CAPABILITY OF LEMIGAS LABORATORIES IN SUPPORTING EOR STUDIES*

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ABSTRACT

Eor methods hold the promise of adding to the production levels and reserve base of world's maturing oil fields.

In Indonesia, very few EOR project have been under taken, olny few of the EOR methods that have been evaluated in the laboratory and tested in the field.

Many of the seservoirs in Indonesia represents unique technical challeuges. These include the high geothermal gradients, significant offshore reserves and the presence of strong waterdrive recovery mechanisms. Nevertheless, engineering efforts to assess the EOR potential in mayor fields should be initiated as early as possible so that planning and considuration of EOR can provide suffidient lead time to develop any viable projects.

In this connection, LEMIGAS endevours to be an institution having EOR laboratories and other facilities to support the oil industry in Indonesia which emphasises EOR studies.

I. INTRODUCTION

Even though the Indonesian petroleum industry has been growing for more than 100 years, the application of EOR (including secondary recovery) methods and its constribution to oil production in Indonesia are still very limited. In order to maintain the production at the current level, PERTAMINA as well as its PSCS start to enchance the recovery from several of their producing oil fields.

Actually, the conventional primary depletion and secondary recovery techniques recover on average one third only of the original oil in place because of capillary, viscous and gravity forces; accordingly the EOR methods are basically designed to take into account the physical, chemical and hydrodynamic phenomena involved in these tranning mechanisms, to decrease their effects and to gain as much as possible the oil by :

- mobilizing the oil trapped in the pore space, in form of residual oil saturation.
- sweeping more homogeneously the entire reservoir
- keeping the production rate as high as possible.

Based on the type of injected fluid and processes the EOR methods are generally classified into 3 groups :

- improved water flooding wherein chemicals such as polymer and surfactants are added to injected water.
- new forms of gas drive wherein the miscibility of injected gas with reservoir oil is the primary target
- thermal processes wherein heat is transfered to oil through steam or air injections.

In recent years about 35 EOR (including waterflood) projects have been implemented in Indonesia. Some are still in the study phase, others are already applied on the pilot or commercial scale.

All of these efforts, apart from capability on the operational aspects, require continued and consistent support from the R & D activities in order to implement those projects effectively. For this reason, LEMIGAS as one of the oil and gas R&D institutions, is encouraged to support the EOR activities in Indonesia by developing an integrated laboratories system with the reservoir and production engineering laboratories as nucleus, supported by geological and other related laboratories already existing in LEMIGAS.

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II. LEMIGAS INVOLVEMENT

LEMIGAS is one of the R&D institutions responsible for oil and gas resouces development in Indonesia, under the Directorate-General of Oil and Gas, Department of Mines and Energy. Its functions include :

- research and development in oil, gas and geothermal resources
- technical services to the industry
- data dan information services.

LEMIGAS activities concentrate on seven major research programs, which include research on the improvement of the oil recovery; These activities are supported by ten upstream laboratories and eleven downstream laboratories (Table 1). At present LEMIGAS has about 1000 employees among which 400 are professionals.

The Reservoir Engineering laboratory was first established in LEMIGAS in 1972, when the exploration activities in Indonesia were at their peak. Conventional, special core and PVT laboratories were set up at that time and services to industry have been increasing ever since. The EOR laboratory was set up in 1985 and has been gradually developed depending on funds available.

In recent years the domestic oil industry has been placing increasing emphasis on enhanced oil recovery, since the cost of finding new oil has been increasing, conditions for the exploration are becoming more severe and discovery large new fields is becoming rare in connection with these situations, LEMIGAS endeavours to support EOR laboratories for the oil industry in Indonesia, which emphasises EOR studies, especially EOR screening and feasibility studies.

The total proven unrecoverable oil in place in Indonesia is estimated at around 40 billion barrels. The majority of this remaining oil cannot be drained with current technology (including EOR), because of unfavorable geological conditions or besause remaining oil is disppersed through out pore spaces in reservoir rocks. But part of those 40 billion barrels is certainly a potential target for EOR, which may substantially contribute to Indonesian oil production.

III. LEMIGAS ACTIVITIES

A. *Preleminary screening studies*

A preliminary screening study covering about 3500 reservoirs was carried out by LEMIGAS jointly with PERTAMINA.

