CHAPTER VI

Results and Discussion

In the pressure decay experiment, CO_2 pressure from 500 psi to 900 psi was applied to condensate (API 63.9), oil sample and n-decane. The pressure decay curves and total pressure drop curves were plotted to determine MMP. The MMP is maximum total pressure drop from total pressure drop curve. The pressure decay curve is the curve which is a plot of pressure against time as shown in Figure 4.1 – Figure 4.3 to determine equilibrium time of each samples.

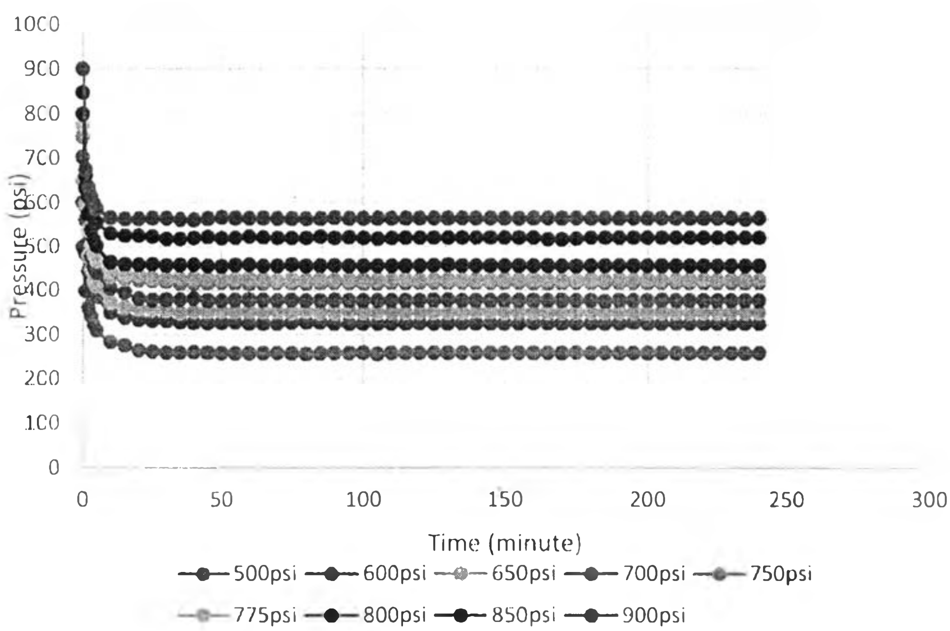

Figure 4.1 Pressure decay curve of condensate API 63.9 at 20 °C.

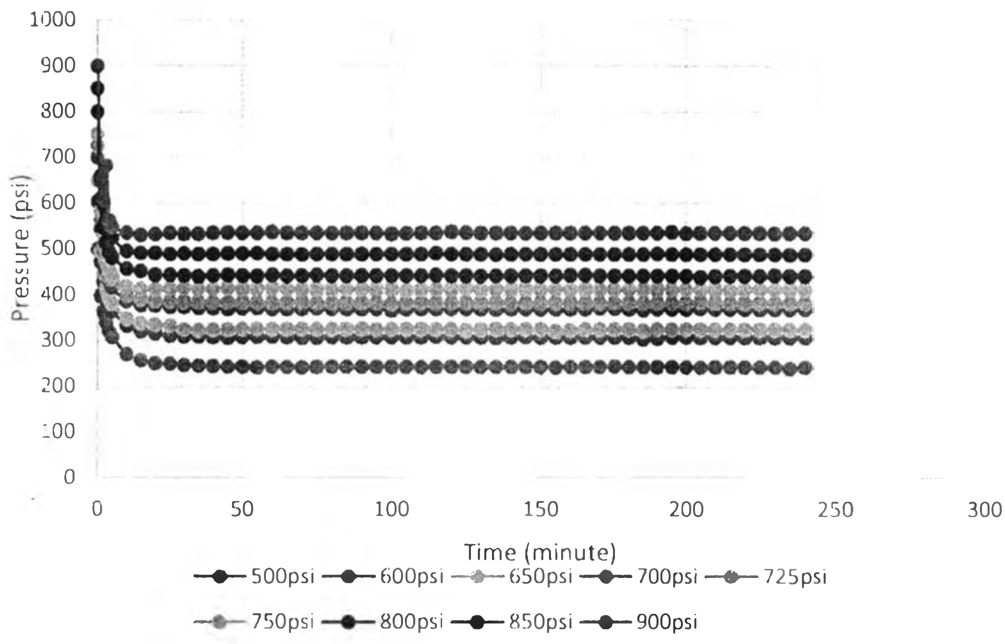

Figure 4.2 Pressure decay curve of oil sample at 20 °C.

