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# Study on Maximum Efficiency Rate Test on Gas Injection Well

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***Abstract***
*Some reservoirs may be unable to sustain the life of a well over a period of time due to declining primary energy and subsequent decrease in production even with sufficient oil recoverable in place. One strategy to address this is to deploy associated gas re-injection process that would provide sustainable energy in place. The performance of this re-injection process is controlled by the level of safety as well as the volume of gas injectate which help ensure optimal recovery of the hydrocarbon fluids. In this work, a real case study of field X based on Maximum Efficiency Rate Test (MERT) was carried out at three different gas re-injection rates (expressed in percentages - 25% , 50% and 75%, respectively). Results show that the maximum rate at which the hydrocarbon fluids can be produced without damaging the reservoir's natural energy is 50%. It was also found that above the maximum efficiency rate (MER), natural pressure of the reservoir declined, thus creating potential for water breakthrough and reducing ultimately recoverable hydrocarbon fluids. Overall, the best percentage of the gas injectate at which hydrocarbon fluids flow optimally is established.*

***Keywords:*** *Gas injection well, Maximum Efficiency Rate Test (MERT), Enhanced Oil Recovery*

## 1.0 INTRODUCTION

Gas injection wells are an integral part of enhanced oil recovery (EOR) strategies, which aim to maximize hydrocarbon production from mature oil reservoirs (Alvarado & Maranrique, 2010). In order to ensure the effectiveness and sustainability of gas re-injection processes, it is essential to conduct comprehensive tests, one of which is the Maximum Efficiency Rate Test (MERT). MERT will guide operators against under re-injection or over re-injection as both situations can lead to low recovery of hydrocarbons, operational inefficiency, and relatively high operational cost.

Enhanced oil recovery functions by altering the reservoir's physical and chemical properties, thereby reducing the oil's viscosity and improving its flow towards production wells (Hawthorne et al.,2021). EOR employs a variety of techniques, which can be categorized into three primary methods: (1) Thermal EOR, which involves increasing the reservoir temperature to reduce oil viscosity, making it easier to flow. Common thermal EOR techniques include steam injection and in-situ combustion (Alvarado & Manrique, 2010); (2) Chemical EOR, which alters the properties of oil and reservoir rock to enhance oil mobility. This includes techniques like surfactant flooding and polymer flooding, which reduces interfacial tension and increases sweep efficiency (Hawthorne *et al.*, 2018); and (3) Gas EOR or Gas injection, such as the injection of carbon dioxide (CO2) or natural gas, which displaces oil by improving reservoir pressure and reducing oil viscosity. Gas EOR is considered one of the most widely used and effective methods (Kumar & Mandal, 2017).

Gas injection plays a pivotal role in EOR as it addresses two critical aspects of oil recovery. First, injected gases, such as $CO_2$ or natural gas, physically displace oil in the reservoir by maintaining or increasing reservoir pressure, thereby driving the oil towards production wells and improving recovery rates. Second, the injected gases interact chemically with the trapped oil, reducing its viscosity and facilitating its flow. This dual action makes gas injection a highly effective EOR method, enabling the recovery of a substantial portion of remaining oil reserves in mature reservoirs (Jin et al.,2022). Gas injection wells are designed with specific components and considerations to ensure their effectiveness in EOR projects. These wells are equipped with high-pressure systems and downhole equipment that allow for the injection of gases into the reservoir (Jin et al., 2022). Key components include wellhead valves, tubing, packers, and downhole pumps, which are designed to withstand the high pressures and temperatures associated with EOR.

The well's design and components must also consider the reservoir's geological characteristics to optimize gas injection and oil displacement . Natural gas is valued for its pressure-enhancing capabilities and cost-effectiveness. The selection of the gas type for injection depends on reservoir characteristics, project objectives, and economic considerations (Kumar & Mandal, 2017).

Maximum efficient rate (MER) means the maximum sustainable daily oil or gas withdrawal rate from a reservoir that will permit economic development and depletion of that reservoir without detriment to ultimate recovery. This is a crucial procedure in the field of gas injection well operations, particularly in EOR projects. The Maximum Efficiency Rate Test (MERT) is conducted with the specific objectives of optimizing the well's performance and preventing inefficiencies and potential damage. MERT assists in identifying the upper limit of the well's capacity, ensuring it operates at the highest possible injection rate without exceeding its mechanical or reservoir limitations (Hoffman, 2016).

