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# An Investigation Into the Effect of Liquid Viscosity on the Performance of an Oil Well

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## ABSTRACT

Liquid viscosity is an important fluid property that can affect the productivity of an oil and gas well. Therefore, petroleum engineers must investigate this parameter to determine the most efficient way to mitigate the impact, while improving the performance of an oil and gas well to save resources and overall cost for future projects. To investigate the research question on "How liquid viscosity affects well performance", we elected to use PIPESIM to perform a sensitivity analysis on how API gravity affects oil production rate and well flowing pressure, since there is a strong correlation between API gravity and viscosity of a fluid. Beggs and Robinsons correlation forms the foundation of the method chosen. For a vertical well with a static pressure of 4000psi, a temperature of 175°F, API gravity of 32°API and a productivity index of 2.5STB/d/psi were some of the parameters adopted during this investigation. From the simulation, it was observed that the higher the API gravity value, the higher the flowrate. Whereas the opposite effect was observed for the well flowing pressure as this significantly reduced, confirming an indirect relationship between the API gravity and viscosity. In addition, it was observed that the maximum operating conditions occurred between 40° and 46° API, as two values produced the same flowrate of 3163.95 STB/day offering the suggestion that after a certain degree of API gravity (viscosity) there would be no further pronounced effect on flowrate. To conclude, the findings will imply that viscosity has a negative impact on productivity, however, can be mitigated with methods such as gas injection, steam flooding and in-situ combustion, to increase the API gravity.

# ABBREVIATIONS

| Abbreviations | Definition |
|---|---|
| **API** | **American Petroleum Institute** |
| **IPR** | **Inflow Performance Relationship** |
| **EOR** | **Enhanced Oil Recovery** |
| **OPR** | **Outflow Performance Relationship** |

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# CHAPTER ONE
# INTRODUCTION

- *Viscosity:*

Viscosity is the resistance to the flow of a fluid, with research suggesting that fluids with low viscosity flow easier than those with higher ones (Wang et al, 1964). This parameter is greatly important, as it can seriously hinder the production of an oil well. Therefore, a lack of research into viscosity could prove costly, especially with the global issue of climate change brought on by fossil fuels adding increased pressure to the oil and gas industry. Oil wells must be capable of producing hydrocarbons in short time to satisfy the demand.

- *Focus of the Research:*

As fossil fuels are non-renewable, there is a growing need to enhance the production of hydrocarbon and oil-well performance. However, to achieve this desired result there needs to be a detailed study of reservoir rock and fluid properties such as porosity, permeability, viscosity, and oil formation volume factor. These variables all form a crucial part of the production of hydrocarbons and require investigation to reduce their limitations to productivity. Therefore, this research will aim to investigate the variable 'viscosity' and how viscosity affects the productivity of an oil well.

- *PIPESIM:*

In recent years, the ability to investigate reservoir rock and fluid properties has significantly increased. Software such as 'PIPESIM' has revolutionised how petroleum engineers can investigate the effects caused by these properties, allowing the creation of simulations to optimise the productivity of the well and thus saving time and money in the efforts of acquiring hydrocarbons. PIPESIM is software, that allows a researcher to model an oil well and analyse the impact of different variables through sensitivity analysis.

- *Aims of the Research:*

The group aimed to investigate the following question:

- *"How does liquid viscosity affect the oil well performance and optimised operating conditions?"*

The research will use quantitative methods, applying Beggs and Robinsons' correlation to determine API gravity as well as, the use of computer-aided simulation with PIPESIM to perform a sensitivity analysis to determine the optimal operating conditions for the well.

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# CHAPTER TWO
# REVIEW OF LITERATURE

➢ *How Does Viscosity Affect the IPR Productivity:*

In recent times, investigations into oil well performance formed the concept of the 'Inflow Performance Curve', which demonstrated the relationship between the flowing bottom pressure 'P' and oil production rate 'Q' (Gilbert, 1954). This research is critical to understand how varying factors can affect the performance of a well and allow the mitigation of negatives reducing productivity.

