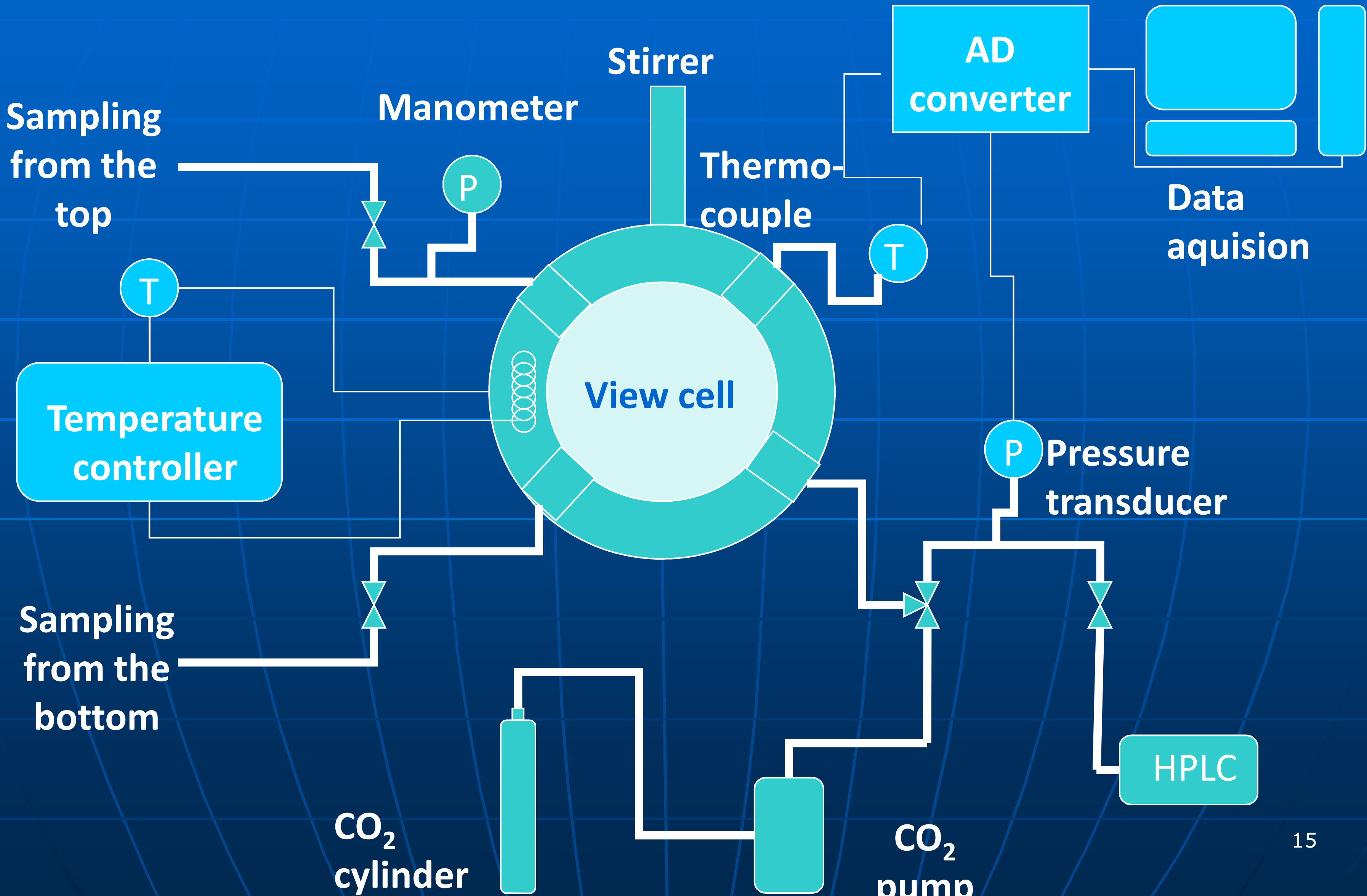
Experimental techniques

- Dynamic solubility determination technique
- View cell unit for cloud point measurements
- View cell unit for measurement of distribution coefficients
- Fall-tube viscometer
- Apparatus for solubility and mobility measurement (core flooding)

