ppi 201502ZU4659
This scientific digital publication is continuance of the printed journal impresa p-ISSN 0254-0770/ e-ISSN 2477-9377 / Legal Deposit pp 197802ZU3

La Ciega Historical building. LUZ first headquarter

REVISTA TÉCNICA
DE LA FACULTAD DE INGENIERÍA

“Post nubila phoebus”
“After the clouds, the sun”

LUZ in its 130th anniversary Established since 1891

An international refereed Journal indexed by:

- SCOPUS
- SCIELO
- LATINDEX
- DOAJ
- MIAR
- REDIB
- AEROSPACE DATABASE
- CIVIL ENGINEERING ABTRACTS
- METADEX
- COMMUNICATION ABSTRACTS
- ZENTRALBLATT MATH, ZBMATH
- ACTUALIDAD IBEROAMERICANA
- BIBLAT
- PERIODICA
- REVENCYT

REVISTA TÉCNICA
DE LA FACULTAD DE INGENIERÍA

UNIVERSIDAD DEL ZULIA

VOLUME 44 SEPTEMBER - DECEMBER 2021 NUMBER 3

Determination of the Initial Water Saturation Model based on Capillary Pressure Curves by Rock Type

Eddymar Márquez[1], *César Aguilar*[1], *Américo Perozo*[2]

[1]Estudios Integrados de Yacimientos Occidente. Petróleos de Venezuela (PDVSA). Maracaibo, Venezuela.
[2]Facultad de Ingeniería, División de Estudios para Graduados, CP. 4001. Universidad del Zulia. Maracaibo, Venezuela.
*Corresponding author:marquezeddymar@gmail.com; aguilarcp9@gmail.com
https://doi.org/10.22209/rt.v44n3a01
Received: November 4, 2020 | Accepted: June 4, 2021 | Available: August 1, 2021

Abstract

The log-derived initial water saturation (S_{wi}) is influenced by fluids drainage from the producing wells, generating underestimation of the Stock-Tank Original Oil in Place (STOOIP). To restore the initial conditions of the reservoir, it is necessary to use drainage Capillary Pressure (P_c) tests, which determine the distribution of S_{wi}, prior to any hydrocarbon production. This research aimed to determine the S_{wi} model, based on P_c curves by rock type, for a better estimation of the STOOIP of LUZ reservoir in the Maracaibo Basin. The methodological procedure included: data gathering (logs and cores, with 15 plug samples for P_c analysis), description of rock types, determination of the S_{wi} model and estimation of the STOOIP. Among the results, the following stand out: the J-Leverett model fit best to the P_c curves of the reservoir for all rock types; the estimated STOOIP using the water saturation (S_w) of the proposed capillary pressure based model and the one estimated using logs, showed a discrepancy of 19.8 %, evidencing the importance of a robust model to increase certainty in the estimation of reserves.

Keywords: capillary pressure; initial water saturation; model; rock type; stock-tank original oil in place.

Determinación del Modelo de Saturación de Agua Inicial basado en Curvas de Presión Capilar por Tipo de Roca

Resumen

La saturación de agua inicial (S_{wi}) a partir de registros está influenciada por el drenaje de fluidos de los pozos productores, generando subestimación del petróleo original en sitio (POES). Para restaurar las condiciones iniciales del yacimiento, es necesario utilizar pruebas de presión capilar (P_c) de drenaje, que determinan la distribución de S_{wi} previa a cualquier producción de hidrocarburos. Esta investigación tuvo como objetivo determinar el modelo de S_{wi}, basado en curvas de P_c por tipo de roca, para una mejor estimación del POES del yacimiento LUZ de la cuenca de Maracaibo. El procedimiento metodológico incluyó: recopilación de datos (registros y núcleos, con 15 muestras de P_c), descripción de tipos de roca, determinación del modelo de S_{wi}, y estimación del POES. Entre los resultados, destacan: el modelo J-Leverett se ajustó mejor a las curvas de P_c del yacimiento para todos los tipos de roca; el POES estimado utilizando la saturación de agua (S_w) del modelo propuesto basado en presión capilar y la calculada usando registros, mostró un 19,8 % de discrepancia, evidenciando la importancia de un modelo robusto para incrementar la certidumbre en el cálculo de reservas.

