# DISCREPANCY OF MCMP DERIVED FROM EXPERIMENTS AND PREDICTION MODELS OF SOME INDONESIAN OIL FIELDS

## PERBEDAAN TTMK DIPEROLEH DARI PERCOBAAN DAN MODEL PERKIRAAN BEBERAPA LAPANGAN MINYAK INDONESIA

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**ABSTRAK**

Sebagian besar lapangan minyak di Indonesia telah dikategorikan sebagai lapangan tua, karena pengurasan tahap primer hampir selesai. Maka dari itu teknologi pengurasan tahap lanjut adalah satu satunya pilihan untuk meremajakan lapangan lapangan tua tersebut untuk menaikan perolehan minyak. Injeksi $CO_2$ terbaur, salah satu teknologi pengurasan tahap lanjut yang terbukti, dapat diaplikasikan di beberapa lapangan minyak di Indonesia yang memenuhi kriteria penyaringan untuk injeksi $CO_2$. Pekerjaan lab awalnya harus dikerjakan untuk menentukan beberapa parameters yang akan digunakan kalibrasi program reservoar simulasi. Parameter terpenting adalah TTMK (tekanan terbaur multi kontak), tekanan ini dapat digunakan untuk menentukan efisiensi pendesakan injeksi $CO_2$. Diatas TTMK akan lebih effisien dibandingkan dengan dibawah TTMK. TTMK yang normalnya dapat ditentukan di laboratorium dengan alat Slim tube. Apabila contoh minyak dan gas tidak tersedia, beberapa korelasi yang didasarkan data empiris lapangan juga tersedia didaftar pustaka dan persamaan keadaan untuk memprediksi TTMK. Beberapa fluida reservoar telah dievaluasi tekanan terbaur multi kontak dengan ketiga metoda diatas. Kemudian, perbedaan dihitung untuk membandingkan hasil dari uji Slimtube, korelasi dan persamaan keadaan. Empat korelasi seperti NPC (National Petroleum Council), Cronquist et al, Yellig-Metcalfe, Holm-Yosendal dan satu persamaan keadaan Peng-Robinson (1978) telah dikerjakan untuk memprediksi TTMK dari 14 reservoar. Seterusnya, TTMK ini juga ditentukan dengan uji Slimtube. Korelasi Holm-Yosendal mempunyai 9 reservoar dan kedua Yellig-Metcalfe mempunyai enam reservoar dengan perbedaan dibawah 10% terhadap hasil uji Slim tube. Sementara metoda yang lain kurang cocok juga model persamaan keadaan Peng-Robinson tanpa adanya kalibrasi dengan data lab.

**Kata Kunci:** Injeksi $CO_2$, Tekanan Terbaur Multi Kontak, Persamaan Keadaaan

***ABSTRACT***

*Most of oil fields in Indonesian have been categorized as mature fields, since the primary stages of the oil production nearly finished. Therefore EOR technology is the only option to rejuvenate those old oil fields to increase the oil recovery. $CO_2$ miscible flooding, one of the proven EOR technology, can be implemented in some Indonesia oil fields if they fulfill the screening criteria for $CO_2$ injection. Laboratory works initially should be carried out to determine some parameters for calibrating the reservoir simulation program. The most important parameter is MCMP (multiple contact miscibility pressure), this pressure level can be used to determine the displacement efficiency of the CO2 injection. Above the MCMP will be more efficient compare to below MCMP injection pressure. MCMP is normally can be obtained in the lab by a Slim tube apparatus. In case there are no oil and gas sample available, some correlations based on the empirical field data are also available in the literature as well as EOS (equation of state) for predicting MCMP. Some reservoir fluids MCMP have been evaluated using those three methods. Then, discrepancies were calculated* *to compare the results of Slim tube tests, correlations and EOS calculation. Four correlations such as NPC (National Petroleum Council), Cronquist et al, Yellig-Metcalfe, Holm-Yosendal and one EOS modeling of Peng-Robinson (1978) have been proposed to predict the MCMP fourteen reservoirs. Moreover, those MCMP were also run using Slim tube. Holm-Yosendal correlation has nine reservoirs and secondly Yellig-Metcalfe method possesses six reservoirs with discrepancy below 10% compare to MCMP obtained from Slim Tube tests. While the other methods are not appropriate as well as Peng-Robinson EOS modeling without any laboratory data for calibration.*

*Key words: $CO_2$ Injection, MMCP (Multiple Contac Miscibility Pressure), EOS (Equation of State)*

## I. INTRODUCTION

$CO_2$ injection is a proven EOR technology which has been implemented to improve oil recovery in many oil fields in the world. Sugihardjo et.al. (2013) conducted preliminary screening of $CO_2$ injection in South Sumatera Basin, there were almost 77 fields suitable for $CO_2$ injection with miscible displacement scenarios. While $CO_2$ is available very abundant in South Sumatera region as gas emissions from oil and gas refineries and also burning coal of power generations that have been released into the atmosphere at this time.