## 1.1 Methodology

In this work, the methodology of conducting MERT involves a systematic and controlled process. Typically, the test begins with a gradual increase in the injection rate while monitoring the well's response and reservoir pressure (Jin et al., 2022). The test continues until signs of inefficiency, pressure limitations, or mechanical stress are observed, or until the well reaches its predefined maximum injection rate. Data collected during MERT includes injection rates, pressure profiles such as static pressure, flow tubing head pressure (FTHP), manifold line pressure (MLP), tubing head pressure (THP), casing head pressure (CHP), basic sediment & water (BS&W), liquid flow rate, choke size and orifice plate size. This information is then analyzed to determine the well's Maximum Efficiency Rate (MER) (Jin et al., 2022). operating a gas injection well beyond its

MER can lead to inefficiencies, excessive operational costs, and potential damage to the well and reservoir. Conversely, operating below the MER may result in underutilization of the reservoir's potential, leading to lower oil recovery rates (Hawthorne et al., 2016). Additionally, MERT contributes to economic sustainability in EOR projects by reducing unnecessary operational costs and resource wastage (Jin et al., 2022).

### 1.1.1 Research Design and Data Collection

The research design chosen for this study is exploratory and analytical approach, which is well suited to comprehensively explore and analyze the concept of MERT on gas injection well. The analytical aspect of the research aim in assessing the impact of MERT on reservoir performance, recovery factor and hydrocarbon extraction. The research employs a combination of secondary source, literature review, real world scenarios and a case study of the primary data collection method to gather comprehensive and relevant information regarding maximum Efficiency Rate Test on gas injection well.

### 1.1.2 Case Study

Case study of MERT on X well 22L gas injection well on the Niger Delta stratigraphic formation (Figure 1) is investigated in this work. This well interval was completed during the workover of May 1980. A water breakthrough was observed a month in to production while the production rate subsequently dropped from about 800bpd to 300bpd. This well was shutdown from May 1982 to February 1988 due to low productivity until it was later kicked off on gas lift during the same year. The water cut increased to about 75%. It produced intermittently between July 1997 and April 1999 due to lift gas shortage and it was later closed- same year. It was brought back to production in 2000 and produced satisfactorily till February 2006 when the field was shut-in for security reasons. The interval was opened upon re-entry producing at ~200 bopd and 50% BSW. The proved and expected developed ultimate recovery (DUR) for the interval is 0.66 MMstb and 0.69MMstb, respectively. The cumulative production at 1/1/2009 was 0.63 MMstb. X Well 22L was reopened in February 2021 on open-hole (OH), gas lift at 420 bopd and BSW of 0.05% and FTHP of 100 Psi with CHP equaling 750Psi. The well was last tested in July 2021 on open hole with 692 bopd and 4.77% BS&W.