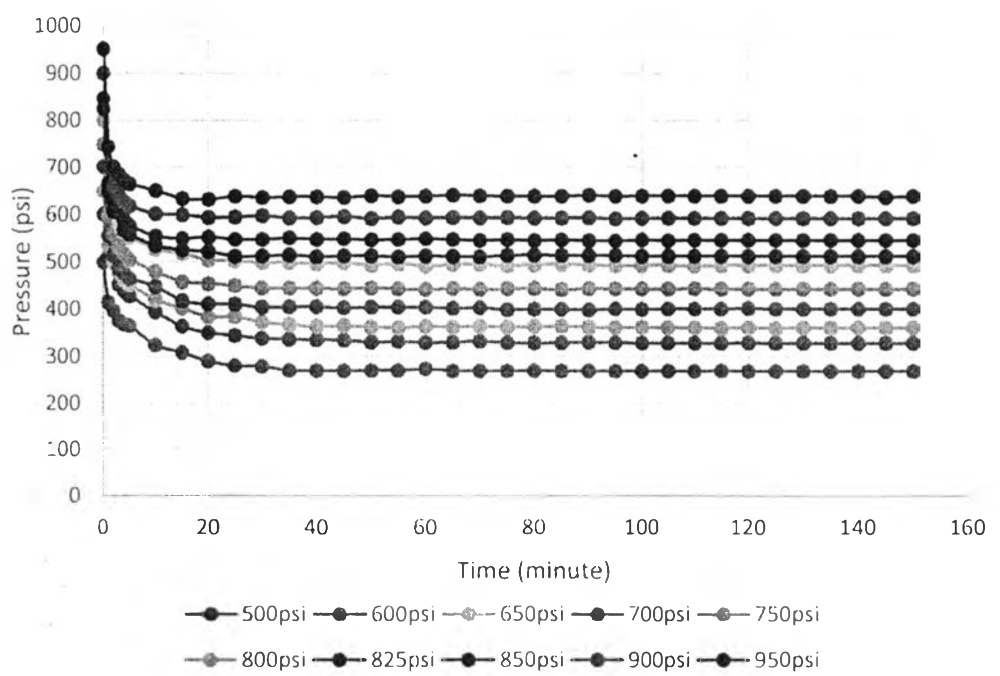

Figure 4.3 Pressure decay curve of n-decane at 20 °C.

After injecting CO_2 gas into the reactor, CO_2 diffuses into the oil. It can be observed by the pressure inside the reactor decreasing at the initial time and slightly decreasing to the equilibrium. Equilibrium time of condensate (API 63.9) is around 30 minutes at 20 °C temperature. In the case of oil sample and n-decane, the equilibrium time are 20 min and 45 min, respectively.

4.1 MMP Determination From Pressure Decay Curve

The pressure drop curve is plotted between total pressure drop against initial pressure. At below the MMP, the total pressure drop is slightly increased with increasing the initial pressure and it increases to the ultimate point. After that it will decrease. The MMP point is the ultimate point of the total pressure drop curve. The results of MMP measured by the pressure decay technique of condensate, oil sample and n-decane are shown in Figure 4.4- Figure 4.6. At 20 °C, the MMP point of condensate API 63.9 is 775 psi. The MMP point of oil sample is 725 psi and MMP point of n-decane is 825 psi. At below the MMP point, the pressure drop of the system is increase with increasing initial pressure. At above the miscible condition, the total pressure drop is increase again with initial pressure that shows in Figure 4.5 for oil sample at 20 °C