$CO_2$ flooding mechanisms include miscible and immiscible processes. The process is called miscible if the $CO_2$ dissolve in the oil, in one hand, which can decrease its viscosity, density, and residual oil saturation, but in the other hand, improve its mobility. Meanwhile, the process will be called immiscible when the $CO_2$ function is only to push the oil bank from a specific well to the existing producing wells. The basic behavior of $CO_2$ gas is capable to develop multi-contact miscibility with reservoir fluids, then, improving the fluid properties. The displacement efficiency of oil by $CO_2$ is highly pressure dependant, above the miscible pressure the displacement is very efficient. Key factor that effect $CO_2$, therefore, flooding include the reservoir temperature, oil characteristics, and reservoir pressure.

The miscibility of $CO_2$ into oil is achieving by dynamic processes or multi contacts miscibility, where these process are called vaporizing gas drive. Figure 1 is the schematic of vaporizing gas drive, and Figure 2 is ternary diagram. Consider first $C0_2$ is injected into the reservoir oil, the first contact $C0_2$ evaporates the intermediate-molecular-weight hydrocarbon of oil and enriching gas composition. When gas moves deeply into the reservoir and makes further contact with fresh reservoir oil, the composition of gas at displacing front is altered and enriched progressively, this process is repeatedly during displacement, until reaching the miscibility. During the miscibility processes, the fluid composition, density, and viscosity change continuously. The fluid properties and transition phase behavior influence the effectiveness and the efficiency of the displacement of oil by $C0_2$. The MCMP generally can be determined using one of

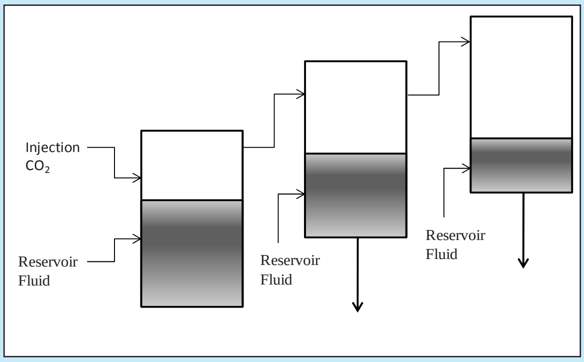


**Figure 1**
**Schematic of Vaporizing Gas Drive**

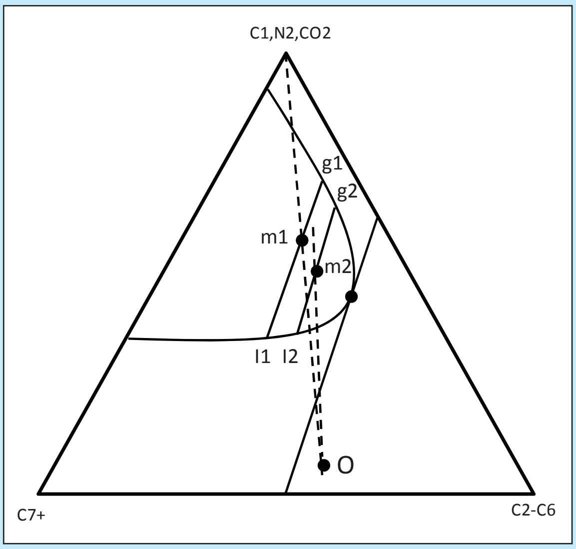


**Figure 2**
**Ternary Diagram of Vaporizing Gas Drive**

the three methods, namely: correlations, equation of state, and experiment.

Empirical correlation have been reported by several researchers (Rocha, et al.). These include correlation of Yellig and Metcalfe (1980), Holm and Yosendal (1974), National Petroleum Council (1976), and Cronquist et.al., (Johnson et al. 1981). These correlation represents relationship between certain variables to the MCMP, such as temperature, molecular weight of $C_5$+, and API gravity. Thus, the conclusion is that the correlation should be used carefully, due to each of the correlation has different variables, therefore it will give different result between the correlations. Users must choose the correlation which has oil compositions nearly similar to the oil used in the correlations.

