REVIEW ON GRAVITY DRAINAGE PERFORMANCE

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Abstract. *Gravity Drainage or GAGD is the name given for the use of gas injection into the crestal primary or secondary gas cap, high on the reservoir structure to displace oil downdip toward the production wells that are completed low in the oil column. A variety of gases can and have been used for GAGD and the immiscible gas displacement, with lean hydrocarbon gas used for most applications to date. Gas injection is particularly effective in high relief reservoirs where the process is GAGD because of the vertical/gravity aspects that increase the efficiency of the process and enhance recovery of updip oil residing above the uppermost oil-zone perforations. GAGD, in the most classical models, is modeled as a modified Buckley-Leverett method approach. Free-fall gravity drainage (without immiscible gas injection use), unlike forced gravity drainage (GAGD), cannot be modeled using a Buckley-Leverett approach because flow rate is not pre-specified, even though it has prediction models on its own.The performance prediction of reservoirs subject to GD is the focus of the present review. After a summary on the fundamentals of free fall gravity drainage and GAGD, the study covers the most recent publications about gravity drainage (GD) efficiency prediction. Including the classic GAGD model, a Li and Horne method for performance prediction of free-fall gravity drainage and a new Sharma and Rao method recommended for GAGD performance prediction, based on Buckingham-Pi dimensional analysis. Besides the instructional value of summarizing in a single paper important concepts and several models related to gravity drainage, one additional purpose of this work is to compare the most straightforward mathematical methods available in literature in order to define their range of use and flexibility when the use of other numerical solutions and reservoir simulation software is not a reasonable option. A comparative study is developed between the models, aiming at the applicability and accuracy of each procedure. A few improvements are suggested along the implementation of the methods, for example, the use of the excel solver tool with Brooks Corey regression for the evaluation of relative permeabilities. All the models are easily programmed in excel spreadsheets and replace the need of reservoir simulation in several specific cases. The Li and Horne model is able to match both experimental and field data. The classical SPE handbook method works suitably well for the GAGD performance prediction once its limitation assumptions are assured. The Sharma and Rao dimensional model for prediction of GAGD "gravity drainage" overall recovery is the simplest of the three methods and works remarkably well for almost every reservoir in which GAGD takes place, except for fractured and oil-wet reservoirs*

Keywords*: Immiscible Gas Injection; Gas Assisted Gravity Drainage; Free-Fall Gravity Drainage; Review; Comparison of Models*

1. INTRODUCTION

1.1. Different Gravity Drainage and Immiscible Gas Injection Applications

Gravity force induced flow (Gravity Drainage) is one of the three most important mechanisms of production of a reservoir. Gravity drainage production may occur both as a "free-fall" drainage or as a forced "gas-assisted" drainage. The first phenomenon is not induced artificially, it occurs in the absence of gas injection, it is believed to occur efficiently in naturally fractured reservoirs after depletion of oil in the fractures or gas injection in the fractured system[1] (Schecter and Guo, 1996) and its modelling is not fully comprehended. The latter phenomenon refers to a particular use of gas injection into steeply dipping gas reservoirs to increase oil recovery by immiscible displacement and is a wide known application. Gas Assisted Gravity Drainage or GAGD is the name given for the use of gas injection into the crestal primary or secondary gas cap, high on the reservoir structure to displace oil down dip toward the production wells that are completed low in the oil column. A variety of gases can and have been used for GAGD and the immiscible gas displacement, with lean hydrocarbon gas used for most applications to date[2] (Lake et alli, 2007)

1.2. Patterns of immiscible gas injection

Immiscible gas injection is usually classified as either crestal or pattern-like, depending on the location of the gas injection wells. The same physical principles of oil displacement apply to either type of operation; however, the overall objectives, type of field selected, and analytical procedures for predicting reservoir performance vary considerably by gas injection method. Crestal gas injection, sometimes called external or gas-cap injection, uses injection wells in higher structural positions, usually in the primary or secondary gas cap. This manner of injection is generally used in reservoirs with significant structural relief or thick oil columns with good vertical permeability. Injection wells are positioned to provide good areal distribution and to obtain maximum benefit of the gravity drainage phenomenon. Because of its higher efficiency, "Gas Assisted Gravity Drainage" occurs when crestal injection is applied. Therefore, crestal gas injection for "gravity drainage" or GAGD is the primary manner in which the immiscible gas/oil displacement process has been used.