In petroleum engineering, the inflow performance relationship is viewed as one of the most fundamental diagnostic tools to evaluate the performance of a flowing well (Basaleh, 2020). An accurate IPR is used to provide the optimum production scheme and maximise reservoir production efficiency. However, several mitigating variables can impact this measurement such as viscosity, skin factor, reservoir temperature, and nondarcy coefficient (Basaleh, 2020). The variable 'viscosity' is of significant interest of its nature to reduce the flow speed within the reservoir, resulting in a lower overall productivity index. Support for this idea comes from Guo, who claims that the combination of permeability and viscosity affects the results within the lower oil rate at given bottom-hole pressure (Guo, 2017). Likewise, it further claims that the IPR curve will suffer a deviation from the linear trendline present in Fig.1. (Guo, 2017).

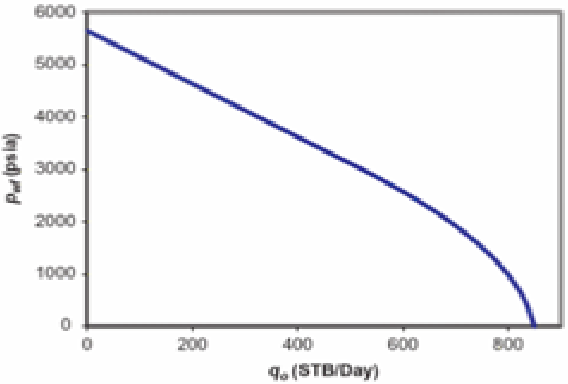


Fig 1 Typical IPR Curve. (Guo, 2017)

➢ *How Does Viscosity Affect the Well Performance:*

Understanding the effect viscosity has on oil well performance is crucial for any petroleum engineer trying to maximise the operating point / operating conditions during the production of hydrocarbons. Proposed by Wang, viscosity relates to the resistance a fluid feels when it tries to flow, suggesting that fluids with lower viscosity's flow easier than those with a high viscosity (Wang et al., 1964). Their research implies that it is essential to reduce the viscosity, to provide the fastest flow of fluid. Supporting this research is Gokcal, who performed an investigation into the effect of viscosity on both low and high-viscosity flow loops, concluding higher discrepancies for the high-viscosity oils in comparison to the low-viscosity ones (Gokcal et al., 2008). In their claims, they base these findings on the higher ones being more carefully examined however, the fact there is a higher degree of uncertainty with the higher viscosity supports Wang's claim of higher viscosities being more resistant to flow, moreover emphasising the negative associated with the liquid viscosity and flow pattern. In contrast, their study was conducted within a lab-based environment, subjecting the study to a lack of ecological validity and discounting the possibility of extraneous variables that may affect the flow within a real-life scenario, making it difficult to generalise the findings.

➢ *Temperature Effect on Viscosity:*

Beggs and Robinson developed a relationship between temperature and viscosity (see Appendix **A**). Their findings show that between 100°F to 150°F the effect of temperature greatly impacts flow rate, based on the previous relationship it suggests a decrease in viscosity. However, the capability of their method appears limited to only above 150°F. Moreover, Lee and Lee confirmed their theory as they also discovered a significant relationship between temperature and viscosity. They suggested that a decrease in viscosity occurs from an increase in temperature and that the more viscous a fluid is, the more sensitive it is to temperature change (Lee and Lee, 2019). This researcher also places emphasis on how improved viscosity contrast favours oil flow better than water flow (Lee and Lee, 2019). The literature suggests that to reduce the viscosity, the temperature must increase. This claim is backed up by Seeton, who suggests most liquids experience an exponential relationship (Seeton, 2006). This is emphasised by certain enhanced oil recovery (EOR) methods, such as in-situ combustion and steam injection as they rely on inducing high temperatures to alter the crude oil viscosity.