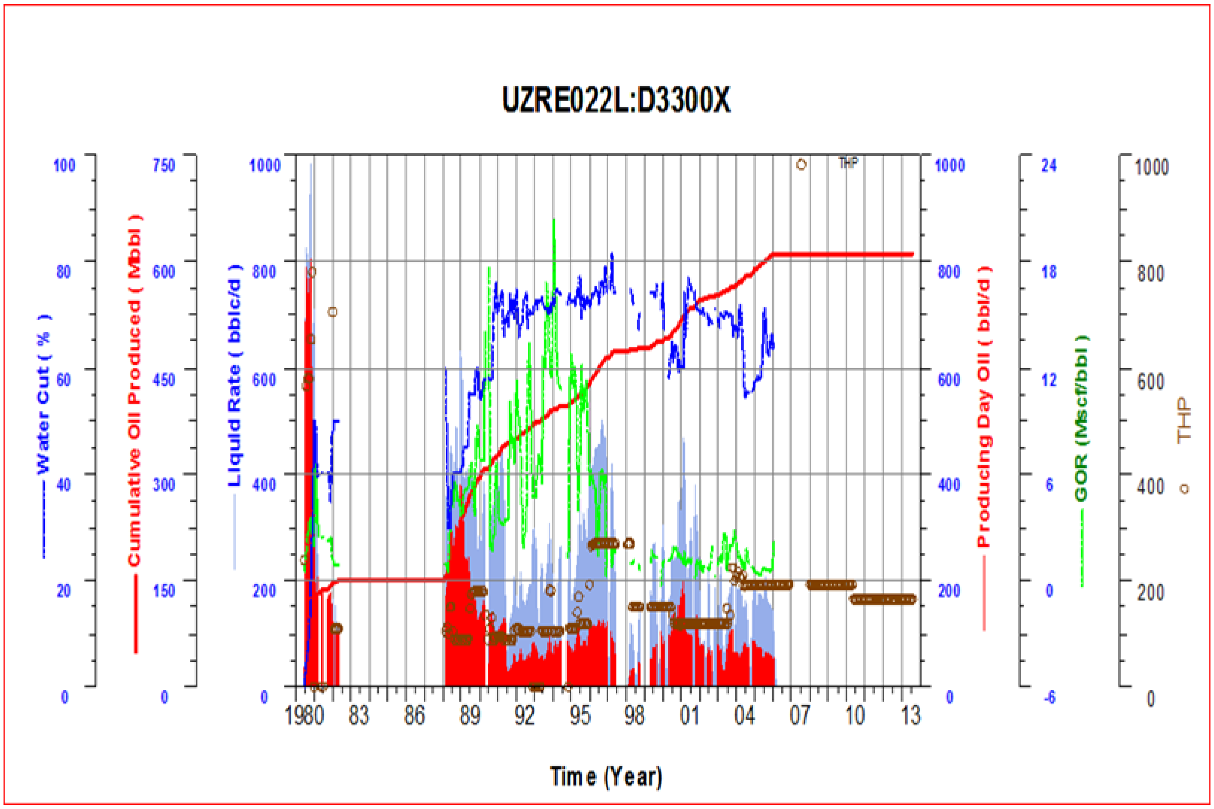


Figure 1: X Well 22L Graphical History

### 1.1.3 Experimental Setup and Instrumentation

The materials used in this study include: Water Displacement 40 formula (WD-40), inlet manifold header, high pressure (HP), low pressure (LP) and test separators, surge vessel, export pump, metering skid, gas set and diesel set, air compressor, auto sampling unit, gas compressor, and gas distribution manifold (see Figure 2). The experiment setup focuses on four areas with three discussed in details, including: (1) Gas Distribution Manifold (GDM); (2) Test Separator; (3) Well Head; and (4) Laboratory/Sample.

The Gas Distribution Manifold (GDM) is a place where various gas re-injection wells gathered with a common header upstream line to deliver gas to various well through the downstream (Anochie et al, 2010).
Gas distribution manifold will be meaningless without gas plant/gas station or compressor station, where the gas plant or gas compressor engine receives Low pressure (LP) gas from flow station at pressure of 2.5 bar and then processes or compresses it to 72 bar. The compressed gas is stored at the final discharge scrubber, thereafter moves to gas distribution manifold where it is finally injected into various well at appropriate gas percentages. The well percentage setting through the Pressure control valve (PCV) may be 25%, 50%, 75%, and 100% which corresponds to 6psi, 9psi, 12psi, and 15psi, respectively, depending on where the well will perform best and this is where

MERT comes into play to help determine the appropriate percentage which will be the company setpoint for few months pending when another test is carried out.
In our X well case study, gas lift compression station is used to provide gas lift to wells to enhance recovery of hydrocarbons from the well. Compressor gas engine is one of the artificial means of gas lifting weak wells i.e wells that can't flow on their own, a matured field. Instruments like pressure control valve (PCV), valve positional, air regulator, flow transmitter, air receiver, pressure gauge and Daniel Orifice Fitting(DOF) are components of the GDM. The GDM test procedure was first performed at 25%, and then repeated for 50% and 75%, respectively. The GDM test procedures follows the following steps:

1. Open air to air regulator.
2. Set pressure control valve (PCV)at 25% corresponding to 6psi by adjusting the air regulator.
3. Ensure your GDM header is on auto line.’
4. Take parameters one 1hrs interval for 6hrs.
5. Also Take well head parameters same time
6. Repeat this test for 50% and 75% .

Figure 2: A typical GDM assembly

Figure 3 shows a typical diagram of a gas-lifted oil well. Gas-lift is a method for activation of low pressure oil wells. In this method, gas is routed through surface gas injection choke (A) into the annulus (B) and then it is injected (C) into casing (D) in order to be mixed with the fluid form reservoir (F). This reduces the density of oil column in tubing and lightens it, hence the production (E) rate from the low pressure reservoir is increased ( Jehanshahi et al 2009)

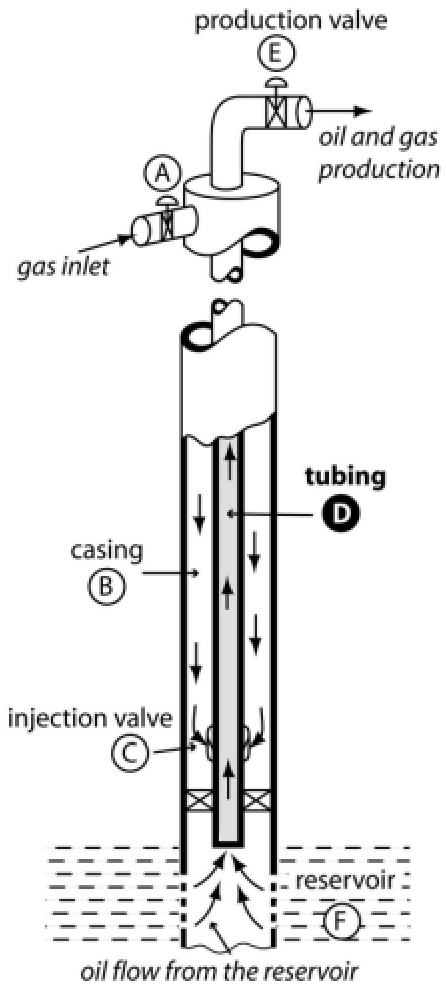


Fig. 3: A typical gas-lifted well (Jahanshahi et al, 2009)