Dynamic solubility determination technique

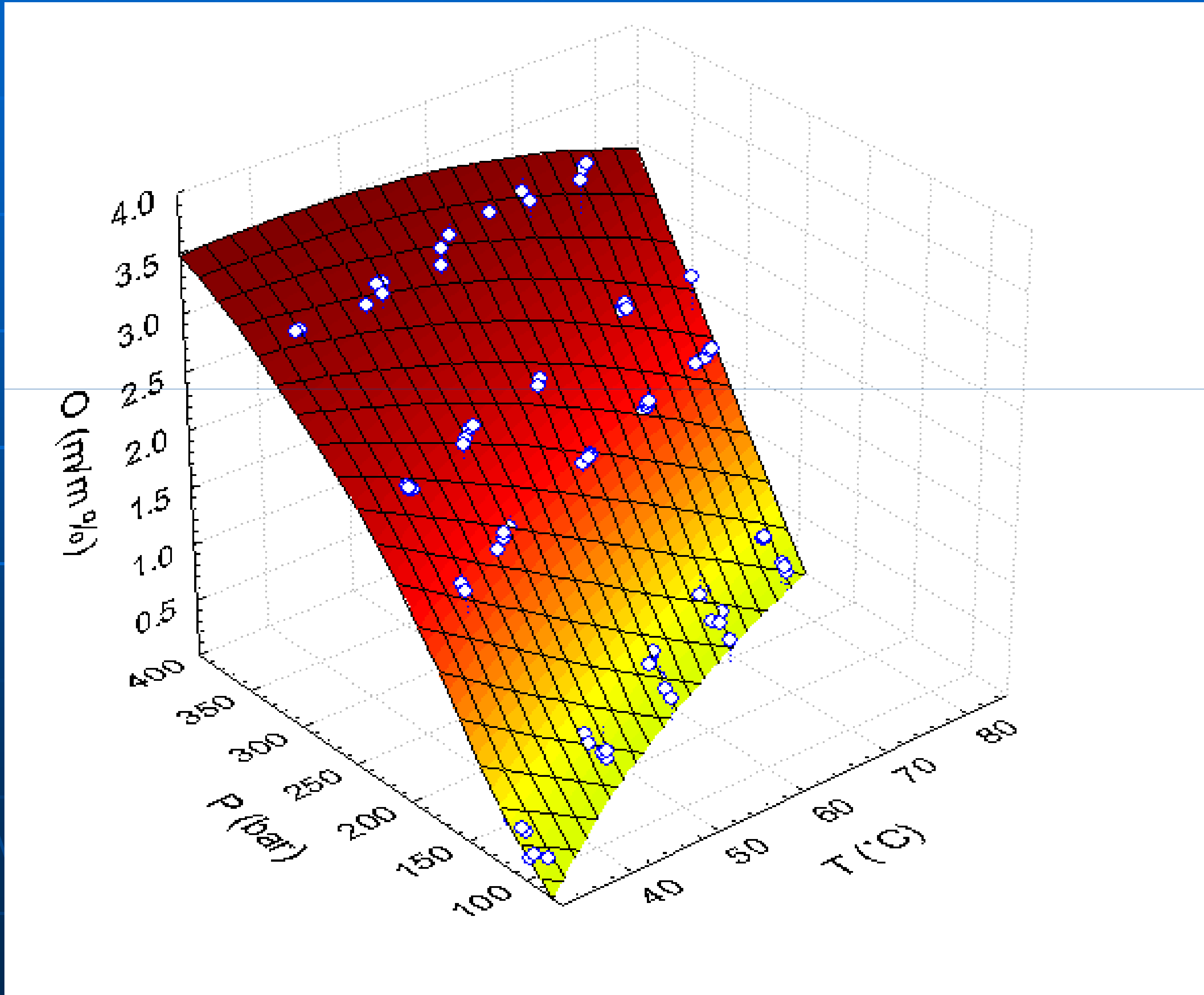


View cell unit for cloud