Th CO2 09

# Huff-n-Puff Test For Minimum Miscibility Pressure Determination For Heavy Oil

E. Shilov[1]*, A. Cheremisin[1]
[1]Skolkovo Institute of Science and Technology

## Summary

This paper presents problems correlated to unsuccessful MMP determination by STT, then procedure of samples preparation for Huff-n-Puff test, intermediate results of Huff-n-Puff test and MMP calculation via MMP correlations for the provided oil samples.

## Introduction

Oil recovery for heavy oil reservoirs is sufficiently small in comparison with conventional reservoirs due to the physical limitations of oil flow through the porous media. Heavy oil reservoirs do not effectively respond to secondary recovery methods, therefore, the tertiary enhance oil recovery techniques should be implemented in oil extraction operations. According to (Hutchinson & Braun 1961), gas flooding was proposed as a process gas-oil interaction, that can lead to the fluids miscibility under reservoir conditions. Then gas injection technique has been successfully employed for conventional reservoirs either in continuous or cyclic injection mode and in even different miscible regimes. Miscible injection is considered as the most favorable regime when the highest oil recovery can be reached along with miscible conditions of injection gas and oil (Chukwudeme & Hamouda 2009). Miscible gas injection depends on the variety of different factors like reservoir temperature, oil composition, swelling coefficient, diffusion, solubility and mainly on pressure above minimum miscibility pressure (MMP) (Ahmed 2010). MMP is an indication of the pressure or gas composition at which complete miscibility is reached (Tathed *et al.* 2010). But in the most cases, researches assume that heavy oil is not miscible (Cuthiell *et al.* 2006; Quoc *et al.* 2017) because MMP in heavy oil reservoir is usually much higher than reservoir pressure. Since carbon dioxide (CO2) gas tends to be almost the best miscible gas (Hawthorne *et al.* 2017), and it has the most interest in scientific studies, field implementation. This paper presents some problems correlated to unsuccessful CO2 MMP determination of heavy oil by slim tube test (STT), then description of novel solution for MMP determination via Huff-n-Puff test for heavy oil, intermediate results of Huff-n-Puff Test and MMP calculation via MMP correlation for heavy oil for future comparison with experimental results.

## Theory

Generally, MMP determination by STT is the most common method (Ahmed 2010), and it is considered as the most accurate technique, but in the same time it is considerably expensive and time-consuming. The main principle is based on injection of gas through a metal tube packed with glass beads or sand saturated with oil. The variable parameters are the gas composition or system pressure in the experiment. When oil recovery is higher than 90%, and it is achieved by injecting 1.2 of pore volumes of gas, the operational pressure is considered as MMP. Graphically MMP is determined as inflection point of the plotted curve of oil recovery versus pressure. There is no unified standard for STT experiment procedure, and the main principle is always the same. However, the operational parameters like tube length, tube diameter, pore volume, injection speed can vary greatly.

***Table 1*** *Reservoir and Oil Properties.*

| Reservoir Properties | | | Oil Properties | | |
|---|---|---|---|---|---|
| Pressure | 14 | MPa | Buble Point Pressure | 3.895 | MPa |
| Temperature | 27 | ˚C | Oil Density for dead oil | 1006.7 | kg/m3 |
| | | | Oil viscosity under reservoir conditions | 948 | mPa*s |
| | | | Oil viscosity for dead oil under reservoir conditions | 1694.56 | mPa*s |

MMP is commonly determined by slim tube technique (Tathed *et al.* 2010), but it was ascertained that MMP determination by STT with provided heavy oil (Table 1) samples in a reasonable amount of time is completely impossible. This work is devoted to introducing novel solution for MMP determination for heavy oil. One of the most prominent technique is effective minimum miscibility pressure (eMMP) determination by the novel technique through Huff-n-Puff injection, starting now referred to as “HnP MMP Test”, proposed by Li & Sheng (2016). According to Li *et al.* (2017) eMMP is almost equivalent to MMP, the problem was that Li *et al.* (2017) used shale samples with ultra-low permeability that decreased the measured MMP in comparison with MMP obtained by STT. But it is should be mentioned that experiment with the almost similar procedure was done by Rudyk *et al.* (2009b), this research was almost unnoticed for inexplicable reasons. In the second work Rudyk *et al.* (2009a) made a chromatographic analysis of extracted oil after gas injection that shows an increase of heavier hydrocarbon fractions at pressure above MMP. The only principal difference between (Li & Sheng 2016) and (Rudyk *et al.* 2009a) works was that in the first case samples were extracted and re-saturated by oil for each pressure step and in the second case one sample stayed the same without extraction and re-saturation procedures for the pressure steps. Therefore, the miscible conditions can be determined through oil recovery values measured after CO2 injection into core samples under different pressures (Li & Sheng 2016). However, the core samples should be consolidated and permeable enough to yield the same result by HnP MMP Test as by STT.