Pattern type immiscible gas injection, sometimes called dispersed or internal gas injection, consists of a geometric arrangement of injection wells for the purpose of uniformly distributing the injected gas throughout the oil productive portions of the reservoir. This latter method of injection has been applied to reservoirs having low structural relief, relatively homogenous reservoirs with low permeabilities, and reservoirs with low vertical permeability. The performance prediction of patter injection is not important, since there are several limitations to pattern-type gas injection. Little or no improvement in recovery is derived from structural position or the gravity contribution and both injection and production wells are located in all areas of the reservoir. Low areal sweep efficiency results from gas override in thin stringers and by viscous fingering of gas caused by high flow velocities and adverse mobility ratios. Typical results of applying pattern injection in low-dip reservoirs are rapid gas breakthrough, high producing GOR, significant gas compression costs to reinject the gas into the reservoir, and an improved recovery of less than 10% of original oil in place (OOIP)[2].

1.3. Factors affecting GAGD efficiency

Immiscible gas displacement, either pattern-type or crestal-type, requires some particular fluid physical properties in order to be effective. One property that must be known is the interfacial tension (IFT) between the oil and gas fluid pair. It must assume values high enough in order to allow immiscible displacement to occur under reservoir conditions. The mobility ratio also is important for effective immiscible gas displacement. All displacements of oil by gas are at "unfavorable" mobility ratios, with typical values of 10 to 100 or more. One factor that illustrates the efficiency of the GAGD gravity drainage is the low occurrence of viscous fingering due to this unfavorable mobility ratio. If the gas/oil displacement is occurring vertically with gas displacing oil downward, gravity will work to stabilize the flood front, reducing this viscous fingering.

Other factors affect the effective immiscible gas displacement. Initial saturation conditions must be respected in order to allow immiscible gas displacement to work properly. If gas injection is initiated after reservoir pressure has declined below the bubble point, the gas saturation will decrease the amount of displaceable oil. If the free gas saturation exceeds the breakthrough saturation, no oil bank will be formed. Instead, oil production will be accompanied by immediate and increasing gas production. Oil viscosity and formation dip also affect the immiscible displacement efficiency. Low oil viscosities increase efficiency. High downdip inclination improves significantly efficiency if permeability is high enough and withdrawals rates do not exceed gravity-stable conditions.

GAGD is the most efficient form of immiscible gas injection. In order to allow it to occur, it is required that the withdrawal rates respect a limit related to the segregation of gas from oil. Depending upon the velocity of gas flow and the relative gas-oil saturation, the oil can either be propelled in any direction by the gas at high gas velocities or at low gas velocities the oil can flow downward under gravity and displace the gas, causing the gas to flow to higher levels. The critical gas velocity at which such counter flow can occur in sand is of much practical importance. Above this velocity dissolved gas-drive conditions will prevail and below it gravity drainage will prevail and the free gas and oil will segregate, the gas making its way to the higher parts of the reservoir and the oil to the lower parts. Another factor critical to immiscible displacement success is the extent to which vertical segregation occurs. Thick reservoirs (>183 m of oil column) are the best for application of the immiscible gas/oil drainage process with gas injection at the crest of the structure and oil production from as far down dip as possible. Geological factors also contribute for good GAGD gravity drainage performance. Within the reservoir sandstone layers, the nature of the sand layering can strongly affect the efficiency of the gas-oil displacement. The gas-oil displacement process is far more efficient in depositional environments in which the highest permeability sands are on the bottom of the reservoir interval. The reason is that the gravity override of the gas is slowed by the vertical distribution of permeability.