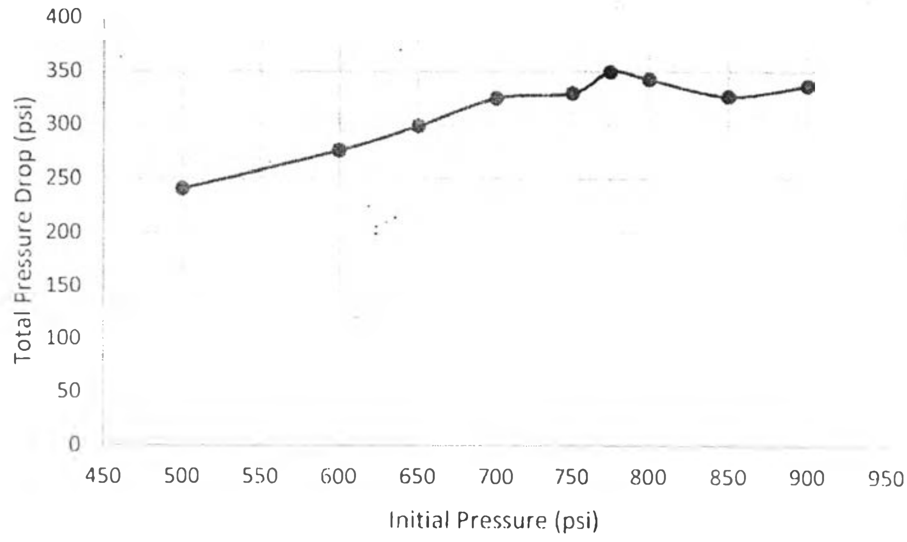

Figure 4.4. Pressure drop curve of condensate at 20 °C.

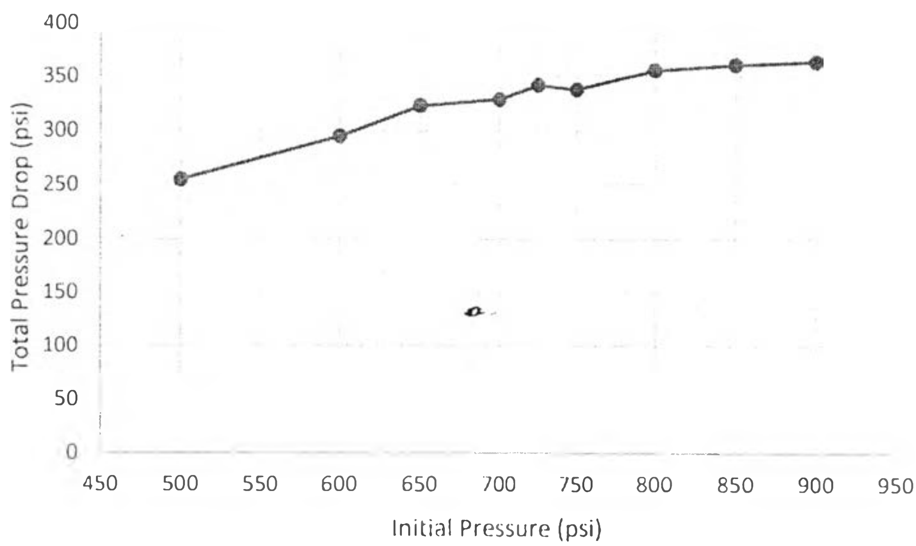

Figure 4.5 Pressure drop curve of oil sample at 20 °C.