point measurements

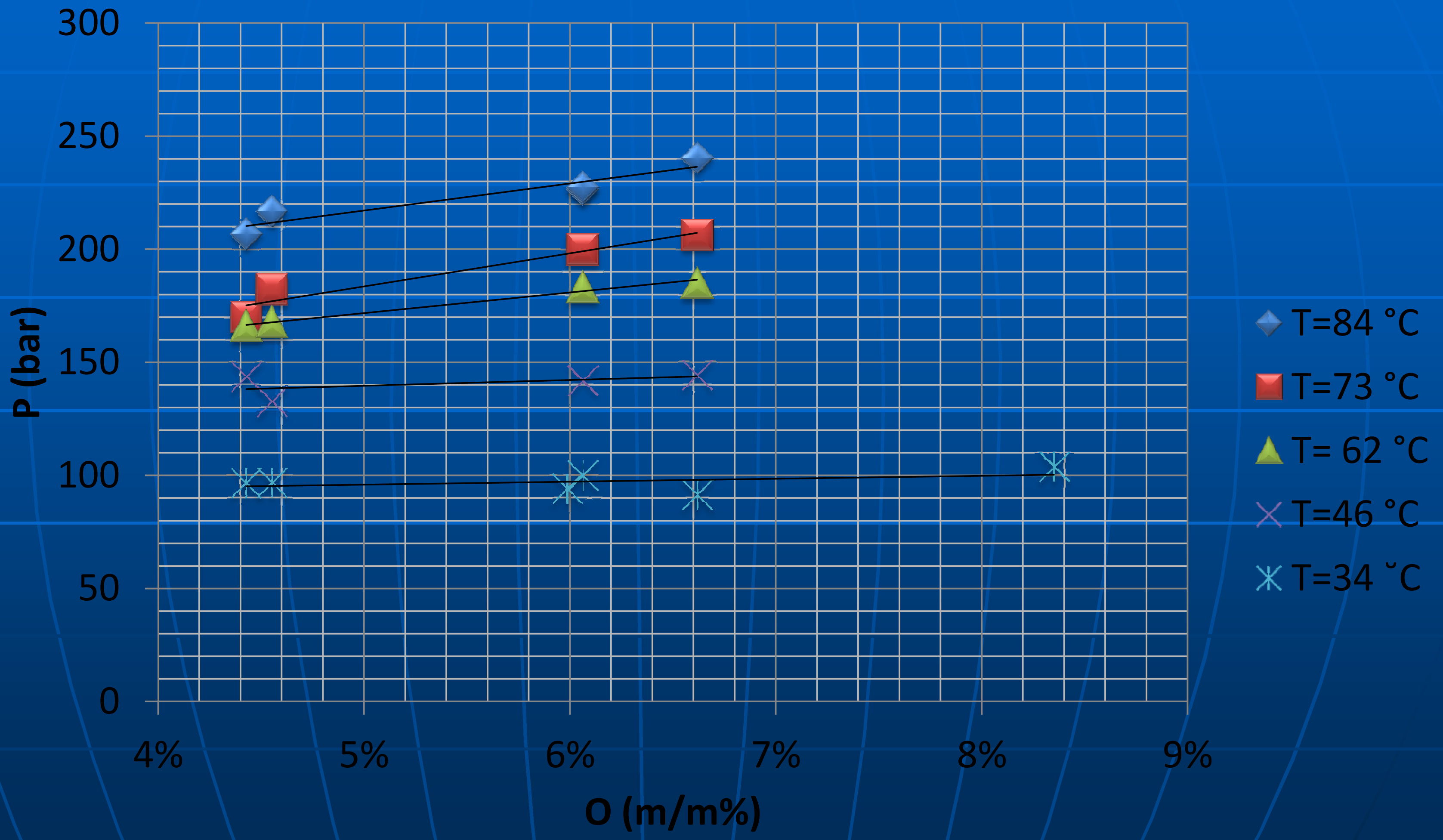


MOLCO-15

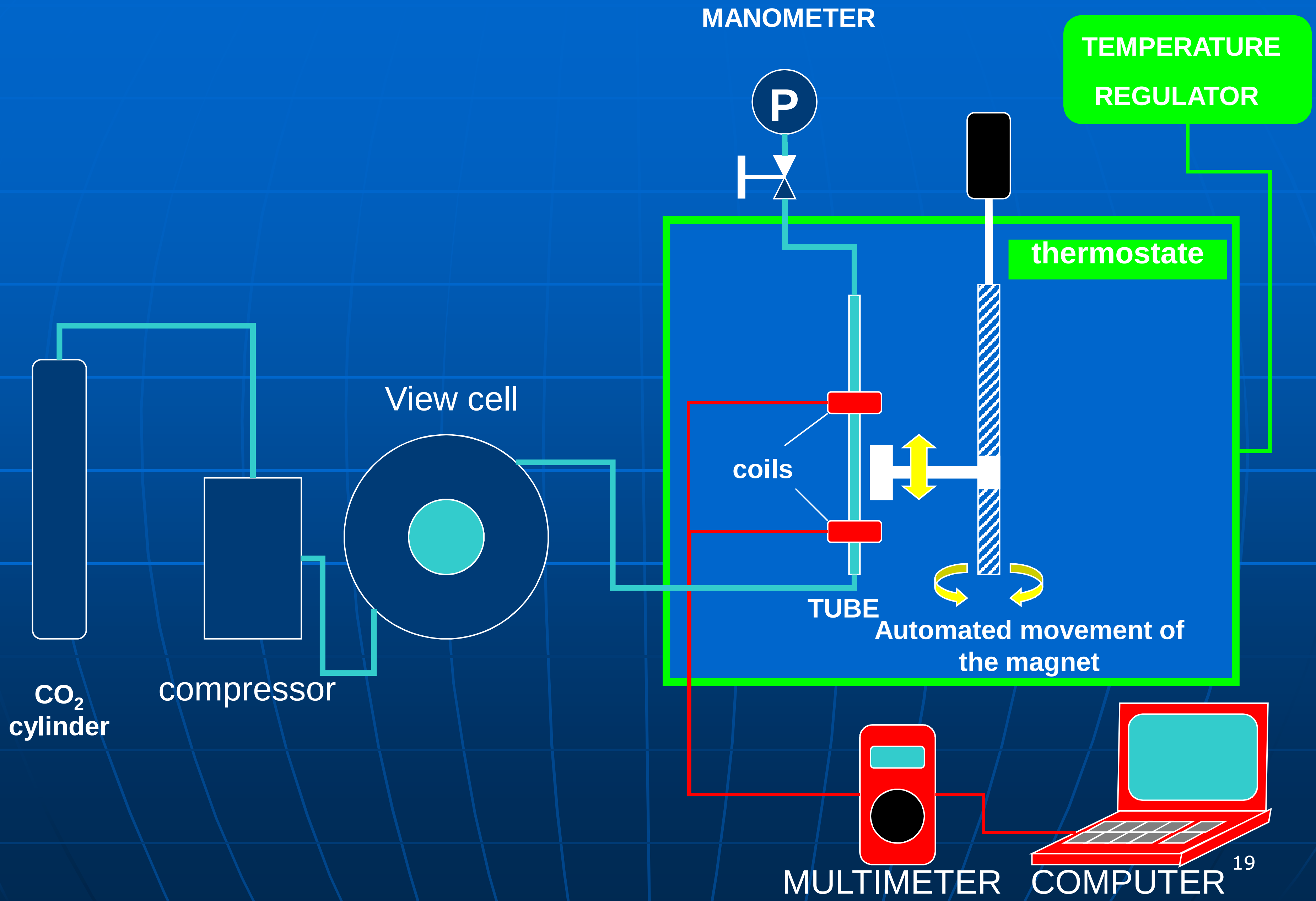