All the data acquired are conserved in the form of a data base installed in LEMIGAS for futher detailed evaluations whenever required.

The following screening guide is set up for such studies, as well as for individual reservoir study :

a. Polymer flooding.
The applicability of polymer flooding is at its best when the water-oil mobility ratio is unfvorable (3-20) which is related to the oil viscosity of 10-100 cp (medium range), or when a significant permeability variation exists in the reservoir.
Implementation of this technique is limited when the reservoirs are limestones/highly calcareous, tempera-ture is high or the field brine is very saline or contains multivalent ions such as boron and iron, or if per-meability is low.

b. Surfactant flooding
The applicability of surfactant flooding is roughly the same as polymer flooding. However, miscellar flood-ing offers a significant interest above polymer flood-ing whenever residual oil is high because of its ability to completely displace contacted oil in the pore space. In association or sequence with a polymer solution, the combined process becomes very afficient as both dis-placement and sweep efficiencies are simultaneously improved.

c. Alkaline flooding
Its applicability is at best when the crude acid index is

high. The limitations of implementing this technique are roughly the same as polymer and surfactant floodings, especially when the divalent ions concentration is high, because of the risks of severe plugging by hydroxide precipitates or extensive consumption of alkaline chemicals.

Caution is exercised before recommending this technique as having potential for particular fields, since the oil recovery is never high, even though alkaline flooding is relatively simple and inexpensive.

d. Miscible gas injections.

This type of displacement works best when flooding downward with very light oil and in fairlya homogeneous and not too permeable reservoirs owing to the importance of density and mobility contrasts between injected gas and the oil.

These techniques are equally suited to flood carbonate and sandstone reservoirs. The main limitations are related to the costs of supply, transportation and compression of injected gas.

e. Thermal Processes.

Steam injection and *in situ* combustion are applied to highly viscous (100 - 10,000 cp), slow flowing oils, in medium deep reservoirs down to 5000 ft. They are applicable in thick, permeable and high oil saturation sandstone as well as limestone reservoirs, but the presence of large amounts of shale may, howeever, be a limiting factor because of possible swelling and heat losses into the shale body.

In addition to the guidance, according to current technological knowledge, several overall limitations are imposed on any type of EOR process:

- fissured, faulted or limited reservoirs wherein the displacing fluid is likely to sweep a negligible part of the seservoir or gross channelling due to high permeability streaks.

- Strong natural water or gas drives may limit the achievement of goog sweep efficiencies because of their affect on strean lines regularity.

B. EOR feasibility studies

Screening guides given previously need complementary studies to determine the most technically and profitable enhanced recovery method matching a given set of field conditions and which may justify pilot demonstration tests. Such studies are carried out in the following successive steps :

1) reservoir data analysis
2) laboratory experiments
3) numerical simulations.

1. Reservoir data analysis

The analysis is carried out to gather as much information as possible concerning the description of the reservoir. These data are collected from geological, petrophysics, PVT, production or reservoir engineering reports.

The following charecteristics are evaluated whenever available :

- reservoir sedimentology and mineralogy
- reservoir continuity
- clay nature and distribution
- reservoir heterogeneity or anisotropy
- natural drive mechanisms
- current oil saturation
- relative permeability curves
- past field performance

A geological model of the reservoir is developed, considering reservoir continuty, areal and vertical distribution of reservoir petrophysical characteristics (in the form of engineering maps such as structure, isopach, isoporosity, isosaturation and isopermeability maps).

These data are needed for the construction of reservoir silmulations to be used later and will help in the choice of the best location for the pilot test as well as the injector producer in the full scale implementation.

Related to the reservoir data analysis LEMIGAS has developed a reservoir data base for about 4000 individual reservoirs in Indonesia, has assisted PERTAMINA developing reservoir data for EOR implementation under Joint Operation Agreement, and conducted more than 100 detailed reservoir studies from which very valuable reservoir data can be derived and conserved for future EOR studies.

2. Laboratory studies

The objective of laboratory studies is to ensure the reliability of the preliminary screening which varies from company to company and depends on the selected process.

Basically LEMIGAS sets up the following procedures;

Preliminary analyses are carried out on the reservoir fluid samples to acquire data on the fluid quality and to assist formulating the methods to be applied.