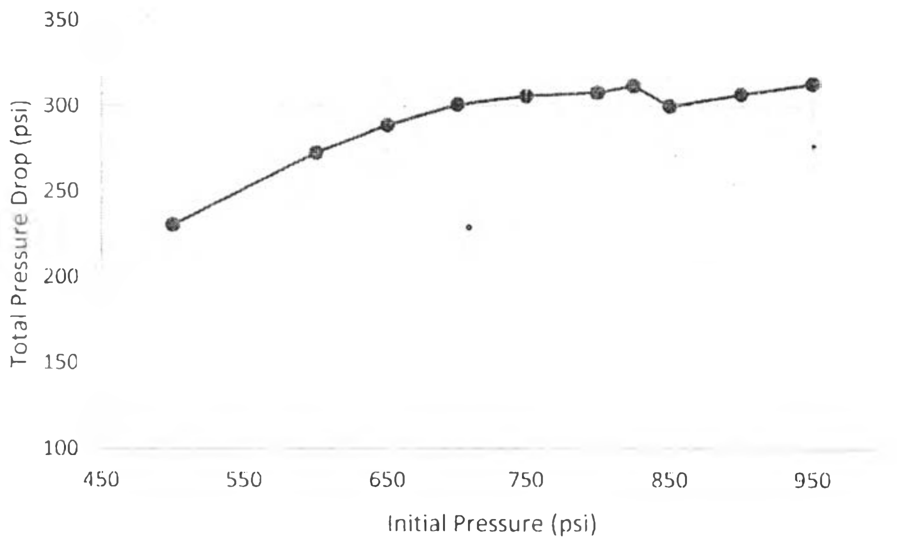

Figure 4.6 Pressure drop curve of n-decane at 20 °C.

4.2 Effect of Molecular Weight on MMP

Effect of molecular weight on MMP is determined in three different samples (condensate, oil sample and n-decane) at temperature 20 °C. The molecular weight on MMP are shown in Table 4.1. Figure 4.7 shows the MMP of the three different samples.

Table. 4.1 Effect of molecular weight on MMP in condensate, oil sample and n-decane at 20 °C

Sample	Molecular Weight	MMP from Experiment
Condensate API 63.9	113.64	775 psi
Oil sample	107.15	725 psi
n-decane	142.28	825 psi

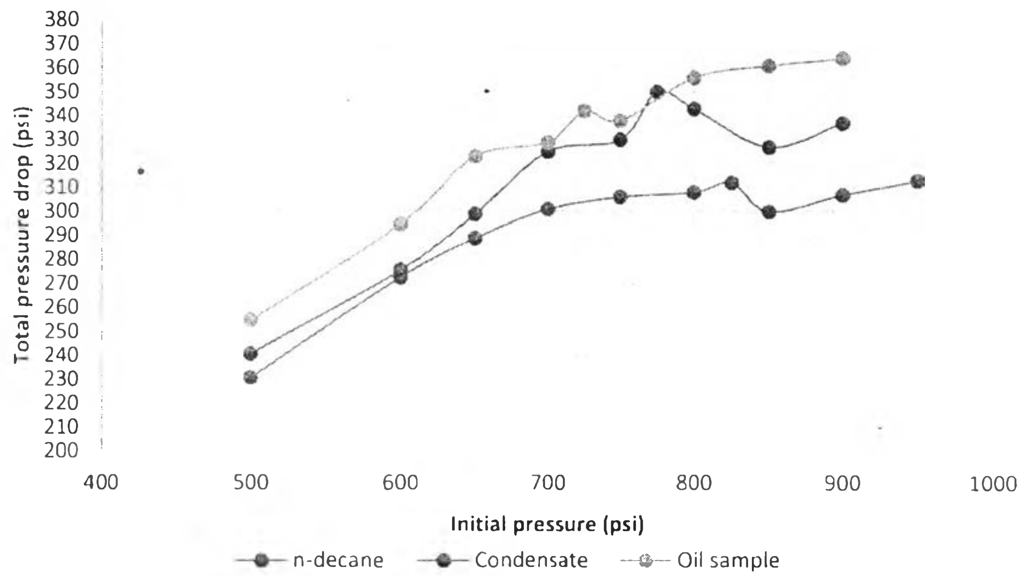

Figure 4.7 Effect of molecular weight on MMP in condensate, oil sample and n-decane at 20 °C.

Figure 4.7 shows the results showed that increase of molecular weight increases the MMP between CO_2 and samples (Rao and Lee, 2003) because viscosity of the sample is increase and it has low amount of light hydrocarbon component. Thus, it is difficult for CO_2 to diffuse in the samples. Hence, it requires higher pressure to achieve the miscibility. At 20 °C, n-decane has the highest MMP, because n-decane has highest molecular weight (144). Oil sample has the lowest MMP because oil sample has the lowest molecular weight (107.32).