Solubility of Brij72



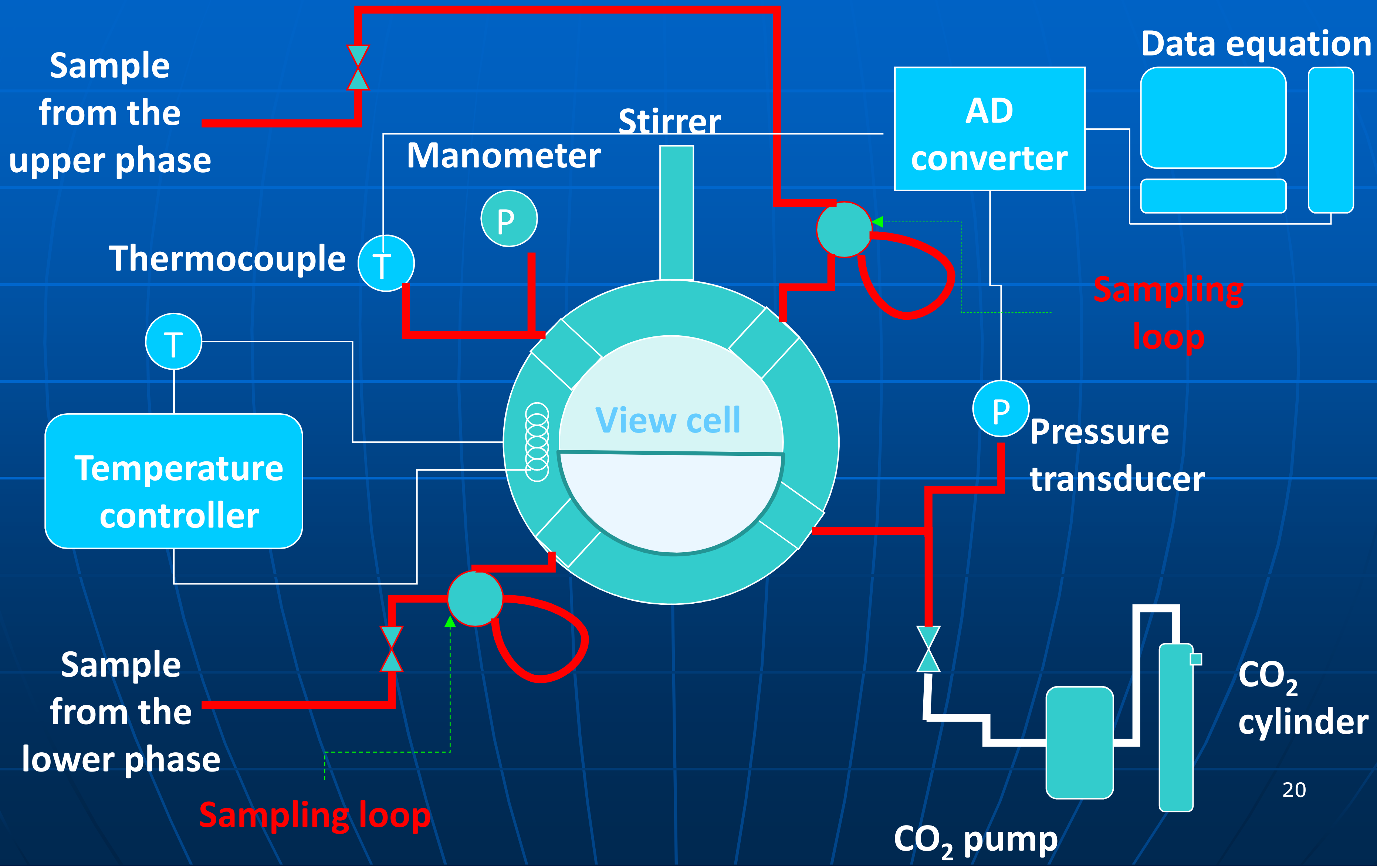
Solubility of MOLCO-2



Fall-tube viscometer