Analysis on injected water, if water is utilized as the main injection fluid, is also carried out to investigate its comptability with the formation water.

If additives are used in the injection water such as the polymer and/or surfactant, the polymer rheology measurement and surfactant prototype determination are required.Additional analyses measuring the interfacial tension and defining the phase behaviour are required to determine the mixture conditions of the oil and formation water with the injected water. Laboratory analysis is needed to optimize the characteristics, volume and composition of the injection fluids. Experiments are conducted in reservoir conditions using linear or radial geometry along with different slug size and compositions.

Other experiments are carried out to estimate chemical losses (adsorption, retention and reaction) along various injection periods.

In these processes the choice of the right chemicals is the prime objective which implies a specific laboratory program. In the most complex type where surfactants, alcohols and polymer are involved, the selection of chemicals will mainly depend on interfacial, rheological and displacement properties at reservoir temperature.

The screening procedure consists of :

- Comparison of brine-crude-surfactant-alcohols phase relationship by use of pseudo-ternary diagrams.
- Control of polymer solution quality by viscosity measurements and filtrability tests through millepore filters at low rate.
- Tertiary flood tests to compare ability of the previously defined micellar slugs and polymer solutions to displace residual oil in stantardized injection conditions and porous media. Besides the range of recovery efficiencies, oil production cut and pressure losses along core are also measured.

If straight polymer flooding looks as having potential the polymer selection will be based on the previously discussed rheology tests.

In the case of alkaline waterflooding, the laboratory experiments include interfacial measurements, compatibility, wettability alteration and inbibition tests, and tertiary flood displacements.

If gas miscible injection has potential evaluation is required of the gas displacements in reservoir conditions to determine the minimum miscible pressure (MMP) as well as recovery. The gas injected could be either CO2, hydrocarbon gas enriched by intermediate components or LPG or hydrocarbon gas/ inert gas under high pressure conditions. The starting point of the study will then be an investigation of thermodynamical and physical properties of injected gas and crude oil mixtures at reservoir temperature.

The phase behaviour and magnitude of hydrocarbon extraction from crude into injected gas forming a rich phase are used to help fix the miscibility pressure range above which total oil displacement can be achieved.

Further core displacement tests at different pressures will be needed to assess previous results and to display any flow difficulties due to asphaltene precipitation and possible permeability reduction.

In thermal methods, experiments are performed under isothermal conditions to determine the residual oil saturations, as well as under conditions close to adiabatic to study propagations of a thermal method in a porous medium representing a basic volume of reservoir. Very specific laboratory equipment such as isothermal and adiabatic cells are required in both experiments. Apart from the thermal process laboratory which is still in limited conditions LEMIGAS has the following laboratories :

- The Miscible Gas injection laboratory consists of a slim tube rig to determine the MMP and two different types of Gas Miscible core flood rigs (one of them is shown in Figures 2 and 5).
  Experiments have been conducted with various crudes taken from several oil fields in Indonesia to determine:
- MMP of various crudes under different reservoir temperature conditions.
- optimization of CO_2 as well as enriched gas slug sizes followed by displaced water.
- efficiency of CO_2 injection on the life oil (with dissolved gas).
- the effect of HC gas mixture with injected CO_2 on the MMP.
- mechanisms and processes of high pressure lean gas as well as N_2 injection.

The polymer flooding laboratory consists of two different type of polymer core flood rigs (Figures 3, 6, and 7), rheology test equipment with low shear rate measurement. Several commercial polymer products such as those from Cyanamide, Rhone Poulenc and Mitsubishi habe been used with various reservoir fluids to study the rheology behaviour, stability with time and temperature, the plugging properties due to presence of microgels and retention.

The Surfactant flooding laboratory consists of a surfactant core flood rig (Figure 4), retention apparatus and interfacial spinning drop equipment. Commercial Petroleum Sulfonat has been used along with various reservoir fluids taken from several fields in Indonesia to determine the optimized surfactant-co-surfactant solutions, retention, slug size and recovery resulting from the surfactant as well as complex surfactants, alcohols and polymer displacement through tertiary flood tests.