4.3 Effect of Temperature on MMP

Effect of temperature on equilibrium time and MMP at two different temperature (20 °C and 30 °C) was determined shown in Table 4.2 and Table 4.3, respectively. The pressure decay curves are shown in Figure 4.8 - 4.10. The total pressure drop curves are shown in Figure 4.10 for crude oil and in Figure 4.11 for the oil sample.

Table. 4.2 Effect of temperature on equilibrium time in condensate and oil sample

Sample	Temperature (°C)	Equilibrium Time
Condensate	20.1 ± 0.12	30 minute
	30.16 ± 0.09	20 minute
Oil sample	20.15 ± 0.13	20 minute
	30.32 ± 0.34	15 minute

Table. 4.3 Effect of temperature on MMP in crude oil and oil sample

Sample	Temperature (°C)	MMP from Experiment
Condensate	20.1 ± 0.12	775 psi
	30.16 ± 0.09	850 psi
Oil sample	20.15 ± 0.13	725 psi
	30.32 ± 0.34	800 psi

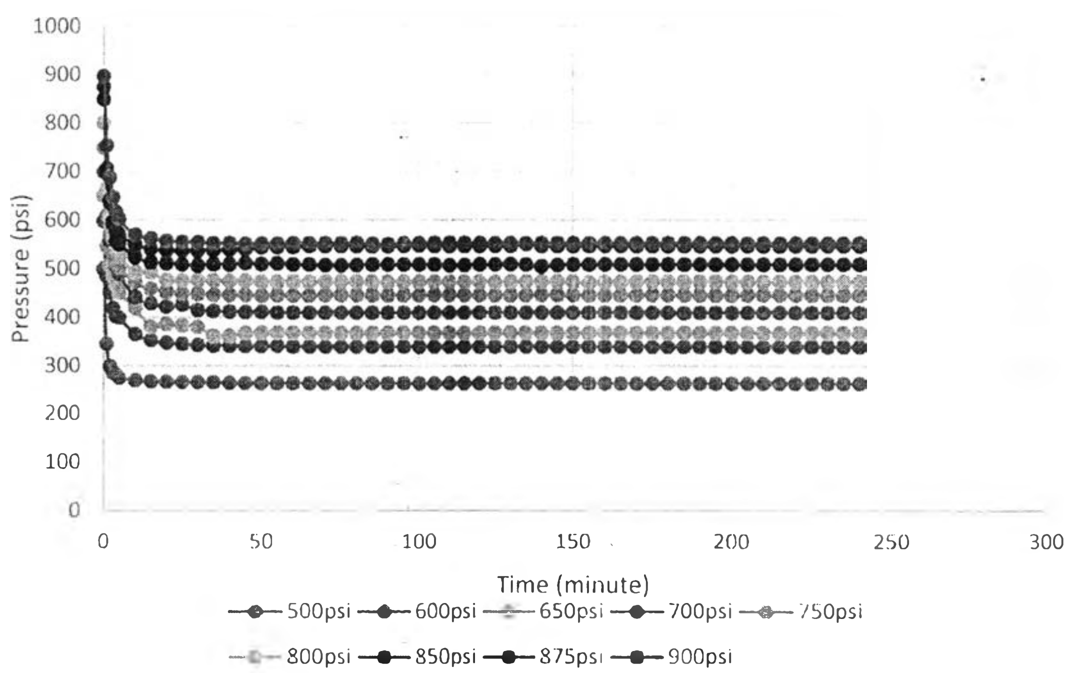

Figure 4.8 Pressure decay curve of condensate API 63.9 at 30 °C.