- *The Effect of API Gravity on Viscosity:*

The economic value of crude oil and field development decisions are significantly influenced by the API gravity. Since it aids in the design of the equipment used for exploration and field productivity in addition to the oil value, it has a significant impact on the economic viability of producing fields (Santos et al., 2018). Beal correlated the viscosity of dead oil as a function of API gravity (Beal, 1946) (Beggs and Robinson, 1975). By claiming it is a function, the researcher highlights a direct relationship between the two. Although, Ubong disputes this claiming their correlations are of limited accuracy because of the variation between geological, lithological, and petrophysical conditions (Ubong,2014). (Bergman and Sutton, 2007) proposed the use of Watson characterization factor to account for this anomaly, especially with crude oils with less than 25°API. In addition to this, some EOR methods such as those mentioned earlier and miscible gas injection can be used to alter the API gravity of crude oils, ultimately influencing oil viscosity.

# CHAPTER THREE
# METHODOLOGY

This research used quantitative research methods in the form of licensed software PIPESIM to perform a sensitivity analysis of a well with pre-determined parameters. These consisted of altering the API gravity to record the correlation by Beggs and Robinson's. From this method, it was possible to determine the maximum operating conditions.

➢ *Parameters:*

For a well of static pressure **4000 psi**, temperature **175°F**, and productivity index **2.5 STB/d/psi**. The PVT data, deviation survey, geothermal data, and tubing configuration are represented in tables 1 ,2 ,3, and 4. (see Appendix)

➢ *Simulation Procedure:*

To perform the simulation, the following steps were taken:

- We created a well in PIPESIM.
- We applied the parameters (see Appendix) and chose a nodal point below the tubing to have a well as seen in Fig 2.
- We ran the simulation to obtain a P/T profile.
- We carried out a nodal analysis to obtain the IPR and OPR curves.
- We carried out a sensitivity analysis by using different API gravity values to investigate the effect of viscosity on well performance and optimal operating point.

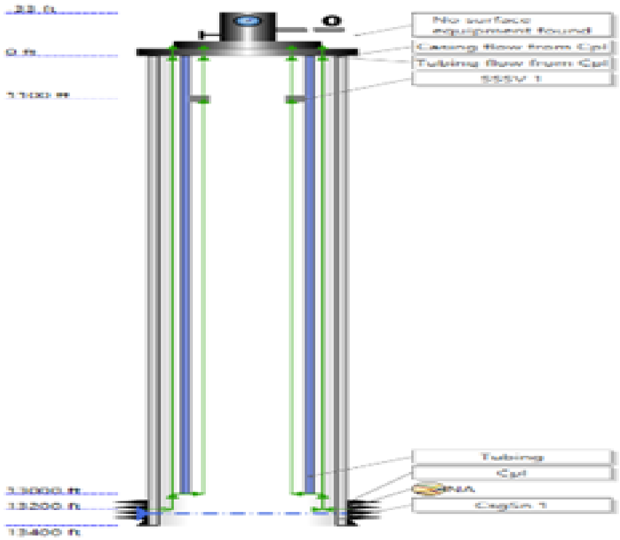

Fig 2 Well Model

✓ *Sensitivity Analysis Procedure:*

Due to the inability to carry out a direct sensitivity analysis with viscosity on PIPESIM, we used calculated API gravity values which were obtained from Beggs and Robinsons' dead oil viscosity correlation. The compressed form of the equation can be seen below:

$$\mu_{od} = 10^{10^{3.0324-0.02023G} T^{-1.163}} - 1 \quad (1)$$

For which, μ relates to the viscosity of dead oil (**Cp**) and the T is the temperature in (**°F**) and G the API gravity of the oil (**°API**) (Beggs and Robinson, 1975).

✓ *Beggs and Robinson Correlation Modification and Calculations:*

We established a new correlation where API gravity became a function of temperature and dead oil viscosity by modifying Beggs-Robinson's correlation (Ahmed Tarek, 1946).

$$\mu_{od} = 10^{X} - 1 \quad (2)$$

Where;

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$X = Y(T - 460)^{-1.163}$
$Y = 10^{Z}$
$Z = 3.0324 - 0.02023°API$

Rearranging all these and making API gravity the subject of the formula will give

$$°API = \frac{3.0324 - Z}{0.02023} \qquad (3)$$

Hence;

$Z = \frac{logY}{log10}$
$Y = \frac{X}{(T-460)^{-1.163}}$ or $Y = X(T - 460^{1.163})$
$X = \frac{\log(\mu_{od} + 1)}{log10}$

Subsequently, we used MS Excel to calculate API gravities at different viscosities and at a constant temperature (175°F). Refer to Table 5 in the appendix section.