Palabras clave: modelo; petróleo original en sitio; presión capilar; saturación de agua inicial; tipo de roca.

Introduction

To estimate the STOOIP, it is required to know the Sw at the initial reservoir conditions. Well logs (resistivity) are often affected by fluids drainage of the reservoir; additionally, old resistivity curves had problems of not being focused and having a poor vertical resolution (Rider and Kennedy, 2011), for which laboratory experiments are convenient to represent the reservoir saturation history or the hysteresis phenomenon, being the special core analysis, such as Pc drainage tests, capable of simulating the initial reservoir conditions.

According to Valenti et al. (2002), when the Pc curves are observed together, different shapes of these are appreciated, as well as dispersion of data, representing the heterogeneity of the reservoir. This behavior suggests that the data should be classified according to the sample rock quality (Obeida et al., 2005; Xu y Torres, 2012).

The purpose of this research was to determine the Swi model, based on Pc by rock type, of a siliciclastic reservoir in the Maracaibo basin, to improve the estimation of the STOOIP. Results are based on core and log data processing and analysis; these consisted on the description of the rock types present in the reservoir, classification of Pc curves by rock type, selection of the model that best fit and represented the reservoir data, generation of water saturation equations, comparison of the Sw curves of the proposed model with the log-derived in the first drilled wells, as well as the contrast of the STOOIP in an area of the reservoir, obtained from the Sw model, with the log-derived Sw (Obeida et al., 2005; Paradigm and Epos, 2011; Xu and Torres, 2012).

Materials and Methods

Phase I: information gathering and validation

Data were collected and validated from the reservoir (due to confidentiality rules of the PDVSA company, the original names of the reservoir, study area and wells have been changed), cored wells, among which stand out: routine or conventional core analysis (RCA) to determine rock types and special core analysis (SCAL) such as Pc drainage tests to determine the Swi model, as well as conventional logs. A robust database was generated using a petrophysical software.

Phase II: description of rock types based on statistical parameters

It was used the Flow Zone Indicator (FZI) methodology of Amaefule et al. (1993), based on porosity (ϕ) and permeability (k) data, corrected by overburden pressure, in accordance with Jones (1988). The FZI was calculated for all the samples using Equations 1, 2 and 3, and results were analyzed using statistical tools, which allowed identifying the rock types present in the reservoir.

$$\text{Reservoir Quality Index: RQI } (\mu m) = 0.0314 * \sqrt{\frac{k}{\phi_e}} \quad (1)$$

Where, ϕ_e: effective porosity (fraction); k: permeability (md)

$$\text{Normalized Porosity Index: } \phi_z (\text{fraction}) = \frac{\phi_e}{(1-\phi_e)} \quad (2)$$

$$\text{Flow Zone Indicator: FZI } (\mu m) = \frac{RQI}{\phi_z} \quad (3)$$

Phase III: preparation of Pc data and their relationship with the core-derived petrophysical properties

In this phase, the data obtained from the drainage Pc tests were classified by rock type; previously, corrections were made to the data obtained from the laboratory Pc tests and converted to reservoir conditions.
The equations to correct data by overburden pressure indicated by Paradigm and Epos (2011) are detailed below:

$$P_c \text{ corrected by overburden pressure: } P_{c_{corr}} (\text{psi}) = \frac{P_{c_{lab}}}{\sqrt{\frac{\phi_{res}}{\phi_{lab}}}} \quad (4)$$

Where, $P_{c_{lab}}$: capillary pressure at laboratory conditions (psi); ϕ_{res}: porosity at initial reservoir conditions (fraction); ϕ_{lab}: porosity at laboratory conditions (fraction).