Equation of state (EOS) can also be used to calculate MCMP of $CO_2$ injection. So far the development of equation of state has been modified from originally Van Der Waals formulation by SRK (Soave-Redlich-Kwong) and Peng-Robinson. Normally the value MCMP generated from laboratory experiment is used to validate EOS modeling. However, if there are not available MCMP from lab, EOR modeling is used to determine MCMP and need to adjust the properties of $C_{7+}$ component. In practice, the fluid model after tuning does not always give good prediction for all properties (Dzulkarnain et al. 2011). If there are no available data for validation, MCMP will be calculated using EOS base on composition data only. But there is no way to be sure whether or not a give EOS characteristic is predicting the aspect of oil-injection gas phase behaviour adequately or not (Stalkup, et al. 2005).

There are two types of experiments to determine MCMP which are Risng Bubble Apparatus (RBA) and Slimtube. The first apparatus is very simple and quick to analyze MCMP of $CO_2$ injection into a reservoir oil compare to Slimtube experiments. Figure 3 Shows schematic of the Rising Bubble Apparatus. $CO_2$ is injected by syringe at the bottom into the glass fully with oil at specific pressure. It moves upward slowly.

MCMP is inferred from the pressure dependence of the behavior of the rising bubbles. Bubble behavior varies significantly over a range of pressures. As the pressure approaches MMP, a bubble still remains nearly spherical on top, but the bottom interface of the bubble changes from spherical to flat and at or slightly above MMP, tail-like features quickly develop on the bottom of a rising bubble, which remains spherical on top. Then, starting at the bottom of the bubble, the gas/oil interface vanishes, and the contents of the bubble rapidly disperse in the oil. This work can be done within one hour and the development of miscibility between a gas bubble and an oil can be observed visually (Christiansen, et al. 1987). The results of MCMP from RBA are actually comparable to the results from Slim-Tube tests (Elsharkawy et al. 1992). However, it absolutely depends on the visual interpretation to find the right MCMP values.

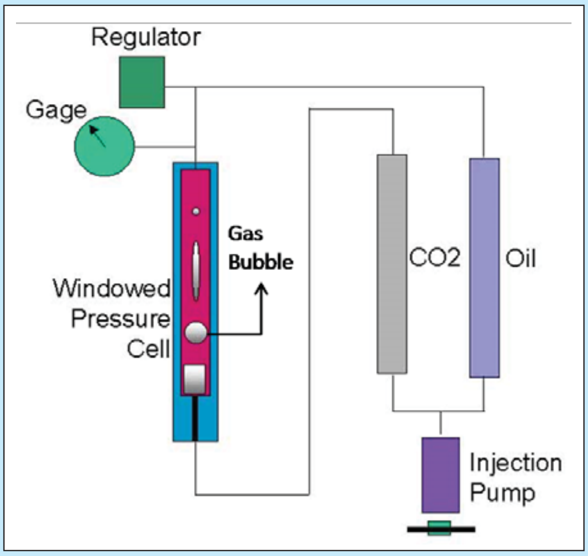


**Figure 3**
**Schematic of RBA**

The best option to determine MCMP is Slimtube tests in case there is enough reservoir oil sample and budget available. It normally is used as standard industries due to the MCMP determined by optimum recovery factor. This tube was packed with unconsolidated 200-240 mesh quartz sands, which has very good sorted, rounded, and grain size similarity. Figure-3 shows the schematic picture of the equipment, the coiled tube has properties as followed: 6.39 mm ID, 1890 cm long, 25.7% porosity, 156 cc pore volume, and 15.803 Darcy gas permeability. see Figure 4.

Before running reservoir simulation step prior to field implementation, some lab data should be generated several important parameter that basically can be used to calibrate the simulation study. MCMP

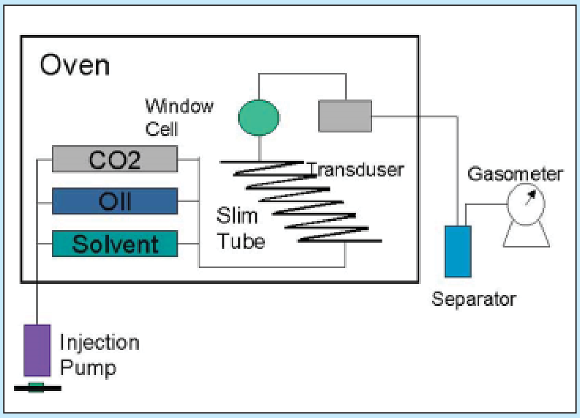


**Figure 4**
**Schematic of Slim Tube Apparatus**

is the key parameter to design $CO_2$ injection pressure. If the MCMP is above the initial reservoir pressure and reservoir fracture pressure, then miscible displacement cannot be achieved. The rule is that the $CO_2$ injection pressure must be below the reservoir fracture pressure.