Table 2 shows a complete surfactant-polymer laboratory test program. An example of the EOR tests relationship with other laboratory measurements such as core analysis (integrated laboratory system) is shown in Figure 1. For detailed EOR studies petrographic analyses such as thin sections, scanning electron microscopication exchange capacity and X-ray mineralogy are needed, besides the conventional routine and special core analysis.

3. Numerical simulation

The model developed through laboratory experiments (flood test) mostly has linear geometry. The purpose of such studies is to investigate the displacement phenomena limited to the microscopic level (pore space), and not at the macroscopic level where rock anisotropy and heterogenity become important. To adapt the previous one-dimensional laboratory results to a full scale project, reservoir simulations are needed. For this purpose, based on reservoir data (especially the areal and vertical distribution of reservoir rock), a reservoir simulation with a two or three dimensional model is developed to predict the pilot or full scale performance.

Through this reservoir simulation, sensitivity analysis could also be carried out to investigate the affect of factors influencing the efficiency of the whole process, such as gravity, capillary and dispersion, slug size, and chemical losses. The ultimate objective of reservoir simulation is to provide several alternatives for the injection - production system, from which the technical and economic interests of the project can be evaluated.

Up to now LEMIGAS has conducted more than 30 detailed reservoir simulations related to waterflooding and gas injection as well as EOR processes, among others:

- compositional modeling integrated with PVT (equation of states) model to be used for gas miscible processes studies.

- thermal simulation to be used for optimization of steamflooding development (Duri field).
- black oil reservoir modelling to be used for optimization and monitoring the gas injection / waterflooding of major fields in Indonesia (for instance Minas, Handil, Rama, Khrisna, Arjuna, Walio and Widuri fields).

The software installed in LEMIGAS computer facilities include black oil compositional simulators, simplified EOR process models phase behaviour models supported by a set of reservoir engineering software. The commercial EOR simulators as well as mainframes are accessible through the third parties whenever needed.

IV. CONCLUSIONS

In recent years the domestic oil industry has been placing greater and greater emphasis on EOR. Some of the technologies are already applied in pilot or commercial scale. In order to maintain Indonesian oil production on top of the exploration activities, efforts to increase oil production through EOR implementation have to be encouraged.

In this connection LEMIGAS endeavours to be an institution having EOR laboratories and other facilties to support the oil industry in Indonesia which emphasises EOR studies.

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Table 1. LEMIGAS Laboratories

UPSTREAM LABORATORIES

1. Biostratigraphy
2. Sedimentology
3. Geochemistry
4. Geophysics
5. Conventional and special core analysis
6. Reservoir fluid analysis
7. E O R
8. Drilling mud & cement
9. Mud logging & production
10. Instrumentation/calibration

DOWNSTREAM LABORATORIES

1. Composition, molecular & element analysis
2. General chemistry & environment analysis
3. Bioconversion
4. Separation & catalyst techniques
5. Flow, oxidation & valatility & volatility test
6. Industrial process development
7. Polymer
8. Syntheses and petrochemical products development
9. Fuels
10. Lubricants
11. Automative

Table 2. Laboratory studies program surfactant polymer – flood

I. PRELIMINARY SCREENING LABORATORY - FLUID PROPERTIES

1. Oil characterization
2. Water analytical studies
3. Basic polymer rheology evaluations
4. Microumulsion formulation tests
5. Interfacial tension tests

II. CORE ANALYSIS

1. Combination petrography studies
2. Capilary pressure tests
3. Gas-oil relative permeability tests
4. Water-oil relative permeability and mobility determinations
5. Fresh water sensitivity tests

III. LABORATORY SCREENING

1. Capillary number determinations
2. Polymer injectivity tests
3. Surfactant injectivity tests

IV. PREMINARY PROSESS LABORATORY TESTS

1. Basic polymer core flood tests
2. Polymer shear tests
3. Polymer retention tests
4. Multistep polymer core flood tests

V. ADVANCED PROCESS LABORATORY TESTS

Micellar - polymer recovery tests
Optimization of Miscellar slug design
Optimization of plymer slug size