1.4. Physical mechanisms of GAGD gravity drainage

The primary physical mechanisms that occur as a result of gas injection (and hence of the GAGD gravity drainage) are (1) partial or complete maintenance of reservoir pressure, (2) displacement of oil by gas both horizontally and vertically, (3) vaporization of the liquid hydrocarbon components from the oil column and possibly from the gas cap if retrograde condensation has occurred or if the original gas cap contains a relict oil saturation, and (4) swelling of the oil if the oil at original reservoir conditions was very undersaturated with gas. As with any immiscible displacement, all these mechanisms occur with GAGD gravity drainage.

2. Comparative Study of Models

2.1. Li and Horne analytical model for prediction of free-fall "gravity drainage" overall recovery

Li and Horne (2003)[3] proposed a modified model to match and predict the oil production by free-fall gravity drainage in which the constant governing the rate of convergence and the average residual oil saturation can be estimated. Their study was based on the empirical model by Aronofsky et al (1958)[4]. Their analytical model for performance prediction requires either laboratory data related to a gravity drainage experimental recovery from a sample core of the reservoir or field data concerning the history of production of a reservoir. Knowing the gas-oil contact depth, the connate water saturation and residual oil saturation allows obtaining the average residual oil saturation. Then the data for oil production as a function of time, or oil recovery as a function of time, allow to predict convergence coefficient beta and to predict the free-fall recovery behavior through time.

The model is based in four main equations. The average residual oil saturation is given by:

$$\cancel{S_{or}} = S_{or} + (1 - S_{wi} - S_{or})\, z_c \quad (1)$$

where:
$\cancel{S_{or}}$= average residual oil saturation; S_{or} = residual oil saturation determined from the capillary pressure curve; S_{wi} = connate water saturation

$$z_c = \frac{L - z_e}{L} \quad (2)$$

where:
L=length of the length of the core sample; z_e = the depth corresponding to the entry capillary pressure, p_e

$$N_{po} = V_p(1 - S_{wi} - \cancel{S_{or}})\left(1 - e^{-\beta t}\right) \quad (3)$$

where:
V_p=ALϕ = the reservoir or core sample porous volume; A = the cross sectional area ; β= the constant governing the rate of convergence; N_{po}=the oil produced by free-fall gravity drainage

$$R = \frac{(1 - S_{wi} - \cancel{S_{or}})}{1 - S_{wi}}\left(1 - e^{-\beta t}\right) \quad (4)$$

where:
R= the oil recovery in units of original oil in place

Non-linear regression software can be used in order to match history or experimental data, allowing to calculate convergence coefficient beta and the average residual oil saturation, leading to the relation that predicts oil recovery through time using free fall gravity drainage. The examples studied by Li and Horne have been reproduced and are going to be explained on the next sessions.

2.2. Li and Horne analytical model range of application

The model mentioned previously is only meant to predict the behavior of free-fall gravity drainage, that is, in the absence of immiscible gas injection. Also there are some requirements that must be respected in order to allow a good prediction by the model. First, a significant history of production or experimental data is needed, second, the pore size distribution index must be known or be assumed to approach infinity. Third, the water phase is assumed to be immobile. Fourth, the only two forces involved in the process are gravity and capillary pressure

2.3. Li and Horne analytical model results, accuracy and reproducibility

The work of Li and Horne[3] was tested against three sets of gravity drainage published data. One was based on an experimental work done by Pedrera et alli (2002)[5] in gas-oil-water rock systems. Another set of data was derived from a work by Li and Firoozabadi (2000)[6] that conducted oil-gas gravity drainage tests in a Berea sandstone core with different wettability. The third set of data came from a work published by Dykstra (1978)[7], reviewing the Lakeview pool, Midway Sunset oilfield, in which the oil was produced by strictly free-fall gravity drainage, a real case reservoir. Therefore, Li and Horne[3] model was tested against both experimental and field data. Li and Horne[3] concluded that their model could work satisfactorily for all examples presented at both core scale and field scale.