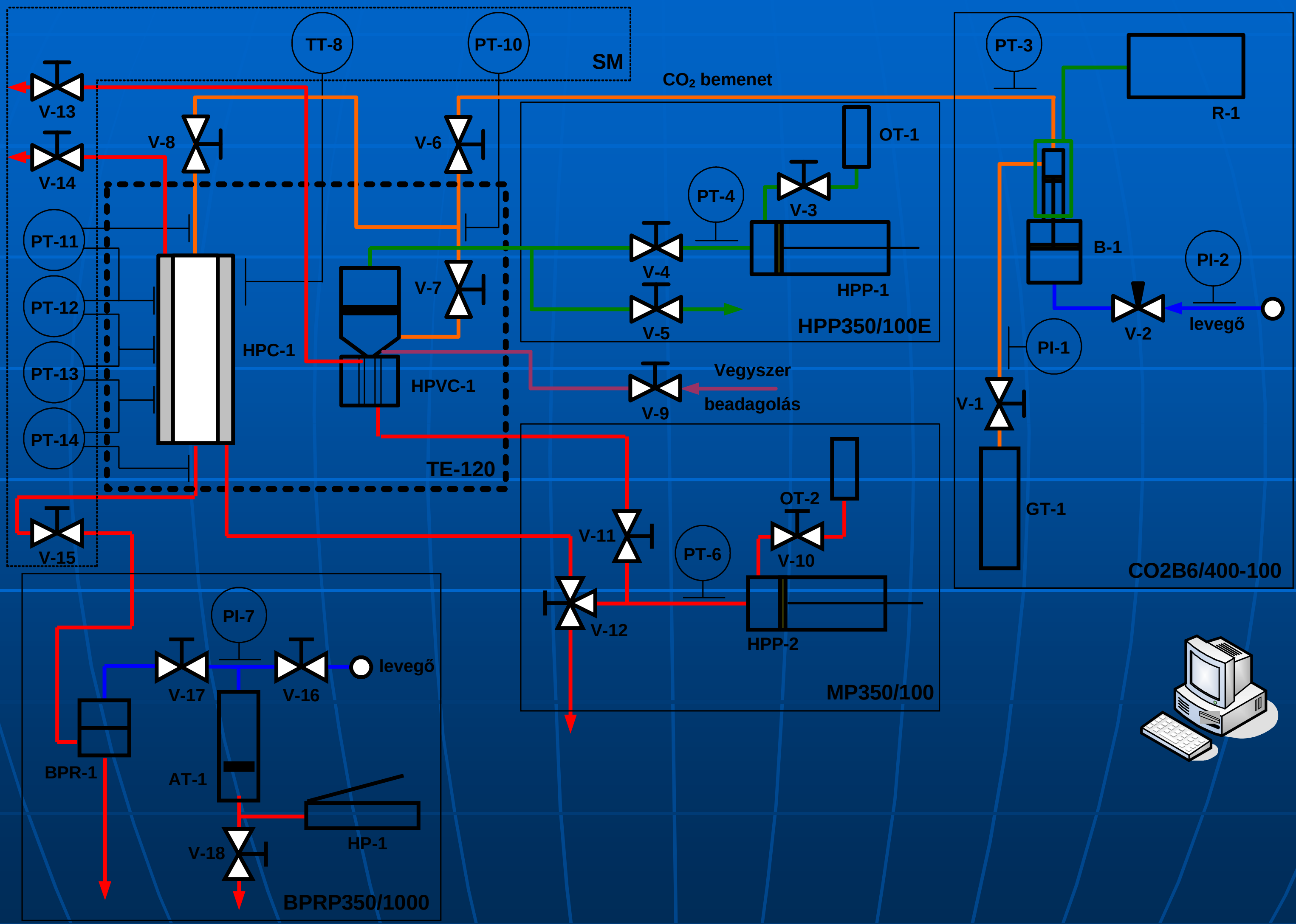
View cell unit for measurement of distribution coefficients