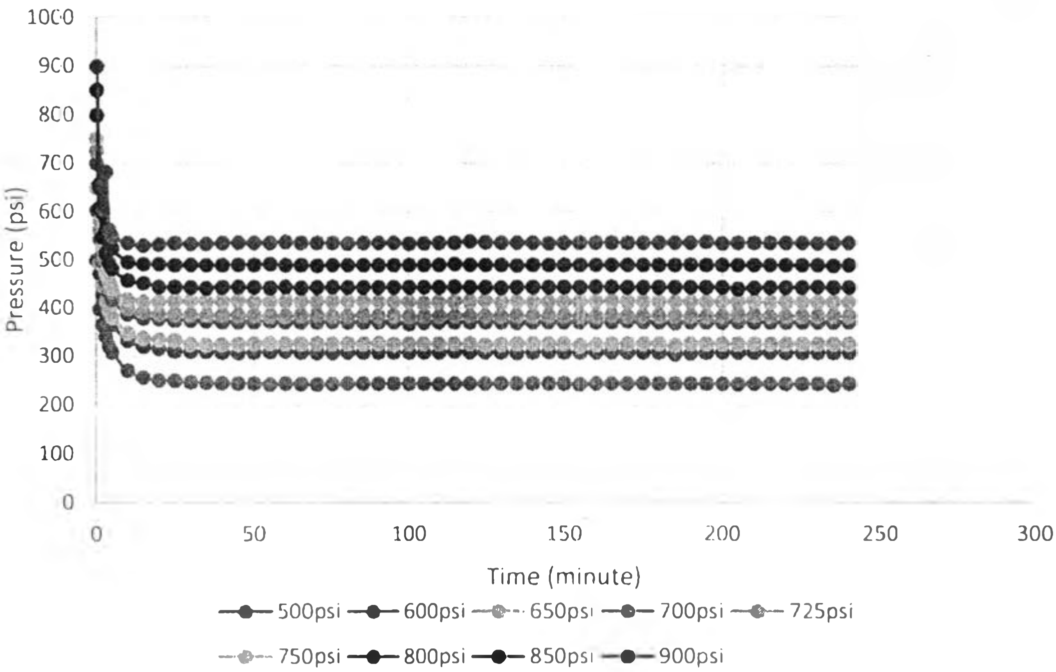

Figure 4.9 Pressure decay curve of oil sample at 20 °C.

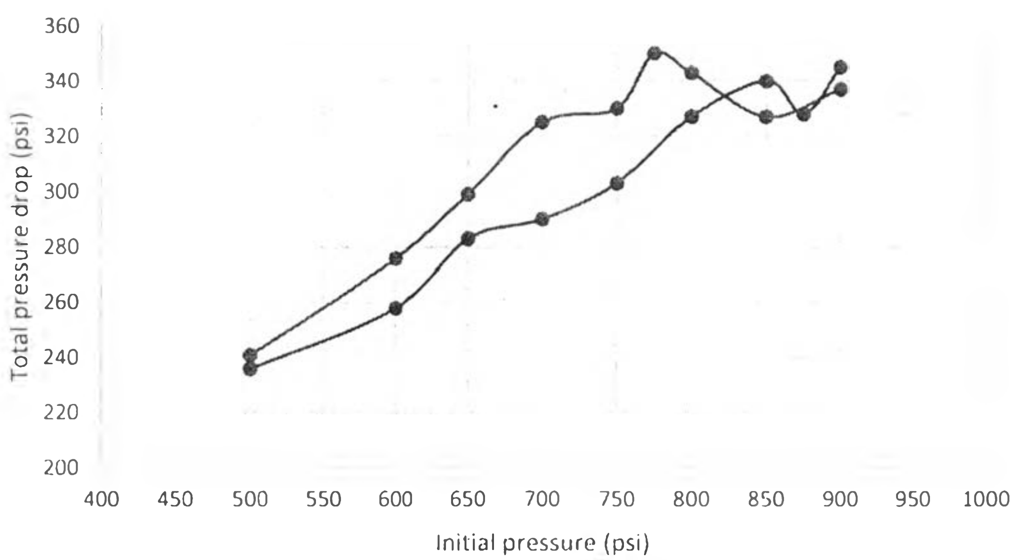

Figure 4.10 Effect of temperature on MMP on CO_2 and condensate system at 20 °C and 30 °C.