In order to reproduce their work, all the three sources of data were sought and the model was applied again in a excel worksheet using the four formulas developed by Li and Horne in order to reproduce and test their work. It was not possible to extract a smooth curve of experimental data from the Pedrera et alli[5] paper, therefore making impossible the non-linear regression. The first result of Li and Horne paper[3], therefore, was not confirmed successfully. Then, Li and Firozaabadi[6] paper data was tested with Li and Horne model[3]. The experimental core data provided are shown in Tab. 1.

Table 1: Core Data

L (m)	S_{wi}	S_{or}
0.189	0.11	0.45
A (10^{-6} m^2)	Φ	Vp (10^{-6} m^2)
5.474	0.213	22.03
ρ^o (kg/ m^3)	$k^*k_{ro}^*$	μo (10^{-6} Pa*s)
730	1089	95

Fig.1 displays the experimental recovery data and its non-linear regression.

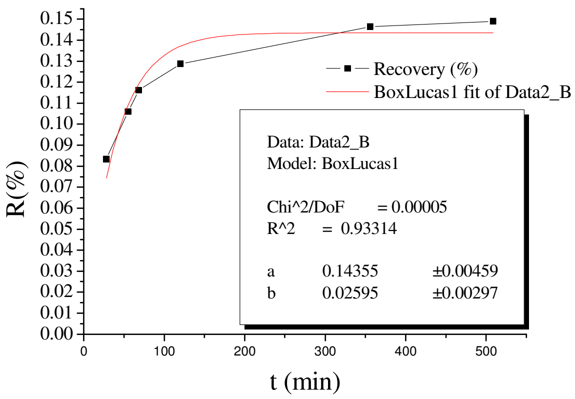

Figure 1: Core Data Non-Linear Regression

The calculated results were compared to the results provided by Li and Horne, as summarized in Tab. 2:

Table 2: Review vs Li and Horne for Core Data

	β (min^{-1})	~~Sor~~
Review	0.02595	0.714
Li and Horne	0.02053	0.867
difference	26.400%	-17.65%

Considering that the data was obtained from graphic reading, it is possible to conclude that Li and Horne model is able to predict the free-fall gravity recovery from laboratory data satisfactorily. Finally, Dykstra field data was tested with Li and Horne model. The data provided is shown in Tab. 3.

Table 3: Dykstra Field Data

ze (m)	L (m)	Swi	Sor
493.78	687.93	0.29	0.10
A (sqm)	Φ	Vp (MM m3)	Soi
588.00	0.23	11.82	0.71
qoi (m^3 OPY)	ρo (kg/m^3)	k*kro*	μo (10^{-3} Pa*s)
446833.81	804.00	1100.00	2.30

The corresponding production history and obtained non-linear regression are displayed in Fig.2.

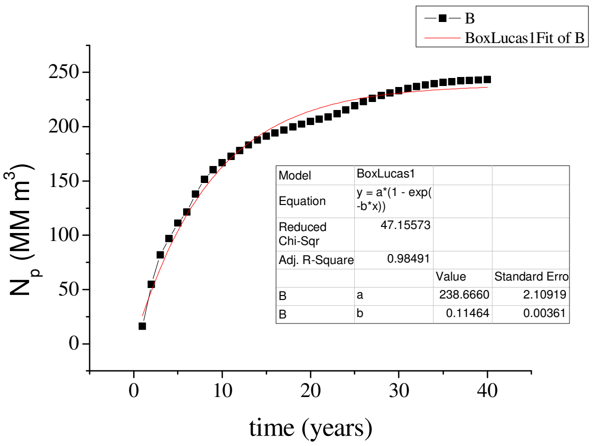

Figure 2: Field Data Non-Linear Regression

The calculated results are compared to the results provided by Li and Horne in Tab. 4.

Table 4: Review vs. Li and Horne for Field Data

	β (year^{-1})	~~Sor~~
Review	0.11464	0.272
Li and Horne	0.11463	0.285
difference	0.009%	-4.505%

Given the simplicity of the method, the results provided by Li and Horne[3] model show it is able to reasonably predict the overall tendency and values within the acceptable range for the free-fall gravity recovery for both laboratory and field data.