For the purpose of the study eleven reservoir oils have been sampled and sent to EOR laboratory for MCMP determination. Beside that 3 experiments which had been done by Husodo (1984) for his thesis has been added to this essay. Then the results were compared to the correlations and EOS modeling. Trial has been made to compare the value of MCMP resulted from laboratory experiment with the predicted using correlations and EOS model. The discrepancy among MCMP values and the experimental data will be used as a guidance in case there are no fluid sample for laboratory experiment which models or correlations have smallest discrepancies.

## II. METHODOLOGY

Methodology applied to this study consists of several steps consecutively. Those are as follows:

- Fluid sampling
- Reservoir data collection
- Compositional analysis
- MCMP determination by correlation methods
- MCMP determination using EOS modeling
- Determine MCMP by laboratory experiments

### A. Fluid Sampling

Fluid sampling was done to collect reservoir fluid that can represent the reservoir fluid properties properly. Normally reservoir fluids are taken at well down hole which is called bottom hole fluid sample (BHS) and it can also be sampled at the separator test. If the bubble point pressure (saturation pressure) is still below the current reservoir pressure, BHS is suggested to be carried out soon. However if the current reservoir pressure is below the saturation pressure therefore sampling at separator test is adequate to catch oil and gas at certain separator condition (P and T). Furthermore, recombined reservoir fluid is necessary to produce representative reservoir oil based on adjusted GOR (gas oil ratio) in which the saturation pressure is similar to the current reservoir pressure.

### B. Reservoir Data Collection

Some data should be collected during reservoir fluid sampling. At sampling time the pressure and temperature of the separator test must be written down accurately, then gas and oil rate, API gravity, and also GOR. Those data were acquired after almost one day production tests and the samples taken after production rate and GOR almost constant. Additional data taken in the office well files includes current reservoir pressure, temperature, and fracture reservoir pressure if available.

### C. Compositional Analysis

Basically fluid sample from separator test or BHS are analyzed for their components and molecular composition using gas and liquid chromatography. For BHS the result of chromatography analysis directly determine well stream composition as represent the reservoir fluid composition, on the other hand for separator fluid samples that consist of oil and gas it is necessary to be recombined based on GOR, and current reservoir pressure data to generate well stream composition.

### D. MCMP Determination By Correlation Methods

Only four different correlation methods have been applied to this study available in the literatures, those are National Petroleum Council (NPD), Cronquist Et Al., Yellig-Metcalfe, and Holm-Josendal. NPD correlation method only need data input of reservoir temperature and API gravity to determine miscibility pressure of $CO_2$ injection into oil. While data needed for Cronquist Et Al correlation are reservoir temperature and molecular weight of $C_{5+}$. The equation can be written down as follow:

$MMP = 15.988\ T^n$

n : $0.744206+0.0011038\ MWC_{5+}+0.0015279MFC$

MMP : Minimum Miscibility Pressure

T : Reservoir Temperature $^oF$

MFC: Molecular fraction of light components ($C_1$ and $N_2$)

Yellig-Metcalfe correlation method base on the data input of reservoir temperature only, and the correlation is formulated in the equation form below:

$MMP = 1833.7171+2.2518055T+0.01800674T^2-103949.93/T$

Yellig-Metcalfe pointed out that, if the bubble point pressure of the oil is greater than the predicted MMP, then the $CO_2$ MMP is set equal to the bubble-point pressure.

The last correlation is Holm-Josendal. This correlation have a form of monograph that correlate between temperature at the horizontal axis and MMP at the vertical axis while several chart of molecular weight of $C_{5+}$ from approximately 180 to 340 inside in which from 260 to 340 were added by Mungan. If the input data falls in the outside of the chart then interpolation and extrapolation have been generated to get the MMP prediction number.

**E. MCMP Determination Using EOS Modeling**

EOS modeling applied in this study is only Peng-Robinson model (1978). This EOS can be written as follow:

$$P = \frac{RT}{v-bi} - \frac{ai(T)}{v(v+bi)+bi(v-bi)}$$

Where P is the pressure, R is the gas constant, T is the temperature, a and b are respectively the energy parameter and the covolume, v is the molar volume (Jaubert et.al., 2013).

Most of EOS used today are semi-empirical, because they are fitted to the available experimental data generated prior to be use in the modeling for simulation study. However, in this study MCMP was determined using a software where the input data were only composition of well streams and no other data for calibration.