For MERT to be carried out, the well head must be properly lined up first and the well must flow for the period of 12hrs prior to the test, this is to ensure pressure stability in the reservoir. Well head is the components near the surface of an oil or gas well that provides structure and pressure containing interface for drilling and production equipment. Well head components include: casing head, tubing head, surface controlled Subsurface safety valve (SCSSV), surface safety valve(SSV) choke valve, christmas tree, lower and upper master valves, wing valve, and swab valve (Anochie et al, 2009).Figure 4.show a typical well head and christmas tree. Wellhead operations procedure include the following steps: 1. Open the Lower master valve then upper master valve; 2. Closed the wing Valve; 3. Open the swab valve; 4. Take parameter of closed in tubing head pressure if okay with that well history; 5. If okay then open the wing valve; 6. Close the swab valve; 7. if not okay as a result of Low CITHP the use Hydraulic hand pump to pressurize the down hole valve to require pressure of about 3500psi then engage step 5 and 6; 8. Then take your parameters at regular interval.

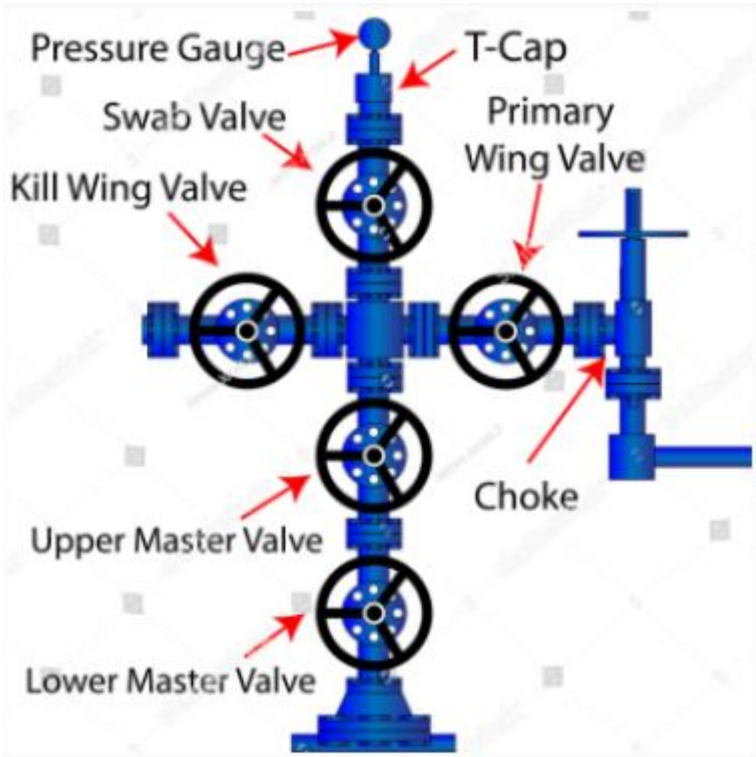


Figure 4: A typical well head with Christmas tree

A test separator is a vessel which is used to separate and measure small amounts of oil and gas. Each well is periodically tested by diverting the flow from the production separator to a test separator which determines the well's production rates of oil, gas, and water. Test separators with gas and liquid flowmeters are often provided for periodic measurement of the production rate from individual wells or groups of wells. Test separator are in phases and type, either two phase or three phase, horizontal or vertical type, and for the purpose of this work, we are using two phase liquid-gas separator and the horizontal type (Figure 5).

Well test is done under low static condition and will also not involve DCS/Control room rather a Coriolis and Emerson flowmeter is deployed. The test separator as a vital equipment when it comes to MERT has the following components: (1) Senior Daniel orifice fitting; (2) Coriolis meter; (3) Level controller; (4) Pressure switch; (5) Pressure relief valve; (6) Level sight glass; (7) Dump valve; (8) Pressure guage; and (9) Barton meter.