2.4. Range of use of the classical analytical model for prediction of GAGD production rate

The model based on the Buckley and Leverett**Erro! Indicador não definido.** theory provides reliable predictions once the following assumptions are granted: First, that resistance to gas flow and capillary effects are negligible (Cardwell and Parsons, 1948)[8]. Second, the same assumptions of Buckley Leverett[4] are assured, that is, that gas injection rate is kept constant, with steady state flow, constant pressure, no compositional effects, no production of fluids behind the gas front, movement of advancing gas parallel to bedding plane, immobile water saturation, and no gravity segregation f fluids within the element. Third, it requires that the gas injection rate obeys the stable gravity drainage operation rate, relative to the critical rate, discussed in the next section

2.5. Assurance for stable "gravity drainage", operation rate for classical analytical prediction of GAGD production rate

Unlike the pattern type immiscible injection and unlike free-fall gravity drainage, the displacement of oil by GAGD gravity drainage may be described by one simple mathematical analytical model when it is gravity stable. This happens when the rate is **less than one-half** the critical rate. The critical rate is given by:

$$\left(\frac{q_T}{A}\right)_{critical} = \frac{0.044\, k\Delta\rho\, sin\alpha}{\left(\frac{\mu_o}{k_o} - \frac{\mu_g}{k_g}\right)}) \qquad (5)$$

2.6. Classical analytical model for prediction of stabilized GAGD overall sweep efficiency

Though modern numerical reservoir simulators are commonly used to calculate the projected performance of applying immiscible gas injection to a particular reservoir, it requires sufficient production and field data and the use of resources that many times are not available. The main focus of this study is the analytical model for simpler efficiency prediction. The use of simple analytical solutions becomes particularly important in the cases when lack of data or economic reasons does not allow a reliable numerical reservoir simulation. The classic analytical model for gravity drainage gas injection is relatively easy to program in computer spreadsheets, provided that the equation development is correctly done. Generally, analytical procedures have a limited range of accuracy. These methods must assume equilibrium between injected gas and displaced oil phases and the most of the assumptions of Buckley-Leveret method in order to work properly. Though, if significant deviations from the basic assumptions of Buckley-Leverett**Erro!**

Indicador não definido. are of concern, then the more practical approach is to use numerical reservoir simulation. Nevertheless, this aspect will not be covered in this article.

The classical recovery efficiency prediction through the gravity drainage process is available for the case in which production rate allows it a stable behavior. This stable rate of production can be estimated by the simple engineering calculation technique explained on the previous section. Then, the efficiency may be estimated. One widespread classical method for calculation of displacement efficiency uses a modified method of Buckley-Leverett method for gas. The original equations that characterize the mechanism of oil displacement by an immiscible fluid were developed by Buckely and Leverett[Erro! Indicador não definido.] using relative permeability concepts and Darcy's law describing steady-state flow through porous media. Assumptions inherent in their work are steady-flow, constant pressure, no compositional effects, movement of advancing gas parallel to the bedding plane, immobile water saturation, and uniform cross-sectional flow (no gravity segregation of fluids within the element). Subsequent work by Welge**Erro! Indicador não definido.** made solving equations easier.

The Welge equation for the fractional flow of gas at any gas saturation (Sg) is calculated as follows:

$$f_g = \frac{1 + {(0.044 k k_{ro} \Delta\rho A \sin\alpha)} \big/ {q_t \mu_0}}{1 + 1 \Big/ \dfrac{k_{rg}\mu_0}{k_{ro}\mu_g}} \tag{6}$$

To relate the fraction of gas flowing to time, Buckley and Leverett**Erro! Indicador não definido.** developed the following material-balance equation:

$$L = \frac{q_T t}{\phi A}\left(\frac{df_g}{dS_g}\right) \tag{7}$$

where:
L = length, m; S_g = gas saturation, fraction; t = time, s; ϕ = porosity, fraction.