**Problems**

Experimentally we defined that it is impossible to conduct a slim tube test with such viscous oil. The slim tube was made from a non-corrosive tube with 10 meters length, 8 mm of internal diameter and 2 mm of wall thickness (Figure 1). Permeability and porosity of the system were 8 Darcy and 35% accordingly. However, even a step of kerosene replacement became somewhat challenging. The pressure inside the slim-tube was 25 MPa. After 40,5 hours of pressure support at 28 MPa no evidence of oil displacement was registered at the inlet of the slim-tube (Figure 2).

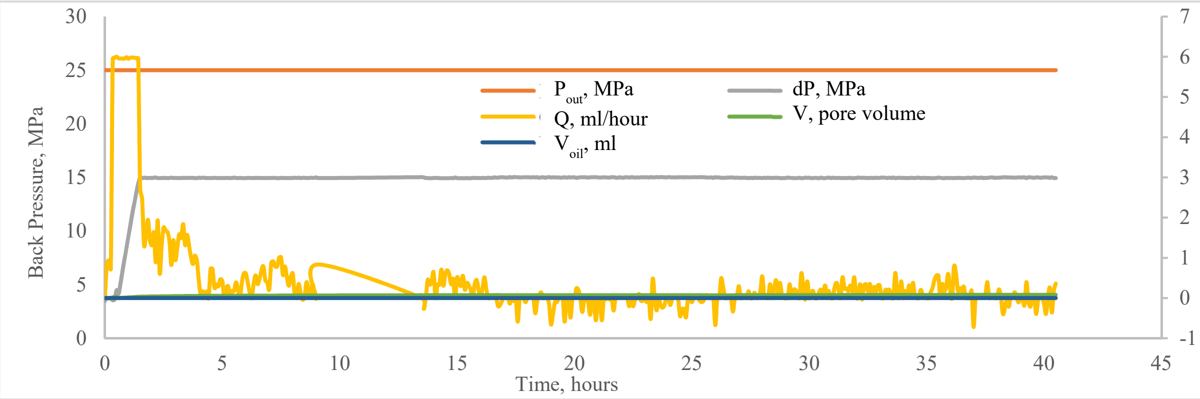


***Figure 2*** *The evolution of experimental parameters during CO2 injection into the slim-tube.*

**Materials and Methods**

To avoid the MMP change due to the low permeability that mentioned in his research (Li *et al.* 2017), it was decided to use the standard samples of Berea sandstone drilled close to each other from one piece of the rock. Assuming that the samples are almost equal (Table 2), according to Li & Sheng (2016) such differences in core size we have are inessential, and permeability of samples is high enough to be inessential in the experiment either. Therefore, it was decided to use ten core samples, two samples for each pressure step among five different pressure points for decreasing the time of the experiment. Samples were vacuumed for 24 hours, then saturated under the reservoir pressure and temperature above the temperature of paraffin (50 ˚C) depositions using two piston accumulators and quizix pump.

***Table 2*** *Samples Properties.*

| № | Pressure Step, MPa | L, cm | d, cm | Mass, g | Porosity, % | $k_{air}$, md | $k_l$, md |
|---|---|---|---|---|---|---|---|
| 3 | 6 | 4.764 | 2.941 | 68.4948 | 20.16 | 156.5 | 153.2 |
| 4 | 6 | 4.725 | 2.938 | 67.7889 | 20.16 | 159.7 | 156.4 |
| 7 | 10 | 4.375 | 2.94 | 62.7824 | 20.4 | 177.2 | 173.7 |
| 9 | 10 | 4.282 | 2.941 | 61.4112 | 20.42 | 174.9 | 171.4 |
| 1 | 14 | 4.819 | 2.94 | 69.3302 | 20.14 | 156.8 | 153.5 |
| 2 | 14 | 4.76 | 2.941 | 68.5755 | 20.21 | 161 | 157.6 |
| 5 | 19 | 4.698 | 2.943 | 67.5543 | 20.15 | 159.9 | 156.5 |
| 6 | 19 | 4.503 | 2.941 | 64.5404 | 20.35 | 171.8 | 168.3 |
| 8 | 24 | 4.371 | 2.94 | 62.5718 | 20.42 | 178.5 | 174.9 |
| 10 | 24 | 3.892 | 2.937 | 55.5681 | 20.63 | 178.3 | 174.8 |