Fig 5: A typical test separator (2-phase)

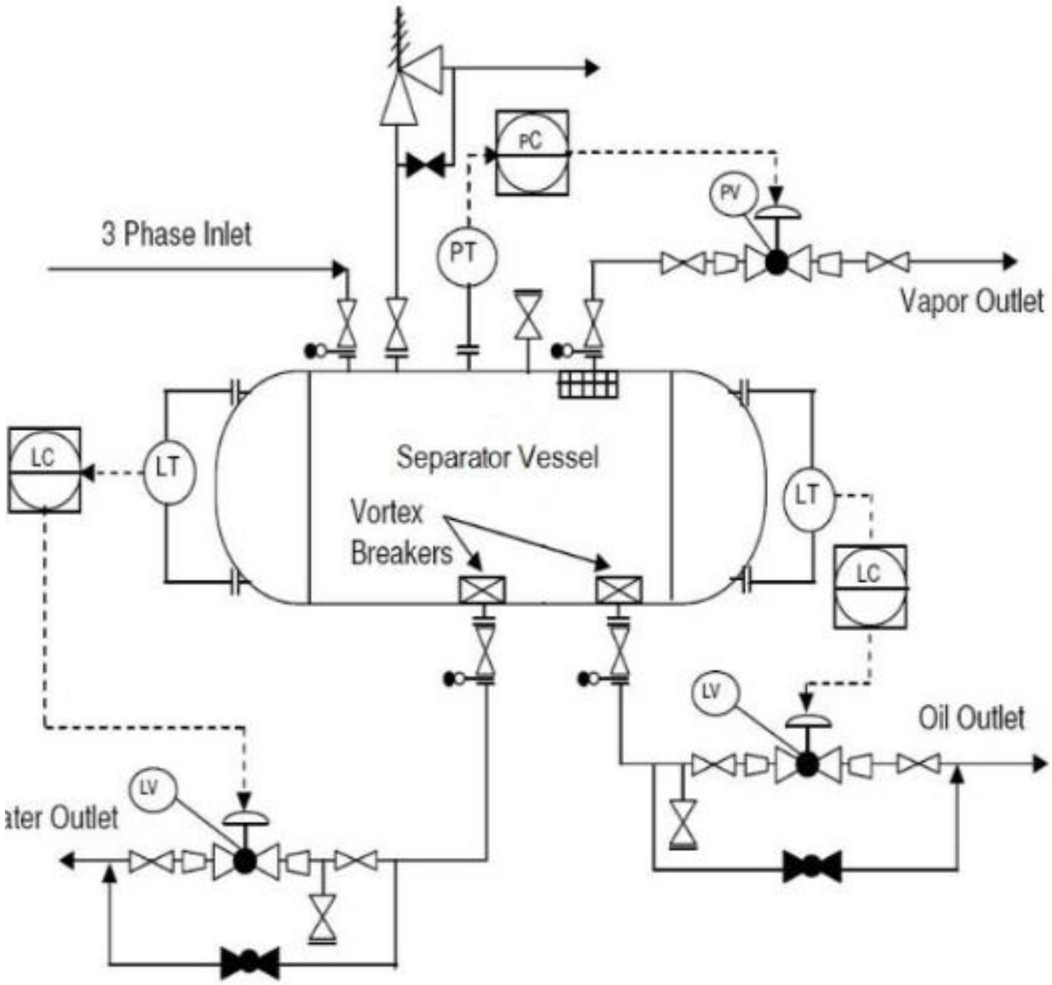


Fig 6: A typical test separator (3-phase)

You can measure hydrocarbon fluid through varieties of different devices such as coriolis, vortex, magnetic, utrasonic, turbine and positive displacement meters. In this MERT, the Coriolis meter is used. The fluid here are liquid, gas and slurry. Readings obtained from the Emerson flowmeter are flow rate, volume forward flow, temperature and density. Figure 7 is a typical Emerson flow meter.


Fig 7: A typical Emerson Flowmeter

Procedure for well test on 25% injection follows the following steps: 1. Open the well to test header at the inlet manifold ligament; 2. Line the test separator to Low pressure(LP)static and by opening the LP gas outlet; 3. Open separator oil and gas inlet and close all drains; 4. Open and lineup separator outlet liquid line open to surge vessel; 5.Orific plate size carefully selected and installed on daniel orifice fitting (DOF) ,
6. Allow the well and test separator liquid level to stabilize for about 12hrs; 7. Install chart on your Barton meter and ensure there is ink on the pen recorder; 8. Log in your parameters at regular interval; 9. Repeat the test for 50% and 75%.

In respect of laboratory analysis, samples are collected from the well head on One 1hrs basis which was taken to the Labouratory for analysis, it will help us know the bottom sediment and water percentage, net oil produce, gas oil ratio, gas produce. This challenge is exacerbated by the declining production rates experienced by mature reservoirs over time (Alvarado & Manrique, 2010).