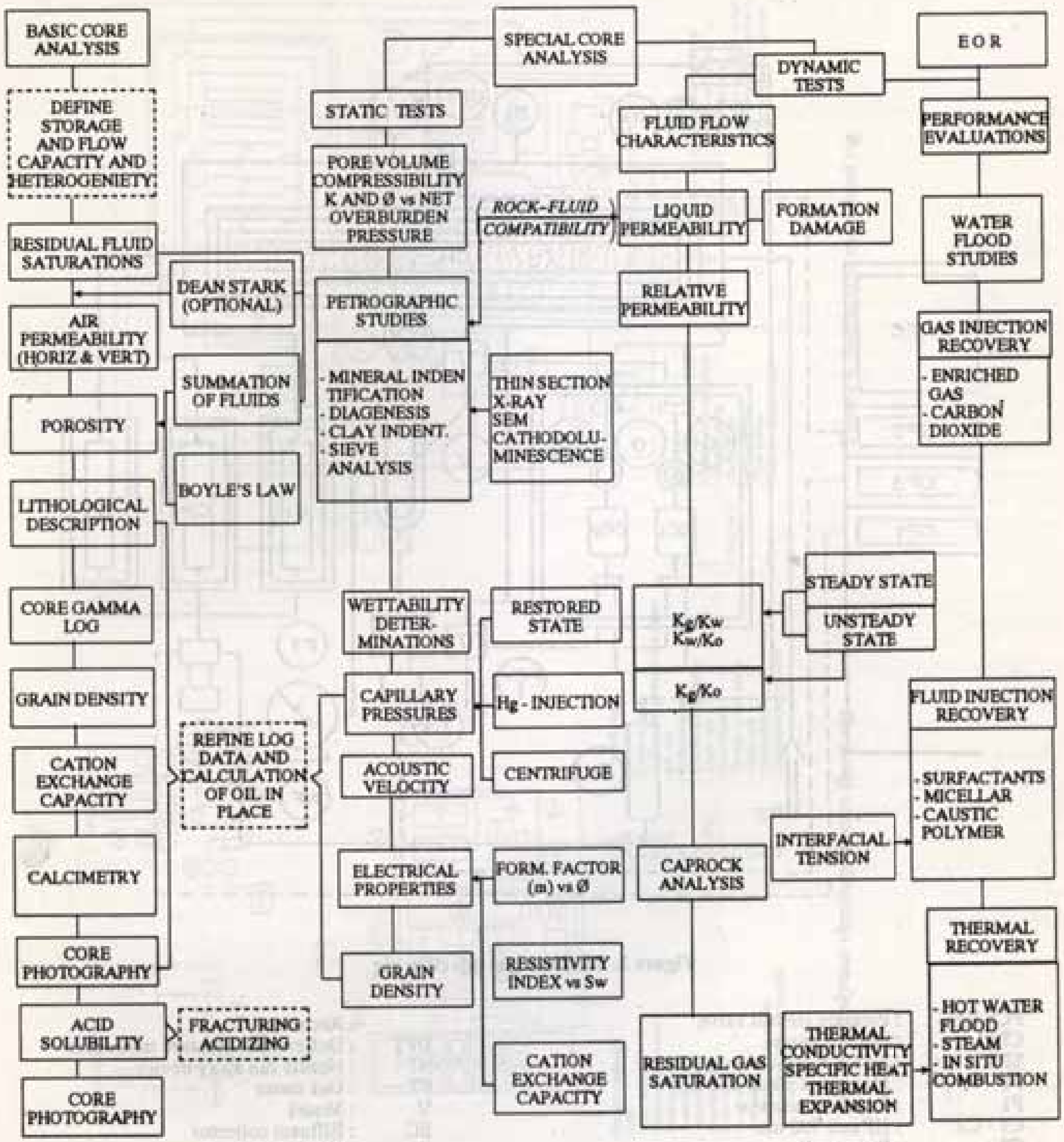

Figure 1. Core analysis – EOR studies relationships

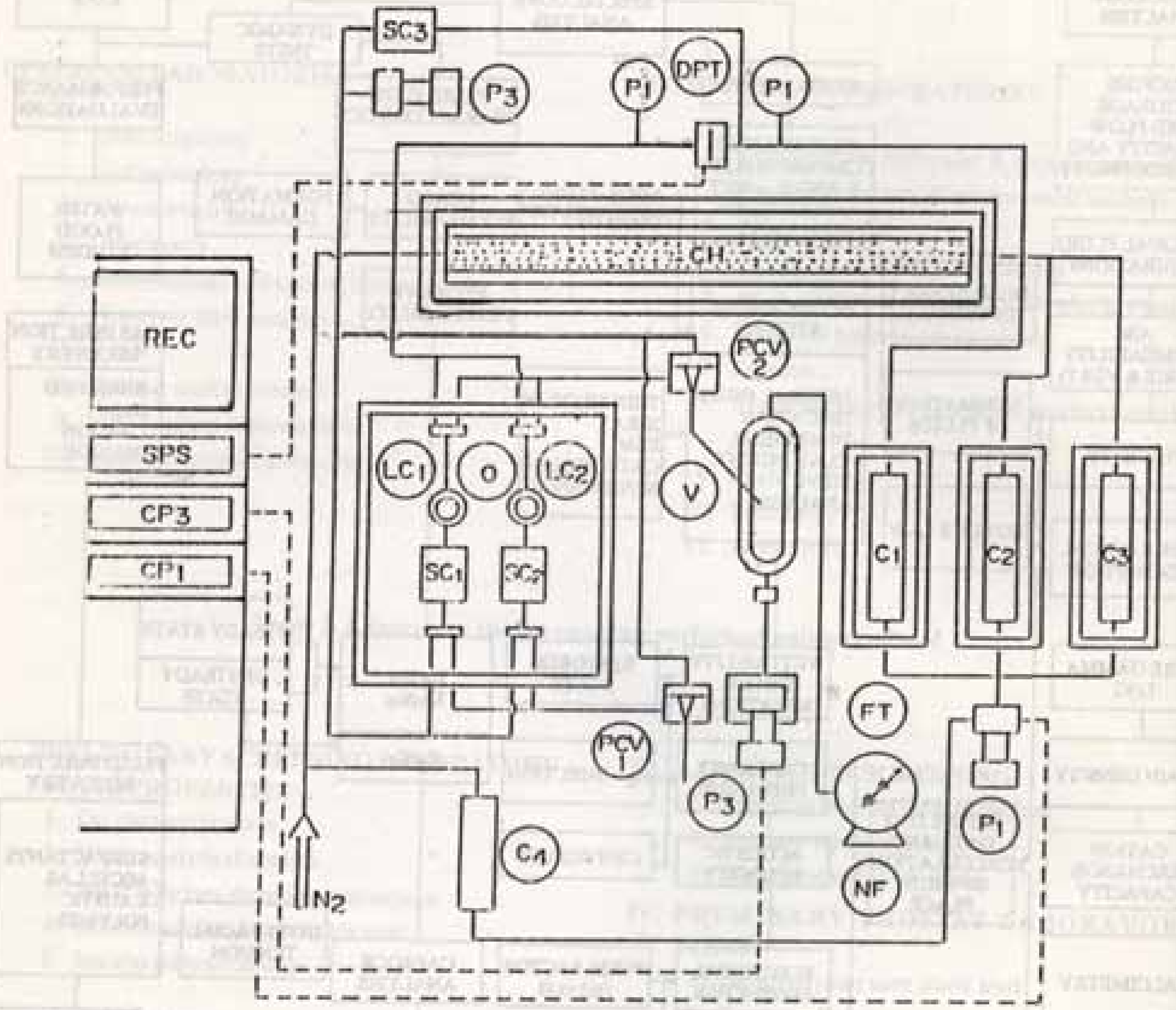

Figure 2. Miscible gas injection rig

PCF REC	: Pressure control valve		: Recorder
CP1	: Control pump	DPT	: Defferential pressure transaucer
SPS	: Stabilized power supply	NF	: Needle run away device
P1	: Motorized pump 600 bars	FT	: Gas meter
P1	: Pressure indicator	V	: Vessel
C1 - C2	: HP cell 700 bar	EC	: Effluent collector
C3	: Piston cell	P2	: Draw off pump
C4	: Core holder	O1 - O2	: Thermostarted cabinet