# CHAPTER FOUR
# RESULTS AND DISCUSSIONS

➢ *Results and Discussions for Liquid Flowrate:*

As discussed in the methodology section of this report, the simulation produced a liquid flow rate of 2730.457 stb/day at an inlet pressure of 4000 psi and an assumed outlet pressure of 400 psi.

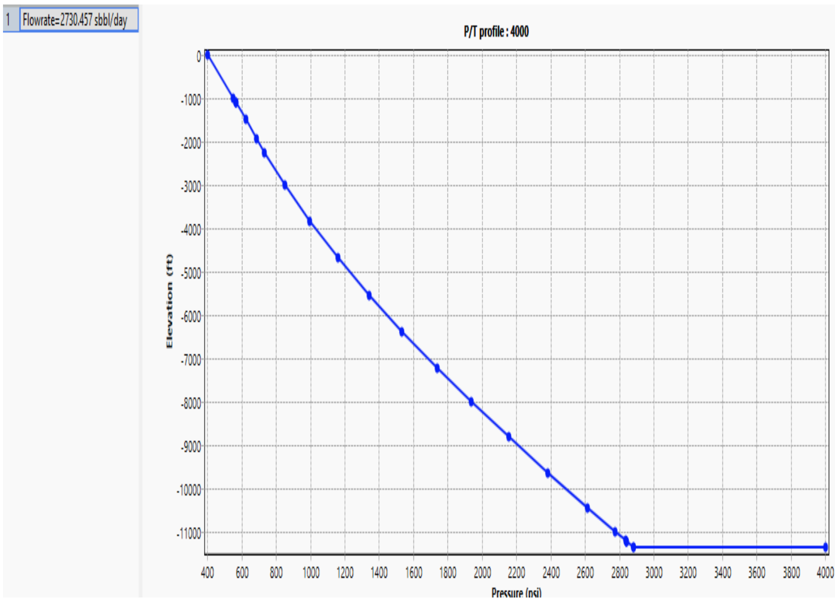


Fig 3 P/T Profile

➢ *Results and Discussions for Nodal Analysis:*

Nodal analysis was carried out to obtain the operating point at a viscosity of 3.5cp (calculated by PIPESIM) and a corresponding API gravity of 32°API which yielded a liquid flowrate of 2730.46 stb/day and a well flowing pressure of 2878.81 psi at the node (below the tubing).