## 2.0 RESULTS

2.1 MERT on different percentage of gas re-injection

Gas re-injected to well 22 at the GDM flow directly to this gas lifted well at high pressure of about 72bar which is needed to open those three set of gaslift valve or Mandrel valve to enable high pressure gas into the reservoir to increase and maintain the reservoir pressure, reduce oil viscosity which aid the oil to flow to the wellbore and then to the surface. For the purpose of this work, three MERT were performed on same gas lifted well on the field, which are 25% , 50% , 75% . Here, gas is re-injected to well 22 at different percentages on same well to determine the best hydrocarbon flow characteristics, taken as the maximum efficiency rate which will be cascaded to operator as their real time setpoint pending when another MERT will be carried out. Below are the MERT results conducted on X well 22L located in Nigeria's Niger Delta.

**Table 1: MERT at 25% Gas Re-injection**

| TE (HRS) | VOL. FWD (bbl) | DENSITY (Kg/M3) | SPOT READING(bbl/h) | S.TEMP (ºC) | FLP (Bar) | CHP (Bar) | FLOW RATE (bbl/d) | PLATE SIZE (Inch) | M.P (Bar) | STATIC.P (Bar) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09:30 | 72994.7310 | 979.94 | - | 34.12 | 5 | 48.3 | 122.58 | 6*1.0 | 3.1 | 3.0 |
| 10:30 | 72999.7670 | 977.10 | 5.04 | 36.37 | 5 | 48.3 | 103.24 | | 3.1 | 3.0 |
| 11:30 | 73008.1864 | 969.35 | 8.42 | 34.62 | 5 | 48.3 | 201.45 | | 3.2 | 3.1 |
| 12:30 | 73016.0591 | 974.66 | 7.87 | 36.65 | 5 | 48.3 | 170.65 | | 3.2 | 3.1 |
| 13:30 | 73022.0233 | 975.01 | 5.96 | 38.52 | 5 | 48.3 | 135.71 | | 3.2 | 3.1 |
| 14:30 | 73031.0740 | 959.83 | 9.05 | 35.71 | 5 | 48.3 | 354.09 | | 3.2 | 3.1 |
| 15:30 | 73043.2352 | 959.79 | 12.16 | 36.48 | 5 | 48.3 | 263.56 | | 3.2 | 3.1 |

Table 1 shows that the first MER Test started at 09:30hrs and ended 15:30hrs. Volume forward will be needed to calculate the SPOT READING and barrels per day which is computed as 194.02bbl/d. Figure 8 shows the temperature, pressure and differential pressure for the duration of the 6hrs test