The value of the derivative $\frac{df_g}{dS_g}$ may be obtained for any value of gas saturation by determining slopes at various points on the f_g vs. S_g curve. Theses slopes can be obtained manually or, more precisely, using the method presented by Kern**Erro! Indicador não definido.** for computer spreadsheets. The area beneath the fractional f_g vs. S_g curve represents the gas invaded zone. The gas/oil displacement efficiency, the percent of the oil volume that has been recovered, can be calculated for any period of gas injection by integrating the volume of the gas-invaded zone as a function of gas saturation. Hence, the fractional flow curves are used to generate saturation profiles that are integrated leading to the average amount of recovered oil, allowing calculating the values for the gas/oil displacement efficiency.

The most common method works in the following order: First, use eq. (1) to assure the stable condition, supposing that the calculation of the critical rate leads to the conclusion that the reservoir drainage rate is less than one-half the critical rate. The second calculation adjusts the relative permeability data to account for low saturation capillary effects using the theory of Corey et alli[9], according to the following equation:

$$kr = \left(\frac{S_o - S_{org}^*}{1 - S_{wi} - S_{org}^*}\right)^n \tag{8}$$

where:
S_{org}^*= residual oil saturation

The third calculation determines the gas saturation just above the gas-oil-contact (at breakthrough) by using equation (6) and the Welge**Erro! Indicador não definido.** graphical technique, plotting the fractional flow versus gas saturation, and finding the tangent to the curve passing through the curve origin. For ease of calculation, the GOC is assumed to move at a constant rate. Then, the time before breakthrough is calculated using eq. (9):

$$t_{BT} = \frac{AL\Phi\Delta S}{q_T} \tag{9}$$

The next calculation determines the quantity of oil that drains from the region invaded by gas until breakthrough. For ease of calculation, this region is divided into arbitrary lengths, and the amount of oil produced by vertical gravity drainage is calculated from the average time since passage of the gas front. A correlation is obtained for the derivative of the fractional flow after the gas-oil front after the assumption that resistance to flow of gas and capillary effects are negligible[8] The equation is then used to calculate the saturation profile for each arbitrary block, using equation (7) and t_{BT}. The plotting of each profile versus oil saturation allows obtaining the average oil saturation of that block by numerical integration. Then, the residual oil saturation is calculated from the average of the saturations at breakthrough. Finally, the oil recovery at gas breakthrough is calculated from the equation:

$$OR@GBT = \left[\frac{(1-S_{wi}-S_{or})}{(1-S_{wi})}\right] \tag{10}$$

2.7. Classical analytical model for GAGD results, accuracy and reproducibility

Warner and Holstein (2007)[2] applied the classical method to a real case data, the Hawkins field, which present the reservoir properties displayed in Tab. 5:

Table 5: Hawkins Field Average Properties

K, Darcies	kv, Darcies	Φ fraction	Swi %	θ, degrees	hv, m	L (along bedding planes), m
3.4	2.38	0.279	8%	6	14.9352	1066.8
μo, 10^{-3} Pa*s	μg, 10^{-3} Pa*s	ρo, kg/m3	ρg, kg/m3	u per unit area, m3/m2-D	pr, 10^5 Pa	
4.45	0.0185	828.154512	85.6987744	0.0111252	10.3421355	

Along with relative permeability curves of Fig. 5.

The relative permeability curves were adjusted through a non-linear regression. First the gas relative permeability was adjusted to function shown in Fig. 3.