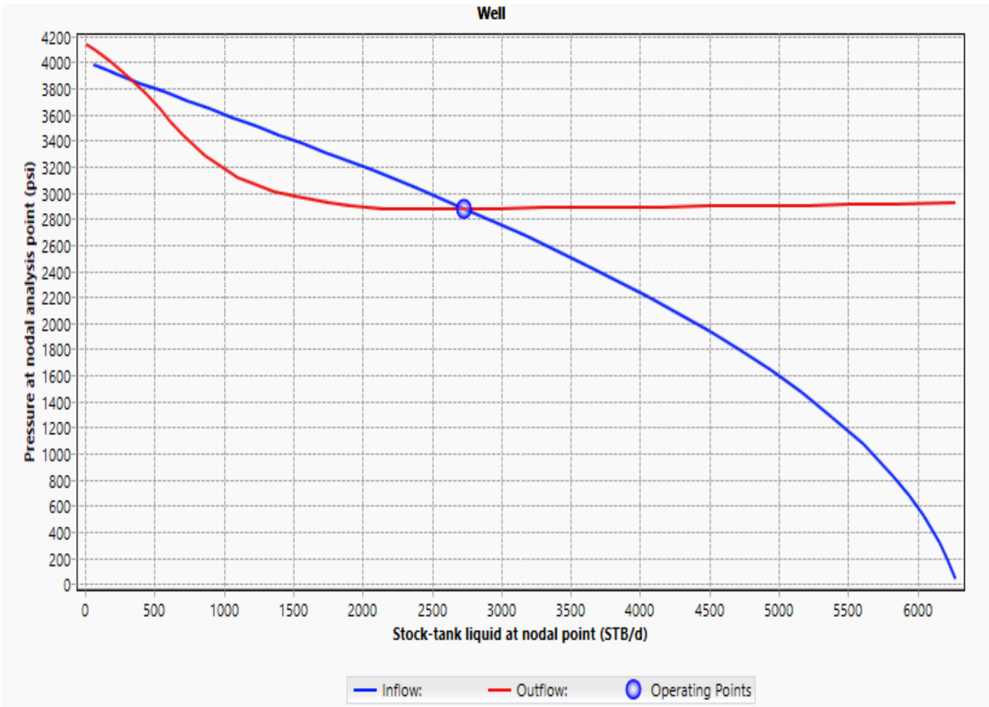


Fig 4 Nodal Analysis (IPR and OPR)

➢ *Results and Discussions for Sensitivity Analysis:*

A sensitivity analysis was carried out to investigate the effect of oil viscosity (API gravity) on well performance and optimal operating point below and above base viscosity (API gravity) value. From our results, we observed that at a viscosity of 20cp (14.95°API), there was no operating point. However, as the viscosity decreased to 1.5cp and 1.0cp (API gravity increased to 40.73°API and 46.72°API), there was a significant increase in flowrate of 3163.95 stb/day and a decrease in well flowing pressure of 2734.16 psi.

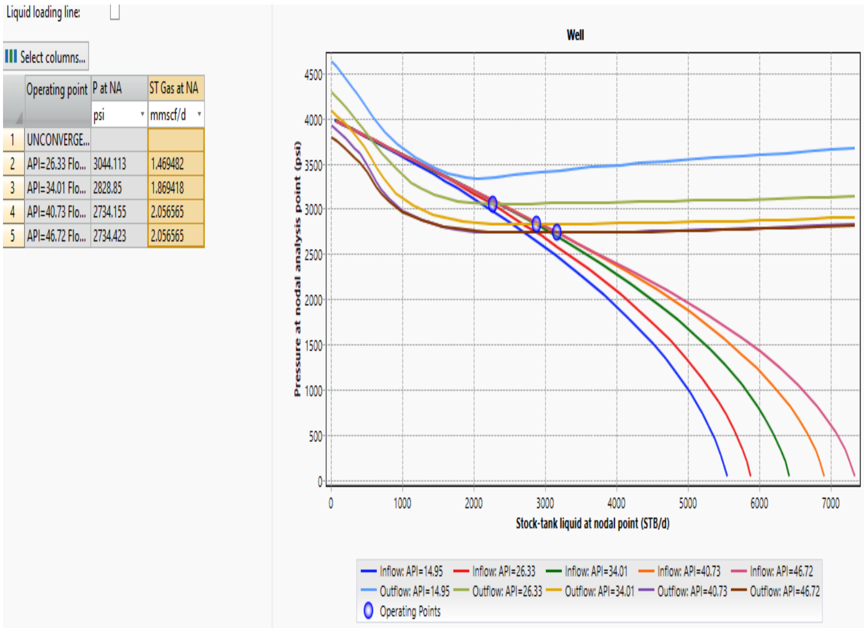

Fig 5 Sensitivity Analysis (IPRs and OPRs)

# CONCLUSION

Based on our findings, it can be said that the well productivity increases with decreasing liquid viscosity (higher API gravity) and decreases with increasing liquid viscosity (lower API gravity). Our investigation showed that the maximum operating conditions occurred at 1.5cp (40.73°API) and 1.0cp (46.72°API), however, the optimal operating point would be at a viscosity of 1.5cp because there was no shift in the operating point to the right of the IPR/OPR curve at a further reduction in viscosity. Because various assumptions were made in order to simplify the model that was employed, it should be noted that this conclusion has certain limits. Furthermore, the viscosity function needs to be added to the software to make it simpler to perform a sensitivity analysis on well performance with PIPESIM.