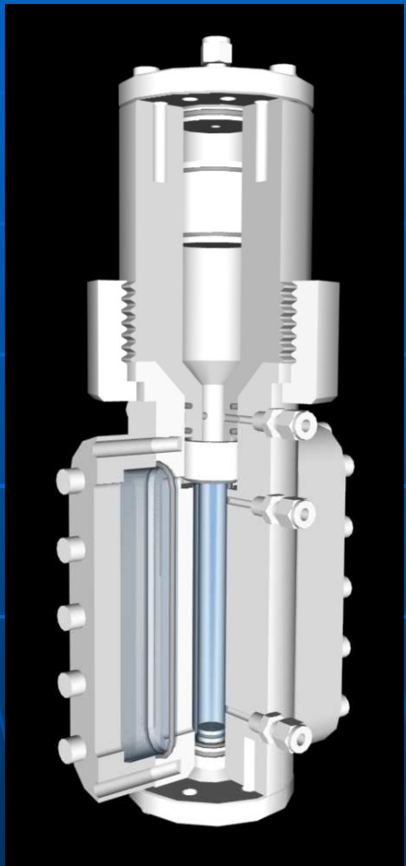
Distribution coefficients in CO_2-electrolyte (water) biphasic system

Material	Average c (mg/ml)	K = $c_{CO2}/c_{elect.}$	P – T range	Notes
MOLCO-2	1.56	>200	11-39 MPa 33-95 °C	The low solubility in water is the limiting.
	8.86	>600	12-38 MPa 35-96 °C	
MOLCO-14	5.22	0.4-0.88	14-15 MPa 35-43 °C	
	5.23	0.61-0.8	14-20 MPa 32-45 °C	
MOLCO-20	1.58-1.78	>1000	20 MPa 50 °C	Solubility in water is very low.
	19.8	>500	15 MPa 50 °C	
MOLCO-23	19.8-19.9	>150	19.8-20.3 MPa, 50°C	

Apparatus for Solubility and Mobility Measurement



High Pressure Cell for Solubility Test



- Two parts
  - upside for pressurising
  - downside for visualising
- Pressure max: 400 bar
- Temperature max: 150 ºC
- Visual observation is possible
- CAD constructed

Comparison of different methods

m/m % iso-octanol	P (bar)	T (°C)	η_{rel} Fall-tube	η_{rel} Core flooding
14 %	153	65	1.5	1.6
20 %	153	65	1.7	1.9
35 %	153	65	2.9	2.8
43 %	153	65	3.9	

Conclusions

- Improved a experimental method to select and caracterise the thickening agent candidates
- Some of examined materials were CO_2 soluble
- These materials increased the viscosity less then 10 %
- Iso-octanol increased the viscosity a 1.5-3 fold in concentration 10-30 m/m%,
- Based on iso-octanol molecule with longer hydrocarbon chains may have a greater chance to give a higher viscosity at lower concentration
- Worldwide research of thickening agents started more then ten years ago but effective materials not have been founded, the problem is actual

Acknowledgments

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