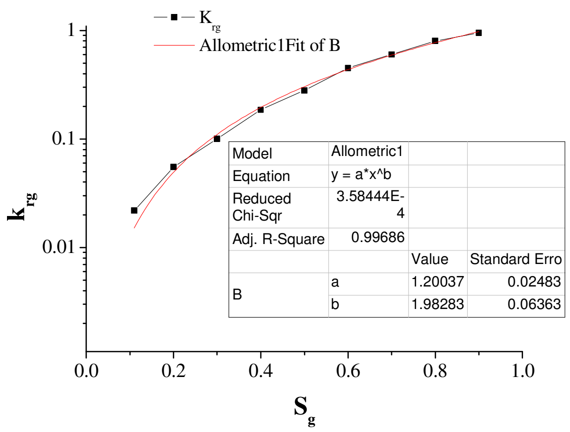

Figure 3: Gas Relative Permeability Non-Linear Regression

Then the oil relative permeability was adjusted using Corey model to improve the low saturation behavior:
A program embedded in a MS Excel solver tool was used to fit the curves, with results shown in Fig. 7.

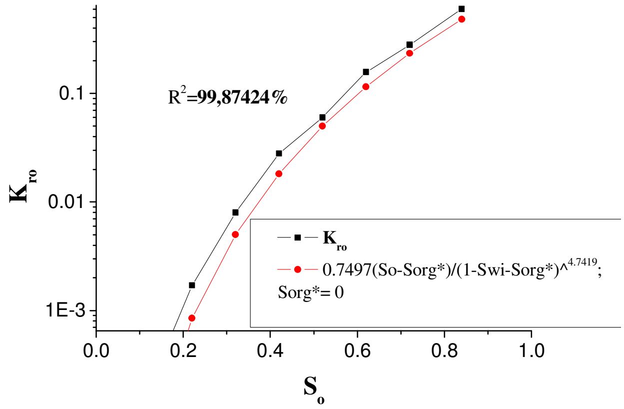

Figure 4: Oil Relative Permeability Algorithmic Fitting to Brooks and Corey model, solver solution

The resulting regression functions for relative permeability are given in Tab. 6.

Table 6: Relative permeability regressions

Equation	$k_{ro} = 0.7497*(S_o\text{-}0)/(1\text{-}S_{wi}\text{-}0)^{\wedge 4.7419}$	
R^2	99.89605%	98.83000%

The average actual rate was compared to the critical rate calculated, as summarized in Tab.7.

Table 7: Critical Rate Comparison and BT calculations

	Reproduced	Handbook calculations	
u per unit area, ft3/ft2-D	0.0111252	0.0111252	-
u critical	0.025	0.0527304	*m^3/D-m^2*
% u critical	44.24%	21.10%	*%*
u actual	38.301	31.6992	*m/yr*
t BT	27.85	34	*years*

The results confirmed that the classical, simpler model for GAGD should apply.

To proceed with recovery calculation, the fractional flow curve of the GAGD is built and the average gas saturation just above the GOC is found to be 38% by the Welge procedure, as depicted in Fig.8.

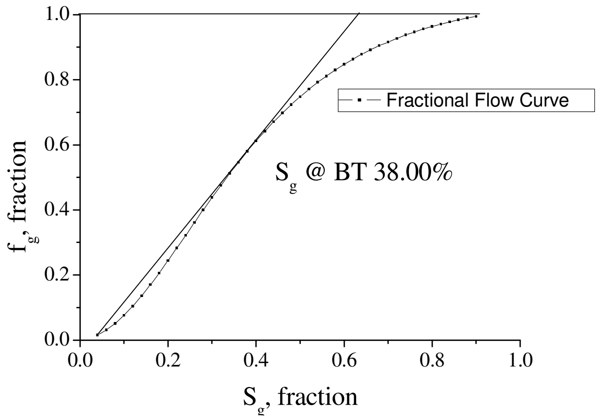

Figure 5: Fractional Flow Curve and Welge Graphical Technique

Recovery at breakthrough was then estimated by dividing the reservoir into seven blocks, each 152.4m long and 14.94 m thick. The saturation profile of each block at breakthrough was estimated, using the same procedure as explained previously. The residual oil left in each block is determined by graphical integration of So vs. height curves.

The final results obtained using the classical method for the example and along with the values reproduced from the Handbook are found in Tab.8.