*Figure 1 Slim-tube model.*


***Figure 3** Berea Sandstone samples saturated by heavy oil.*

A different empirical correlation for MMP determination exist. They can differ in number of parameters like molecular weight, a mole fraction of compounds, reservoir temperature, physical properties of oil, injected gas composition and concentration of $C_1$ and $N_2$. According to Tathed *et al.* (2010) MMP predicted by empirical correlation proposed by Alston *et al.* (1985) shows the best agreement with MMP for heavy oil determined by Vanishing Interfacial Technique (VIT). Rudyk *et al.* (2009a) used Yellig & Metcalfe (1980) correlation, where $T$ is the only correlating parameter, but shown a good agreement with the results obtained by HnP MMP Test. It is worth to mention that the temperature of the reservoir is out of the Yellig and Metcalfe's correlation temperature range (Yellig & Metcalfe 1980). MMP predictions were made according to the reservoir and oil properties.

*Alston's correlation:*

$$MMP = 8.78 * 10^{-4} * T^{1.06} * M_{C_{5+}}^{1.78} * \left[\frac{X_{vol}}{X_{int}}\right]^{0.136} = 16{,}45\ MPa \quad (1)$$

Where, $T$ is system temperature in R˚; $M_{C_{5+}}$ is molecular weight is molecular weight of pentane and heavier fractions in the oil phase $X_{vol}$ is mole fraction of volatile ($C_1$ and $N_2$) oil components and $X_{int}$ is mole fraction of intermediate oil components ($C_2$-$C_4$, $CO_2$ and $H_2S$).

*Yellig and Metcalfe correlation:*

$$MMP = 1833.7217 + 2.2518055 * (T - 460) + 0.01800674 * (T - 460)^2 - \frac{103949.94}{T-46} = 13.24\ MPa \quad (2)$$

Where, $T$ is system temperature in R˚.