**F. Determine MCMP by laboratory experiments**

MCMP was run by Slimtube apparatus. The detail of the apparatus has been explained very detail in the introduction. The step of the experiment using a Slimtube is as follows:

Slimtube initially was saturated with oil at a specific pressure level and reservoir temperature. Then, $C0_2$ was injected at the initial pressure which normally approaches the correlation MCMP values to displace the oil, while rate was maintained at 3 cc/minutes. The displacement was stopped after injection of 1.2 pore volume of $CO_2$. The liquid and gas effluent were collected, and cumulative production at gas breakthrough, and 1.2 pore volume displacement were investigated. This experiment was repeated at 6 different pressure levels, and then plot the $CO_2$ injection volume vs. recovery factor of oil. MCMP is determined as the pressure level, at which the cumulative oil production at 1.2 pore volume of $CO_2$ displacement becomes relatively constant despite of increasing pressure.

## III. RESULTS AND DISCUSSIONS

**A. Fluid Sampling**

Fluid have been collected from several oil field locations in Indonesia such as: South Sumatera, West Jawa, Central Jawa, and East Kalimantan. Even though these data could not represent Indonesian oil characteristics but they can be considered as value added for references to the others Indonesian oil field which have almost similar reservoir properties with these properties used in this experiment for MCMP prediction.

Table 1 is the sample types and oil field locations. Most of the samples were taken from separator test and therefore consist of oil and gas, and then those were recombined to represent the reservoir oil at the current reservoir pressure. Actually the best representative for reservoir oil should be taken at bottom hole of the well, this normally is carried out at the beginning of field starting production. However, it needs more effort to collect the sample. For the field have been produced for some time and the reservoir pressure has declined below the saturation pressure, sampling at a surface separator is also recommended. GOR data is very important to generate representative reservoir oil samples.

**B. Reservoir Data Collection**

Some reservoir data have been collected including API gravity, saturation pressure (Pb), reservoir temperature (Tres), reservoir pressure (Pres), and current Pres. Those data have used for input data for

MCMP prediction and also for calibrate the MCMP such as saturation pressure and current reservoir pressure. If MCMP is above the saturation pressure, therefore the saturation pressure will assumed as the MCMP. Table 2 is the reservoir data.

If another laboratory experimental data such as PVT data is available and also collected during the course of sampling time. Those will be used as calibration parameters for running EOS modeling. However, in this study there are no additional data

**Table 1**
**Sample Type and Oil Field Location**

| Location | Reservoir Name | GOR (SCF/STB) | Sample Taken | Sample Type |
|---|---|---|---|---|
| South Sumatra | Resv-A | 77 | Separator Test | Recombination |
| South Sumatra | Resv-B | 501 | Separator Test | Recombination |
| South Sumatra | Resv-C | 218 | Separator Test | Recombination |
| Kawengan | Resv-K | 0 | Tank | Dead Oil* |
| Kawengan | Resv-L | 0 | Tank | Dead Oil* |
| East Kalimantan | Resv-P | 368 | Separator Test | Recombination |
| East Kalimantan | Resv-Q | 792 | Separator Test | Recombination |
| East Kalimantan | Resv-R | 196 | Separator Test | Recombination |
| East Kalimantan | Resv-S | NA | Separator Test | Live Oil* |
| West Java | Resv-V | 136 | Separator Test | Recombination |
| West Java | Resv-W | 63 | Separator Test | Recombination |
| West Java | Resv-X | 59 | Separator Test | Recombination |
| West Java | Resv-Y | NA | Separator Test | Recombination |
| West Java | Resv-Z | 447 | Separator Test | Recombination |

* Husodo, 1984

**Table 2**
**Reservoir Data**

| Reservoir Name | Gravity $^{o}$API | Pb Psig | Tres $^{o}$F | Pres Psig | Pres current Psig |
|---|---|---|---|---|---|
| Resv-A | 33.0 | 290 | 230 | 2361 | 290 |
| Resv-B | 35.4 | 1860 | 234 | 2767 | 2623 |
| Resv-C | 38.0 | 973 | 202 | 1200 | 973 |
| Resv-K | 32.9 | 0 | 131 | 1044 | 116 |
| Resv-L | 32.9 | 0 | 185 | 1044 | 116 |
| Resv-P | 42.8 | 835 | 167 | 1863 | 1398 |
| Resv-Q | 44.6 | 1721 | 170 | 1929 | 1398 |
| Resv-R | 35.4 | 845 | 195 | 1779 | 845 |
| Resv-S | 31.2 | 2915 | 212 | 3132 | 2393 |
| Resv-V | 38.5 | 454 | 186 | NA | 454 |
| Resv-W | 38.3 | 410 | 201 | 1706 | 410 |
| Resv-X | 39.5 | 317 | 192 | 1800 | 317 |
| Resv-Y | 39.0 | NA | 247 | NA | NA |
| Resv-Z | 39.0 | 1240 | 214 | 1612 | 1240 |

for calibration. It is suggested to run complete PVT data for calibration EOS modeling.