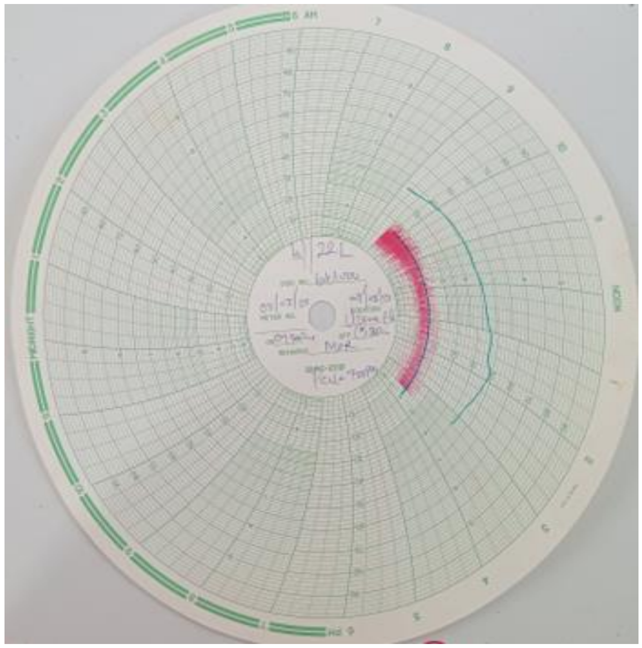

Fig 8: Circular Chart for 25% MER Test

**Table 2: MERT at 50% gas Re-injection**

| TIME (hrs) | VOL FWD (bbl) | SPOT READING (bbl/h) | DENSITY (Kg/m3) | S.TEMP (ºC) | FLP (bar) | CHP (Bar) | FLOW RATE (bbl/d) | M.P (Bar) | PLATE SIZE (INCH) | STATIC PRESS (Bar) |
|---|---|---|---|---|---|---|---|---|---|---|
| 09:30 | 83260.4314 | - | 972.99 | 32.51 | 5.2 | 50.2 | 147.25 | 3.2 | 6×1.00 | 3.0 |
| 10:30 | 73269.3378 | 8.91 | 959.41 | 31.93 | 5.5 | 51.7 | 405.76 | 3.3 | | 3.1 |
| 11:30 | 73289.7926 | 20.45 | 954.30 | 31.84 | 5.5 | 51.7 | 510.75 | 3.3 | | 3.2 |
| 12:30 | 73309.8158 | 20.02 | 959.60 | 31.61 | 5.5 | 51.7 | 498.22 | 3.3 | | 3.2 |
| 13:30 | 73325.1600 | 15.34 | 959.81 | 31.94 | 5.5 | 51.7 | 146.81 | 3.2 | | 3.1 |
| 14:30 | 73330.3886 | 5.23 | 965.36 | 31.95 | 5.5 | 48.2 | 64.809 | 3.0 | | 2.9 |
| 15:30 | 73330.4859 | 0.00 | 974.07 | 32.00 | 5.5 | 40.0 | 0.0000 | 2.8 | | 2.7 |

At the end of 6hrs MER Test at 50% gives 280.2184bbl/h

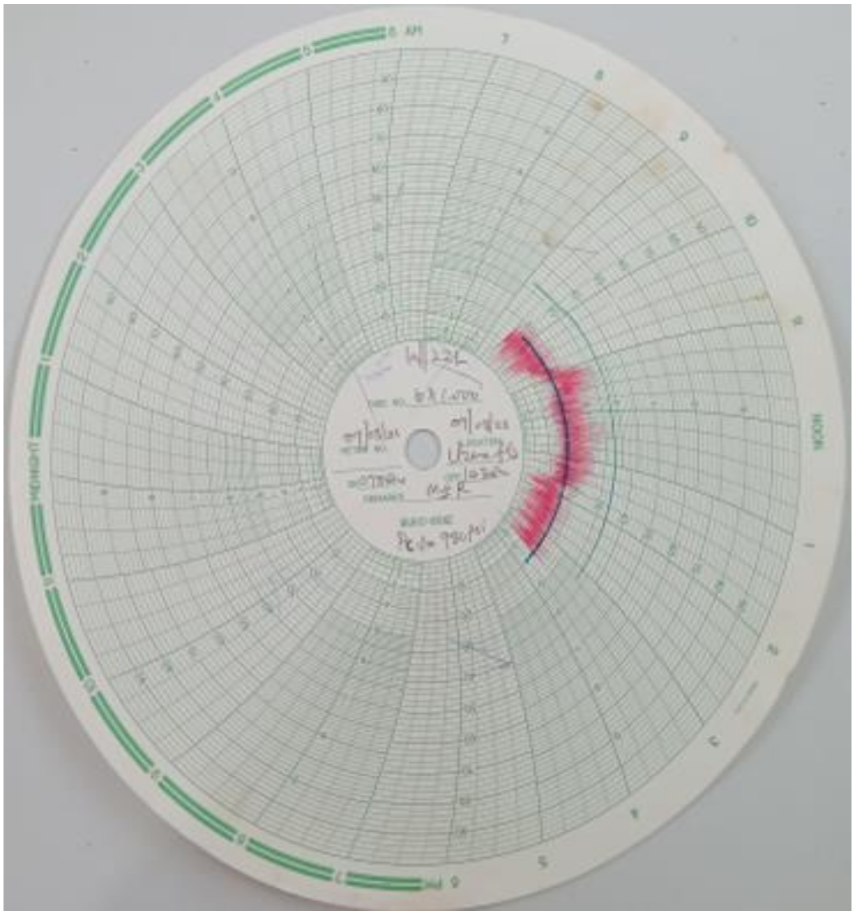

Fig 9: Circular Chart for 50%

**Table 3: MERT results at 75% gas Re-injection**

| TIME (HRS) | VOL FWD (bbl) | SPOT READING (BBL/h) | DENSITY (Kg/m3) | S.TEMP (ºC) | FLP (Bar) | CHP (Bar) | FLOW RATE (bbl/d) | M.P (Bar) | STATIC.P (Bar) | PLATE SIZE (Inch) |
|---|---|---|---|---|---|---|---|---|---|---|
| 11:15 | 73794.9484 | - | 965..41 | 31.67 | 5.5 | 50.0 | 319.37 | 3.3 | 3.1 | 6×1.0 |
| 12:15 | 73808.2489 | 13.3 | 964.88 | 32.42 | 5.8 | 55.2 | 297.82 | 3.5 | 3.2 | |
| 13:15 | 73819.8817 | 11.6 | 962.10 | 34.62 | 6.0 | 55.2 | 272.43 | 3.5 | 3.2 | |
| 14:15 | 73831.2480 | 11.4 | 964.50 | 34.06 | 6.0 | 55.2 | 248.33 | 3.5 | 3.2 | |
| 15:15 | 73842.2990 | 11.1 | 965.38 | 33.61 | 6.0 | 55.2 | 272.74 | 3.5 | 3.2 | |
| 16:15 | 73855.8070 | 11.5 | 967.75 | 33.70 | 6.0 | 55.2 | 270.80 | 3.5 | 3.2 | |
| 17:15 | 73865.1017 | 11.3 | 969.30 | 33.65 | 6.0 | 55.2 | 277.67 | 3.5 | 3.2 | |