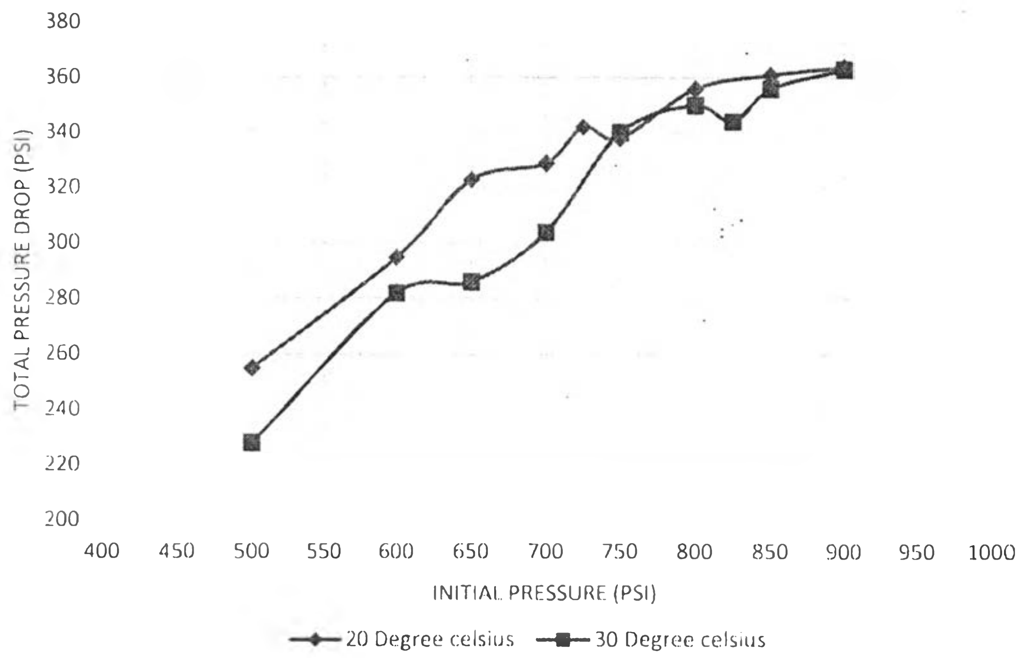

Figure 4.11 Effect of temperature on MMP on CO_2 and oil sample system at 20 °C and 30 °C.

The effect of temperature on equilibrium time which high temperature (30 °C) has lower equilibrium time than low temperature (20 °C) in Table 4.2 because oil viscosity is decreased at high temperature. It is faster for CO_2 to diffuse into condensate than low temperature. The MMP of condensate (API 63.9) is 775 psi at 20 °C and 850 psi at 30 °C (Figure 4.10) and 725 psi at 20 °C and 800 psi at 30 °C (Fig. 4.11) for oil sample system. The results of MMP at two different temperatures are shown; the MMP at 30 °C is higher than the MMP at 20 °C. The increase of temperature of the system increases the MMP because the solubility of CO_2 in the samples is decreased with increasing the system temperature which required higher pressure to achieve the miscibility (Cao and Gu, 2013).

4.4 Effect of Impurity Gas on MMP

Effect of impurity gas (Nitrogen gas) on MMP at two different percent of nitrogen gas (1 % and 3 %) in CO_2 was determined at 20 °C as shown in Table 4.4 and the total pressure drop curve in Figure 4.12. The MMP of CO_2-oil sample system is 725 psi for pure CO_2 injection, 750 psi for the 1 % N_2 in CO_2 injection, and 850 psi for the 3 % N_2 in CO_2 injection. For comparison of the pure CO_2 injection with CO_2 injection containing 1 % N_2, nitrogen gas has lower critical temperature than CO_2 which is more difficult to achieve miscibility than pure CO_2. Thus, the CO_2 injection containing 1 % N_2 in the oil sample required higher pressure to achieve miscibility (Belhaj et al., 2013). The effect of percent N_2 impurity gas was varied between 1% and 3 % N_2 in CO_2 stream with oil sample at 20 °C. The MMP of the 3 % N_2 in the CO_2 stream is higher than that of 1 % N_2 because higher pressure is required which can substantially increase with the amount of N_2 present in the CO_2 stream to achieve miscibility (Dong et al., 2001).