## C. *Compositional analysis*

Compositional analyses to determine mole percent of the constituent components have been done for gas and sample separator samples as well as the well stream or recombination compositions. But in this study only well stream composition are presented up to Pentane plus and together with the molecular weight of Pentane Plus (see Table 3 for the composition). Normally composition determination is performed from $C_1$ to $C_{7+}$ as well as the impurities $N_2$, $H_2S$, and $CO_2$ components. Critical value is that to determine the molecular weight of $C_{7+}$. In running PVT or EOS modeling normally this is subjected to be adjusted to get the appropriate model. It means the model having properties close to the calibration data. Most of the compositional data of the reservoir oil comprise very high content of C5+ and only two with less content indicated more light oil.

## D. MCMP Determination By Correlation Methods

Four correlations have run to determine MCMP for the reservoirs. Those are National Petroleum Council (NPD), Cronquist Et Al., Yellig-Metcalfe, and Holm-Josendal. The results- are presented in Table 4. The value spread out form 1550 psig to 4000 psig indicate that some correlations are not appropriate for predicting $CO_2$ injection MCMP for these reservoirs. all of MCMP of NPD correlation are far from experimental values while some of MCMP from Cronquist Et Al., correlation close to the experiment, then follow by Yellig-Metcalfe, and Holm-Josendal. The Monographs of Yellig-Metcalfe, and Holm-Josendal are more detail and more data used to derive equations compare to those the first two correlation.

## E. MCMP Determination Using EOS Modeling

To run EOS modeling software to predict $CO_2$ injection MCMP the input data were only fluid composition, molecular weight of $C_{7+}$, and reservoir temperature. Then the model was also calibrate with saturation pressure of the fluid at reservoir temperature. The results also can be seen in Table 4. Again without any experimental data for calibration the results were not satisfied, and far from the experimental results. It is suggested to generate complete PVT data in order to fine tune the model to fit experimental data closely. Since prediction of $CO_2$ injection MCMP depends on the EOS model, variation in the models will results in different in the MCMP value (Dzulkarnain, 2011).

## F. Determine MCMP by Laboratory Experiments

Experiment for MCMP determination has been run using a Slimtube apparatus, the detail apparatus and experimental procedures has been written down in earlier paragraphs. Eleven experiments have been performed while additional 3 experiments were quoted from Husodo 1984. The result of the experiments is exhibited at Figure 5. Each experiment has several points of oil recovery factor of different injection pressure levels. The deflection point of the line connected those points of each experiment is point out the MCMP value. Table 4 also presents the $CO_2$ injection MCMP of all experiments.

The best MCMP is derived from laboratory experiments using a slim tube apparatus. If opportunity to collect fluid from fields is available it is suggested to carry out an experimental MCMP determination. Furthermore the MCMP data from experiment must be then utilized to calibrate the EOS modeling for running a reservoir simulation study.

## G. Discrepancy

MCMP is multiple contact miscibility pressure at which pressure a single phase miscibility has been achieved by multi contact of injected $CO_2$ into hydrocarbon fluid. Pursuing MCMP is essential at $CO_2$ gas injection to reduce the interfacial tension between displacing and displaced fluid in the reservoir, and in turn reducing capillary forces. At