At End of 6hrs Test, we have 280.61bbl/d

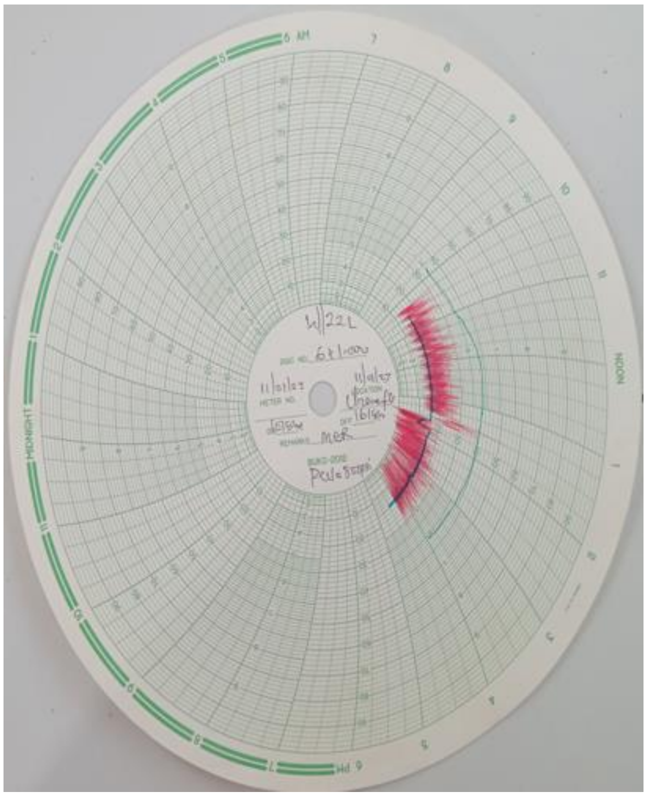


Fig 10: Circular Chart for 75 %

**Table 4: Results of MERT carried out on well 22L with different percentage of gas Re-injection**

| DATE | WELL ON TEST | DURATION OF TEST (HRS) | PCV Gas Re-injection TEST( % ) | GROSS PRODUCTION (BBL/D) | BS &W (%) | NET OIL PRODUCE(BBL/D) |
|---|---|---|---|---|---|---|
| 08/03/23 | 22L | 6 | 25 | 194.02 | 21.61 | 152.09 |
| 09/03/23 | 22L | 6 | 50 | 280.22 | 38.58 | 172.11 |
| 11/01/23 | 22L | 6 | 75 | 280.61 | 53.70 | 129.92 |

From the above MERT results, X well 22L performed best at 75% gas re-injection rate for gross production while the 50% produce better for net production. Our concern should be net highest production which the operator will maintain as their setpoint in order to achieve operational efficiency or increase revenue.

## 3.0 CONCLUSION

This study evaluated the application of Maximum Efficiency Rate Test (MERT) on gas Re-injection well in order to optimally enhance Oil Recovery (EOR). We presented three aspects, including gas re-injection well, enhanced oil recovery techniques and the role of maximum efficiency rate test which are practically done on the field. With reference to case study X well 22L, MERT was carried out at different percentage of gas re-injection rate and the results show X well 22L produce optimal at 75% gas re-injection rate, with gross production of 280.61bbl/d. Laboratory analysis results show 53.70% BS&W at 75% with net oil production of 129.92bbl/d. The 50% rate has second highest optimal gross production of 280.22bbl/d with 38.58 % BS&W and the net oil production is 172.11bbl/d. The 50% rate is chosen over 75% rate because of its optimal net oil production. Secondly conservation of resources that extra 25% gas on top will be saved and channelled to another well. Overall, the results provide a guide to the company and operator on this particular well, pending when another MERT will be carried out. Thus, MERT is a crucial Tool in well performance, where re-injection rate below 50% is under injection/reservoir underutilization and above 50% is over injection/over utilization. With a potential to cause damage to the reservoir, operator will have to avoid both scenarios.

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