S_w corrected by overburden pressure: $S_{w_{corr}}(\text{fraction}) = 1-\left(1-S_{w_{lab}}\right)*\frac{\phi_{res}}{\phi_{lab}}$ (5)

Where, $S_{w_{lab}}$: water saturation at laboratory conditions (fraction).

Equations for the conversion of data from the system used in the laboratory to the reservoir system (Paradigm and Epos, 2011):

Capillary pressure converted to reservoir system: $P_{c_{yac}}(\text{psi}) = P_{c_{corr}}\frac{(\sigma * \cos\theta)_{res}}{(\sigma * \cos\theta)_{lab}}$ (6)

Where, $(\sigma * \cos\theta)_{res}$ = interfacial tension * cosine of contact angle at initial reservoir conditions, equal to 26 dyn/cm for the present system (oil/brine), according to Adams and Van den Oord, (1993); $(\sigma * \cos\theta)_{lab}$ = interfacial tension * cosine of contact angle at laboratory conditions.

Phase IV: determination of S_{wi} model of LUZ reservoir from the P_c tests by rock type

The steps followed are detailed below:

a) Calculate the P_c versus S_{wi} curve, by rock type, for each of the most used models in the literature (Adams and Van den Oord, 1993; Paradigm and Epos, 2011) in cored wells.

b) Select the model that best fit to the core P_c curves for each rock type, adjusting the coefficients proposed by the original authors (Paradigm and Epos, 2011).

c) Predict the S_{wi} curve above the Free Water Level (FWL). To do this, the height above the FWL (H) was calculated for each point. Once the height was obtained, the P_c is calculated at each depth, according to Obeida *et al.* (2005):

$H\ (\text{feet}) = FWL-TVD_{ss}$ (7)

Where, FWL: free water level (feet); TVD_{ss}: true vertical depth sub sea (feet).

$P_c\ (\text{psi}) = 0.433*H*\left(\rho_{water}-\rho_{oil}\right)$ (8)

Where, ρ_{water}: density of water (g/cm^3); ρ_{oil}: density of oil (g/cm^3).

d) Compare the S_{wi} curve obtained from P_c tests and the one calculated with the information from logs of the first drilled wells in the study area (PDVSA, 2019).

e) Propagate the model to all the wells of the study area.

Phase V: estimation of STOOIP in the basal sand of LUZ reservoir, P-1 area

The STOOIP was calculated by the volumetric method (PDVSA, 2005), using both the S_w based on the proposed P_c model, and the log-derived S_w, establishing their level of discrepancy.

Results and Discussion

Phase I: information gathering and validation

The data obtained from conventional and special core analysis of three wells is displayed in Table 1, in which it is showed the total number of conventional analysis samples used to determine rock types, as well as the SCAL P_c tests used to build the saturation height model, specifying the test method and the fluid systems handled in the laboratory, is described.

Table 1. Inventory of P_c tests for the studied reservoir.

Well	Conventional core analysis (ϕ y k)	Special core analysis Capillary pressure (drainage)		
	Number of samples	Number of samples	Method	Fluid system used in the laboratory
LUZ1246	11[1]	4[1]	Porous plate cell	Air/brine
LUZ1348	15[2]	6[3]	Centrifuge	Oil/brine
LUZ1542	15[4]	5[5]	Centrifuge	Oil/brine
Total samples	41	15		

[1]Omni Laboratories de Venezuela (1997); [2]Core Laboratories Venezuela (2000); [3] PDVSA (2019); [4]Omni Laboratories de Venezuela (2007); [5]Core Laboratories Venezuela (2008).

Phase II: description of rock types based on statistical parameters

To show the rock types existing in the reservoir, a log-log crossplot RQI vs ϕ_z (Figure 1) was performed, where 6 lines of unit slope are shown, corresponding to the 6 rock types in the reservoir; the intercept of these lines with ϕ_z = 1 provides an approximate value of the FZI of each rock type, ordered from higher (higher FZI) to lower quality (lower FZI).