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## APPENDIX

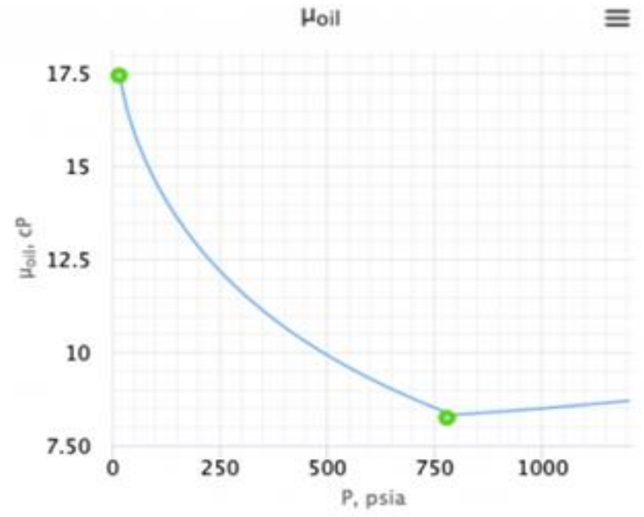


Fig 6 Beggs and Robinsons' Correlation

Table 1 PVT Data for Simulation

| Reservoir Fluid | Oil/Water/Gas |
|---|---|
| Water Cut | 0 |
| Solution GOR | 650 (SCF/STB) |
| Oil Gravity | 32(API) |
| Gas Gravity | 0.65 |
| Water Salinity | 75000 (ppm) |

Table 2 Deviation Survey

| Measured Depth (feet) | True Vertical Depth (feet) |
|---|---|
| 0 | 0 |
| 1000 | 1000 |
| 1500 | 1500 |
| 1954 | 1950 |
| 2262 | 2250 |
| 3077 | 3000 |
| 8993 | 8000 |
| 12672 | 11000 |
| 12960 | 11200 |
| 13435 | 11500 |

Table 3 Geothermal Data

| Measured depth (feet) | Temperature (°F) |
|---|---|
| 0 | 60 |
| 13400 | 175 |

Table 4 Tubing Configuration

| Label | Equipment Type | MD (feet) | ID (inches) | Roughness (inches) |
|---|---|---|---|---|
| Wellhead | Xmas Tree | 0 | N.A | N/A |
| Tubing | Tubing | 1100 | 3.992 | 0.0006 |
| Safety Valve | SSSV | 1100 | 3.6 | N/A |
| Tubing | Tubing | 13000 | 3.992 | 0.0006 |
| Casing | Casing | 13400 | 6.13 | 0.0006 |

| | Equipment | Name | Active | MD |
|---|---|---|---|---|
| | | | | ft |
| 1 | | NA | ✓ | 13200 |
| 2 | SSSV | SSSV 1 | ✓ | 1100 |

Fig 7 Downhole Equipment

CASING/LINER

| | Section type | Name | From MD | To MD | ID | Wall thickness | Roughness |
|---|---|---|---|---|---|---|---|
| | | | ft | ft | in | in | in |
| 1 | Casing | CsgSn 1 | 0 | 13400 | 6.13 | 0.361 | 0.0006 |

TUBINGS

| | Name | To MD | ID | Wall thickness | Roughness |
|---|---|---|---|---|---|
| | | ft | in | in | in |
| 1 | Tubing | 13000 | 3.992 | 0.3065 | 0.006 |