Table. 4.4 Effect of gas impurity on MMP of CO_2-oil sample system at 20 °C

Sample	MMP from Experiment
Pure CO_2 injection	725 psi
1% of N_2 in CO_2 injection	750 psi
3% of N_2 CO_2 injection	850 psi

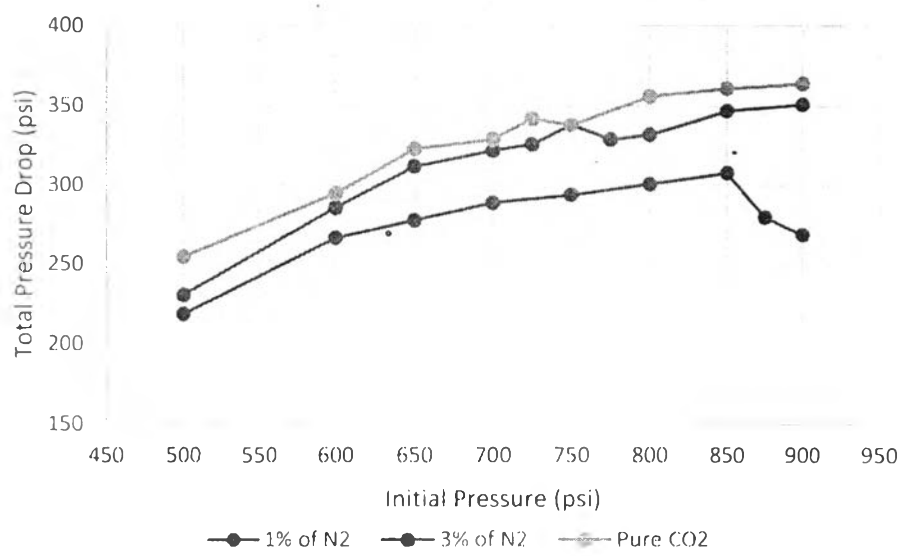

Figure 4.12 Effect of gas impurity on MMP of CO_2- oil sample at 20 °C, pure CO_2 injection, with 1 % of N_2, 3 % of N_2 in CO_2 stream.

4.5 MMP Calculation

To evaluate the results of MMP measured from the pressure decay technique, the MMP values was also calculated using Li *et al.* correlation (2013) in Equation 2.18. It requires MW_{C7+}, X_{VOL}, X_{INT} and T_R as shown in Table 4.5 which MW_{C7+}, X_{VOL}, X_{INT} were found from GC-TOFMS in Table 12.1. However it could not be obtained in this work due to the limitation of the experimental capacity. This prediction was far from the experimental value because in the literature, Li *et al.* correlation was testing at the high temperature (around 100 °C). This correlation wasn't accuracy enough for the prediction at low temperature. This equation should improve the accuracy for calculation in low temperature. The correlation factor for impure CO_2 streams (F_{imp}) was used to find MMP in the effect of impurity gas which it was determined from Alston *et al.* correlation in Equation 2.4-2.6. Nevertheless, F_{imp} is calculated from the critical temperature of the stream. The pseudo-critical temperature of the stream is calculated using the weight-fraction mixing rule as follows in Equation 2.4, and used Equation 2.5 to find MMP.

Table 4.5 Comparison of MMPs from this work with Li *et al.* correlation

Sample	T_R (°C)	MW_{C7+}	X_{VOL}	X_{INT}	MMP (psi)		%AD (%)
					This Work	Li *et al.*	
Pure CO_2 in condensate API 63.9	20.10	113.64	0	0.275	775	594	23.36
	30.16	113.64	0	0.275	850	763	10.24
Pure CO_2 in oil sample	20.15	107.15	0	0.383	725	580	20
	30.32	107.15	0	0.383	800	776.24	2.97
CO_2 with 1 % N_2 in oil sample (F_{imp}=1.08)	20.17	107.15	0	0.383	750	625.66	16.58
	30.24	107.15	0	0.383	850	835.44	1.7
CO_2 with 3 % N_2 in oil sample (F_{imp}=1.29)	20.18	107.15	0	0.383	850	747.22	12.1
Pure CO_2 in n-decane	19.97	142.28	0	0	825	651.12	21.08