Table 8: Residual Saturations: Handbook vs. Reproduction

Segment	Average So, % Reproduced	Average So, % Handbook
1	3.396%	8.70%
2	6.797%	9.20%
3	10.193%	9.60%
4	13.592%	10.40%
5	16.990%	11.20%
6	20.389%	12.80%
7	23.785%	16.90%

Results allowed to calculate recovery through eq. (8), leading to the values displayed in Tab. 9

Table 9: Oil Recovery: Real vs. Handbook and Reproduction

	reproduced	handbook
OR at GBT	85.23%	88%
Real OR	87%	87%
Error	2.038%	-1.149%

Hence, it was demonstrated that the classical method works suitably well for the GAGD performance prediction, for cases meeting the restrictions mentioned previously.

2.8. Sharma and Rao dimensional model

Sharma and Rao (2008)[10] conducted a series of scaled physical experiments in order to characterize and predict the GAGD performance through Buckingham-Pi dimensional analysis. The authors aimed to correlate the recovery observed in field examples with three non-dimensional numbers: the Bond Number, the Capillary number and the Gravity number. One conclusion was that the correlation obtained for recovery versus gravity number worked very well to predict the GAGD recovery in almost every reservoir studied. One restriction is that the model is not able to predict free-fall gravity drainage, also, it does not work with oil-wet type reservoirs or fractured reservoirs. The authors also concluded that higher recoveries were obtained through GAGD at constant pressure gas injection and that GAGD was very superior in performance when compared to WAG process on the same reservoir.

2.9 Buckingham-Pi dimensional model equations

Sharma and Rao[10] model to predict GAGD gravity drainage overall recovery is very simple. It requires determination of a dimensional number called gravity number:

$$N_G = \frac{\Delta\rho g\left(\frac{K}{\phi}\right)}{\mu_o v_d} \tag{11}$$

The overall recovery is given by the equation:

$$Recovery(\%ROIP) = 4{,}9307Ln(N_G) + 30{,}153 \tag{12}$$

In order to confirm the accuracy of the model, the gravity number calculation was obtained for the same example studied at the GAGD classical model and the Hawkins Field data. The gravity number was calculated as $N_G =$ 80710.56921. It leads to the result displayed in Tab. 12, confirming the reliability of the model.

Table 10: GAGD Models final results for accuracy

	reproduced	handbook	Rao et alli 2008
OR at GBT	85.23%	88%	85.863%

Real OR	87%	87%	87%
Error	2.038%	-1.149%	-1.307%

3.CONCLUSIONS

1. Gravity Drainage is an efficient recovery process, with recovery rates unmatched by many other EOR methods. The classic examples studied presented recovery values that suggest that it is the most effective immiscible gas injection process.
2. Three models were studied: one for free-fall gravity drainage recovery prediction and two for GAGD recovery prediction. All models are easily programmed in excel spreadsheets, giving a fast estimate without the use of reservoir simulation in several specific cases.
3. The Li and Horne[3] model is able to match both experimental and field data and, hence, with a set of experimental tests data or field production data, it is able to satisfactorily predict the recovery of free-fall gravity drainage. Once a significant amount of production history or experimental data is available.
4. The classical SPE handbook method[2] works suitably well for the GAGD performance prediction once previously assured that: first, that resistance to gas flow and capillary effects are negligible[8]. Second, assumptions of Buckley Leverett are valid Third, it requires that the gas injection rate obeys the stable gravity drainage operation rate, relative to the critical rate
5. The Sharma and Rao[10] Buckingham-Pi dimensional model for prediction of GAGD gravity drainage overall recovery is the simplest of the three methods and works remarkably well for almost every reservoir in which GAGD takes place, except for fractured and oil-wet reservoirs
6. This work also has an instructional purpose, as it brings together three models of gravity drainage calculation. The behavior analyses of other models can be done to complement the present work. It also states a series of variables that must be optimized in order to improve the GAGD recovery and distinguish the different techniques used for gravity drainage
7. A few improvements were suggested along the implementation of the methods, for example, the use of the excel solver tool with the Brooks Corey[9] regression for the evaluation of relative permeabilities

4. ACKNOWLEDGEMENTS

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