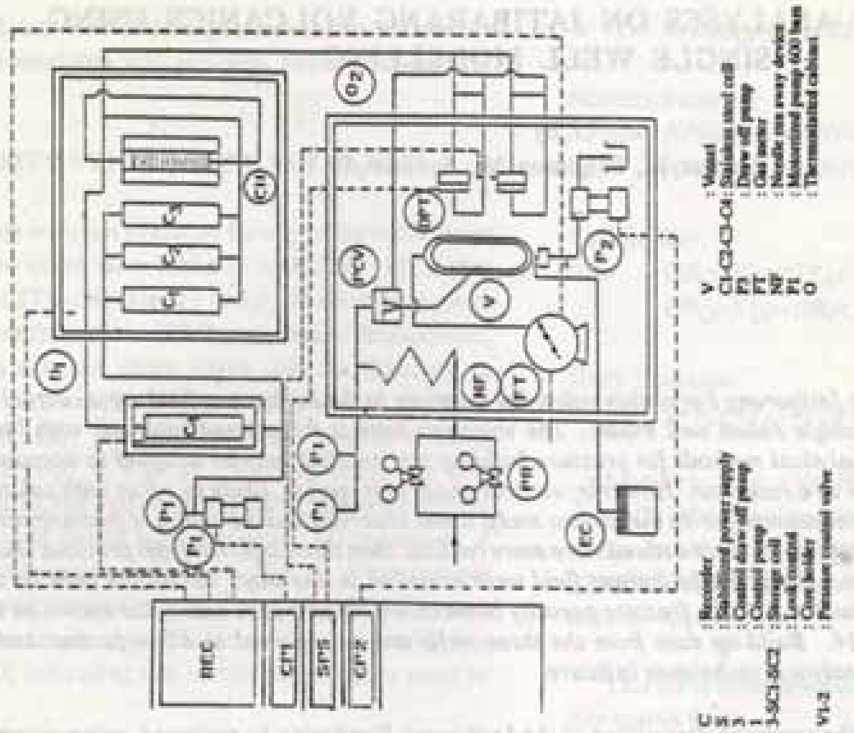

Figure 4. Surfactant core flood rig

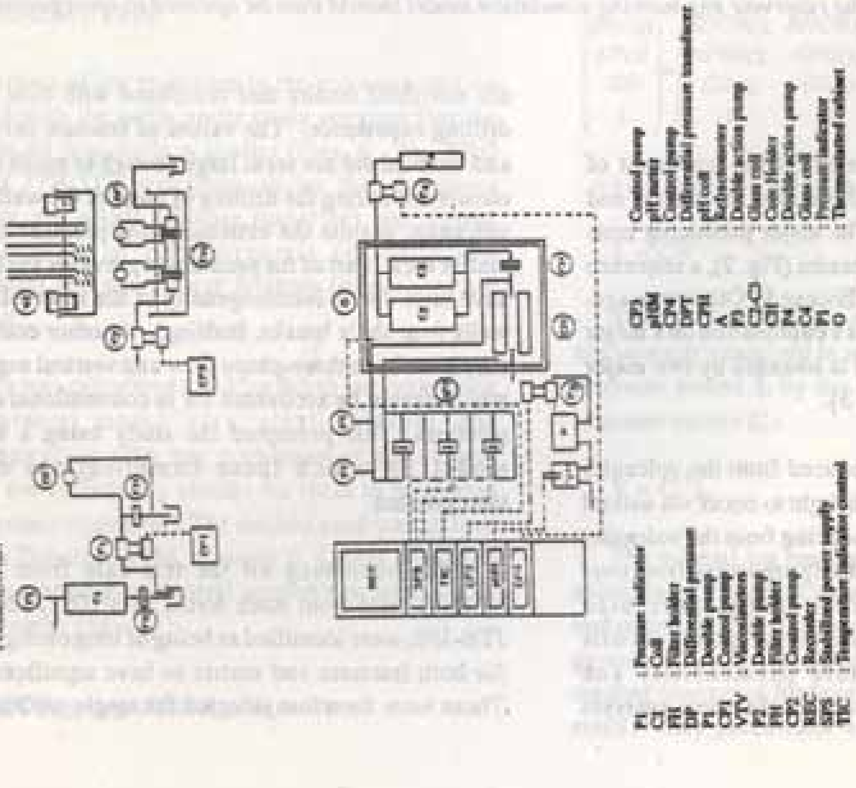

Figure 3. Polymer rheology & core flood rig