Fig 8 Casing and Tubing

REFERENCE OPTIONS

Depth reference: Original RKB

Wellhead depth: 0 ft

Bottom depth: 13400 ft

| | MD | TVD | Horizontal dis... | Angle |
|---|---|---|---|---|
| | ft | ft | ft | deg |
| 1 | 0 | 0 | 0 | 0 |
| 2 | 1000 | 1000 | 0 | 0 |
| 3 | 1500 | 1500 | 0 | 7.611304 |
| 4 | 1954 | 1950 | 60.13319 | 13.08735 |
| 5 | 2262 | 2250 | 129.8756 | 23.03802 |
| 6 | 3077 | 3000 | 448.8191 | 32.31031 |
| 7 | 8993 | 8000 | 3610.948 | 35.36921 |
| 8 | 12672 | 11000 | 5740.511 | 46.01704 |
| 9 | 12960 | 11200 | 5947.74 | 49.82223 |
| 10 | 13425 | 11500 | 6303.022 | 0 |

Fig 9 Deviation Survey Data

| | MD | Ambient temp... | U Value |
|---|---|---|---|
| | ft | degF | Btu/(h.deg... |
| 1 | 0 | 60 | 5 |
| 2 | 13400 | 175 | 5 |

Fig 10 Geothermal Data

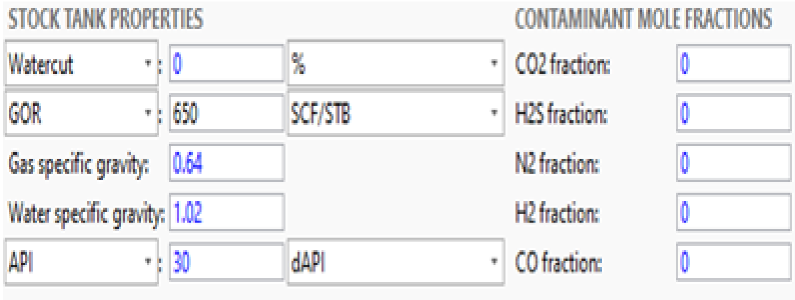


Fig 11 PVT Data 1

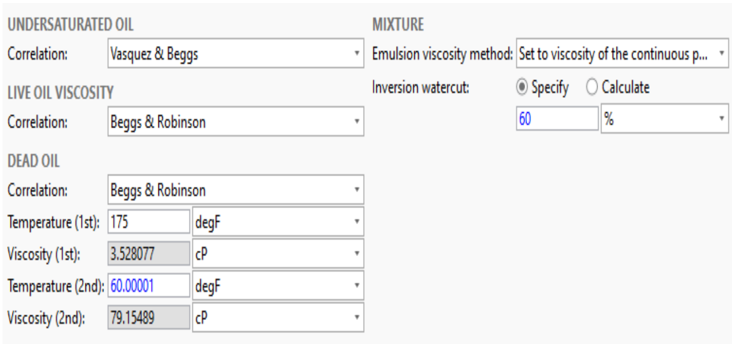


Fig 12 PVT Data 2

Table 5 Viscosity and API Gravity Data from MS Excel

| **µod(cp)** | **X @T=175°F** | **Y** | **Z** | **API (°)** |
|---|---|---|---|---|
| 1 | 0.301029996 | 122.2539846 | 2.087263023 | 46.71957375 |
| 1.5 | 0.397940009 | 161.610977 | 2.208470856 | 40.72808425 |
| 2.5 | 0.544068044 | 220.9563408 | 2.344306469 | 34.01352105 |
| 5 | 0.77815125 | 316.0219658 | 2.49971727 | 26.33132624 |
| 20 | 1.322219295 | 536.9783066 | 2.729956741 | 14.95023524 |

Table 6 Sensitivity Analysis Result

| **µod (cp)** | **API (°)** | **Q (stb/day)** | **Pwf (psi)** |
|---|---|---|---|
| 1.0 | 46.72 | 3163.95 | 2734.42 |
| 1.5 | 40.73 | 3163.95 | 2734.42 |
| 2.5 | 34.01 | 2876.03 | 2828.85 |
| 3.5 | 32 | 2730.46 | 2878.81 |
| 5.0 | 26.33 | 2260.74 | 3044.11 |
| 20.0 | 14.95 | _ | _ |