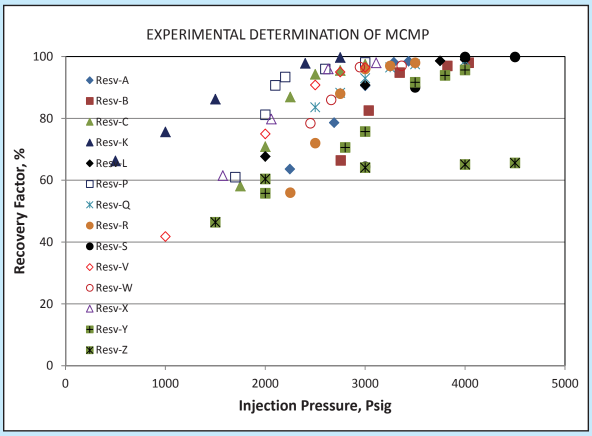


**Figure 5**
**$CO_2$ Injection MCMP of Slimtube Experiments**

**Table 3**
**Well Steam Composition and Molecular Weight of Pentane Plus**

| Component | | Resv-A | Resv-B | Resv-C | Resv-K | Resv-L | Resv-P | Resv-Q | Resv-R | Resv-S | Resv-V | Resv-W | Resv-X | Resv-Y | Resv-Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hydrogen Sulfide | $H_2S$ | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Carbon Dioxide | $CO_2$ | 0.32 | 3.51 | 0.07 | 0.11 | 0.11 | 0.77 | 0.89 | 1.85 | 6.27 | 2.71 | 2.59 | 0.53 | 0.00 | 11.67 |
| Nitrogen | $N_2$ | 0.02 | 0.29 | 0.52 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.02 | 0.33 | 0.25 | 0.41 | 0.00 | 0.61 |
| Methane | $C_1$ | 5.39 | 31.30 | 17.52 | 0.32 | 0.32 | 17.26 | 20.28 | 4.12 | 32.65 | 7.44 | 4.88 | 4.70 | 0.00 | 10.12 |
| Ethane | $C_2$ | 1.25 | 3.74 | 1.85 | 0.17 | 0.17 | 3.30 | 4.38 | 1.18 | 3.61 | 0.92 | 0.53 | 0.52 | 0.00 | 1.08 |
| Propane | $C_3$ | 3.86 | 5.45 | 3.39 | 0.82 | 0.82 | 4.82 | 7.08 | 2.85 | 2.22 | 1.42 | 0.90 | 1.68 | 0.03 | 1.65 |
| Iso-Butane | $i\text{-}C_4$ | 1.19 | 1.62 | 1.22 | 0.57 | 0.57 | 1.96 | 3.06 | 1.49 | 0.60 | 0.46 | 0.37 | 0.75 | 0.15 | 0.98 |
| n-Butane | $n\text{-}C_4$ | 1.78 | 2.43 | 2.20 | 1.04 | 1.04 | 2.77 | 4.55 | 2.79 | 0.89 | 0.80 | 0.66 | 1.77 | 0.29 | 1.42 |
| Pentane Plus | $C_{5+}$ | 86.19 | 51.65 | 73.23 | 96.97 | 96.97 | 69.11 | 59.75 | 85.72 | 53.74 | 85.92 | 89.83 | 89.64 | 99.52 | 72.47 |
| **Total** | | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 | 100.00 |
| Properties of Pentane Plus: | | | | | | | | | | | | | | | |
| Molecular Weight: | | 194.82 | 244.67 | 153.11 | 256 | 256 | 162.6709 | 145. 5 | 254.38 | 243 | 185.95 | 163.63 | 153.99 | 187.31 | 178.16 |

**Table 4**
**MCMP Resulted From Correlations, EOS Modeling, and Experiments**

| Correlation | Resv-A | Resv-B | Resv-C | Resv-K | Resv-L | Resv-P | Resv-Q | Resv-R | Resv-S | Resv-V | Resv-W | Resv-X | Resv-Y | Resv-Z |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| National Petroleum Council | 1700 | 1700 | 1700 | 1500 | 1550 | 1550 | 1550 | 1550 | 1700 | 1550 | 1700 | 1550 | 1700 | 1700 |
| Cronquist Et All. | 2494 | 2494 | 2312 | 2392 | 3409 | 2070 | 1750 | 2158 | 4757 | 2682 | 2301 | 2159 | 2481 | 2722 |
| Yellig and Metcalfe | 2930 | 2930 | 2508 | 1644 | 2305 | 2080 | 2114 | 2424 | 2630 | 2316 | 2490 | 2400 | 3068 | 2654 |
| Holm-Josendal | 3230 | 3230 | 2620 | 2150 | 3700 | 2400 | 2350 | 2650 | 4000 | 2670 | 2750 | 2538 | 3100 | 2950 |
| KOS-Calibration Pb | 2070 | 2105 | 1978 | 1360 | 1855 | 1300 | 1720 | 1893 | 2065 | 1923 | 1998 | 1923 | 2133 | 2050 |
| Experiment | 3180 | 3200 | 2420 | 1815 | 3410 | 2150 | 3150 | 2800 | 3665 | 2575 | 2800 | 2495 | 3500 | UO* |