**Intermediate Results and Conclusion**

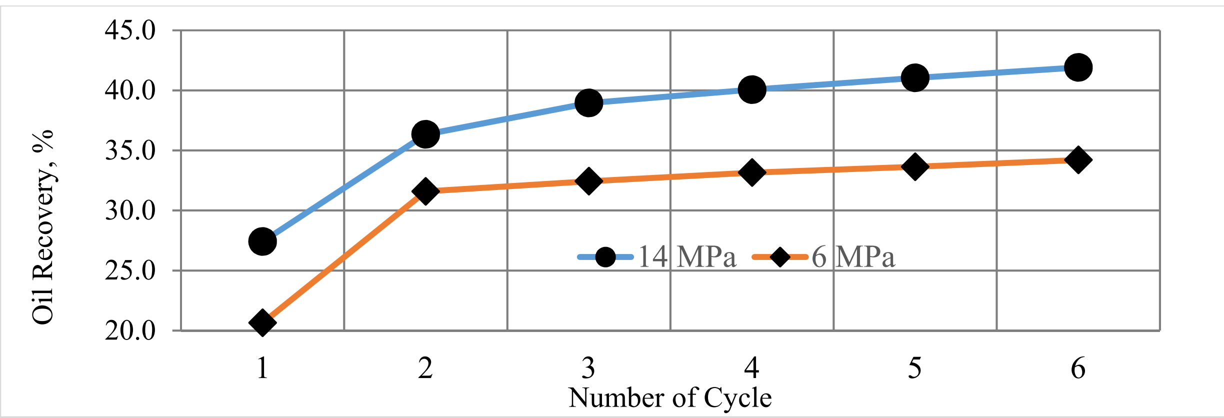


***Figure 4** Root-mean of recovery factor for groups of 2 samples at selected pressure.*

The procedure of HnF MMP Test was the same as the described procedure by (Li & Sheng 2016). Figure 4 shows root-mean of recovery factor of two groups of samples at two different pressures. The results show that there is a difference in oil recovery for the different pressure (6 and 14 MPa). Current results also show that 3rd cycle of injection extract 10 times smaller that was extracted in the first cycle. Obviously, if the MMP exist in the predefined pressure interval (6 – 24 MPa), it will be possible to calculate MMP even such heavy oil. In future results of HnF MMP test will be compared with MMP predicted by correlations, determined by Rapid Pressure Increase Method and calculated using numerical simulation. This research will help to throw the light on the uncertainty of MMP determination for heavy oil.

**Acknowledgements**

I want to express my very appreciation to Skolkovo Institute of Science and Technology for financial and resourceful support. I am particularly grateful for the assistance given by Pavel Zobov, Denis Bakulin, and Sergey Antonov.

**References**

Ahmed, T. 2010. *Equations of State and PVT Analysys*, https://doi.org/10.1016/B978-1-933762-03-6.50010-1.

Alston, R.B., Kokolis, G.P. & James, C.F. 1985. CO2 Minimum Miscibility Pressure: A Correlation for Impure CO2 Streams and Live OIl Systems. *Society of Petroleum Engineers*, **25**, 7, https://doi.org/https://doi.org/10.2118/11959-PA.

Chukwudeme, E.A. & Hamouda, A.A. 2009. Enhanced oil recovery (EOR) by miscible CO2 and water flooding of asphaltenic and non-asphaltenic oils. *Energies*, **2**, 714–737, https://doi.org/10.3390/en20300714.

Cuthiell, D., Kissel, G., Jackson, C., Frauenfeld, T., Fisher, D. & Rispler, K. 2006. Viscous fingering effects in solvent displacement of heavy oil. *Journal of Canadian Petroleum Technology*, **45**, 29–38, https://doi.org/10.2118/06-07-02.

Hawthorne, S.B., Miller, D.J., *et al*. 2017. Measured Crude Oil MMPs with Pure and Mixed CO2, Methane, and Ethane, and Their Relevance to Enhanced Oil Recovery from Middle Bakken and Bakken Shales. *In*: *SPE Unconventional Resources Conference*, https://doi.org/10.2118/185072-MS.

Hutchinson, C.A. & Braun, P.H. 1961. Phase relations of miscible displacement in oil recovery. *AIChE Journal*, **7**, 64–72.

Li, L. & Sheng, J.J. 2016. Experimental study of core size effect on CH4 huff-n-puff enhanced oil recovery in liquid-rich shale reservoirs. *Journal of Natural Gas Science and Engineering*, **34**, 1392–1402, https://doi.org/10.1016/j.jngse.2016.08.028.

Li, L., Zhang, Y. & Sheng, J.J. 2017. Effect of the Injection Pressure on Enhancing Oil Recovery in Shale Cores during the CO2 Huff-n-Puff Process When It Is above and below the Minimum Miscibility Pressure. *Energy and Fuels*, **31**, 3856–3867, https://doi.org/10.1021/acs.energyfuels.7b00031.

Quoc, T., Duy, M., Neogi, P. & Bai, B. 2017. Stability of CO2 Displacement of an Immiscible Heavy Oil in a Reservoir. 1–9.

Rudyk, S.N., Søgaard, E.G., Abbasi, W.A. & Jørgensen, L.W. 2009a. Determination of Minimum Miscibility Pressure in supercritical extractor using oil saturated sample. *Chemical Engineering*, **17**, 1, https://doi.org/10.3303/CET0917256.

Rudyk, S.N., Søgaard, E.G., Abbasi, W.A. & Jørgensen, L.W. 2009b. Determination of Minimum Miscibility Pressure in supercritical extractor using oil saturated sample (Short). 6.

Tathed, V., Dandekar, A.Y. & Patil, S.L. 2010. Determination of Minimum Miscibility Pressure using Vanishing Interfacial Tension ( VIT ) in Support of EOR for Alaska North Slope ( ANS ) Heavy Oil. **7**, 71–76.

Yellig, W.F. & Metcalfe, R.S. 1980. Determination and Prediction of CO2 Minimum Miscibility Pressures. *Journal of Petroleum Technology*, 160–168, https://doi.org/10.2118/7477-PA.