UO : Unobseved

**Table 5**
**Discrepancy Among the MCMP Determination Methods**

| Reservoir | NPC | | Cronquist Et. Al. | | Yellig-Metcalfe | | Holm-Josendal | | EOS | | Experiment |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MCMP | Disc. % | MCMP | Disc. % | MCMP | Disc. % | MCMP | Disc. % | MCMP | Disc. % | MCMP |
| Resv-A | 1700 | 46.54 | 2494 | 21.57 | 2930 | 7.86 | 3230 | 1.57 | 2070 | 35 | 3180 |
| Resv-B | 1700 | 46.88 | 2494 | 22.07 | 2930 | 8.43 | 3230 | 0.94 | 2105 | 34 | 3200 |
| Resv-C | 1700 | 29.75 | 2312 | 4.46 | 2508 | -3.64 | 2620 | 8.26 | 1978 | 18 | 2420 |
| Resv-K | 1500 | 17.36 | 2392 | -31.76 | 1644 | 9.41 | 2150 | 18.46 | 1360 | 25 | 1815 |
| Resv-L | 1550 | 54.55 | 3409 | 0.03 | 2305 | 32.41 | 3700 | 8.50 | 1855 | 46 | 3410 |
| Resv-P | 1550 | 27.91 | 2070 | 3.72 | 2080 | 3.26 | 2400 | 11.63 | 1300 | 40 | 2150 |
| Resv-Q | 1550 | 50.79 | 1750 | 44.44 | 2114 | 32.89 | 2350 | -25.40 | 1720 | 45 | 3150 |
| Resv-R | 1550 | 44.64 | 2158 | 22.93 | 2424 | 13.41 | 2650 | -5.36 | 1893 | 32 | 2800 |
| Resv-S | 1700 | 53.62 | 4757 | -29.78 | 2630 | 28.24 | 4000 | 9.14 | 2065 | 44 | 3665 |
| Resv-V | 1550 | 39.81 | 2682 | -4.16 | 2316 | 10.06 | 2670 | 3.69 | 1923 | 25 | 2575 |
| Resv-W | 1700 | 39.29 | 2301 | 17.82 | 2490 | 11.07 | 2750 | -1.79 | 1998 | 29 | 2800 |
| Resv-X | 1550 | 37.88 | 2159 | 13.47 | 2400 | 3.81 | 2538 | 1.72 | 1923 | 23 | 2495 |
| Resv-Y | 1700 | 51.43 | 2481 | 29.12 | 3068 | 12.35 | 3100 | -11.43 | 2133 | 39 | 3500 |
| Resv-Z | 1700 | - | 2722 | - | 2654 | | 2950 | - | 2050 | - | UO |

this condition normally both fluids, injecting and displaced fluids, flow as a form of one phase and promoting displacement efficiency improvement. Otherwise injection of $CO_2$ will be below MCMP which leads to early gas breakthrough reducing displacement efficiency, and also resulting a very low oil recovery.

MCMP can be determined by 3 methods such as laboratory experiments, approaching by empirical correlations, and last analytical EOS modeling. To compare the results of three approaches in order to know the discrepancy of the last two methods from the experimental displacements has been exhibited in Table-5. To do comparison based on experimental data, 10% discrepancy has been considered suitable. Moreover, NPC's method is generated very bad MCMP, Cronquist Et Al. only has 4 MCMP fulfill the criteria from 13 reservoirs or about 31%, Yellig-Metcalfe has got 46%, while Holm-Josendal has 69%.

## IV. CONCLUSIONS AND SUGGESTION

The best method for determining MCMP is laboratory experiment using a slim tube. If fluid samples are not available therefore they can be approached by correlations and EOS modelings. Four correlations have been tried to determine MCMP. The best correlation is Holm-Josendal method with 69% of reservoir numbers within 10% discrepancy compare to the Slim tube results, Yellig-Metcalfe 46%, while the other two i.e. NPC and Cronquist Et. Al. methods are not suggested to be use due to very high discrepancy. Furthermore EOS modeling stand alone could not be used to predict MCMP without any experimental data for calibration and validation.

The high discrepancies are basically caused by the empirical data are not enough cover a wide range of the parameter used in the correlation such as: temperature, oil API gravity, and reservoir temperatures. Holm-Josendal has more detail parameters including MW of $C_{5+}$. While EOS modeling is normally used to generate fluid modeling for reservoir simulation study after calibrating with fluid laboratory data, without any calibration the results will be inaccurate. It is suggested that MCMP determination should be carried in the laboratory by a slim tube displacement experiment using live oil to find correct numbers.Table 3 Well Steam Composition and Molecular Weight of Pentane Plus.

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