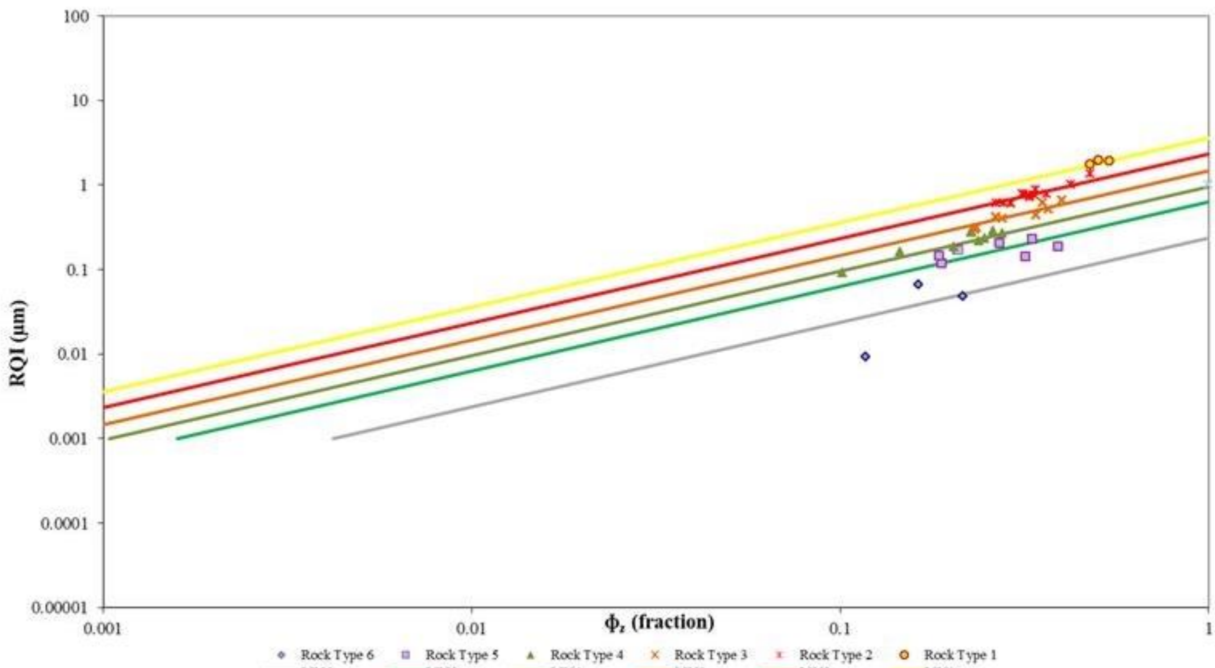

Figure 1. Visualization of the rock types of LUZ reservoir, through the Reservoir Quality Index versus Normalized Porosity Index.

Some statistical indicators of the FZI for each rock type are presented in Table 2. It is observed that the standard deviation for each rock type varies between "moderately low" and "low", thus concluding that the identified classes are consistent from a statistical point of view. For the propagation of rock types, the FZI was calculated using the permeability generated by the Timur model (Uguru, 2004), with modifications in its coefficients.

Table 2. Statistical parameters of the Flow Zone Indicator used to classify the rock types of LUZ reservoir.

Rock Types	Avg FZI	FZI-Min	FZI-Max	Standard Deviation
1	3.593	3.553	3.633	0.056
2	2.347	2.101	2.844	0.217
3	1.460	1.241	1.745	0.180
4	0.960	0.808	1.108	0.102
5	0.630	0.447	0.781	0.141
6	0.237	0.078	0.409	0.166

Avg. FZI: mean value of the Flow Zone Indicator; FZI-Min: minimum value of the Flow Zone Indicator; FZI-Max: maximum value of the Flow Zone Indicator.

Phase III: preparation of P_c data and their relationship with the core-derived petrophysical properties

Once the P_c data had been corrected and converted to reservoir conditions, the irreducible water saturation (S_{wirr}) versus RQI was plotted (Figure 2), where it can be seen that rocks with low RQI show high values of S_{wirr}. According to this, the variables introduced by Amaefule *et al.* (1993) are related to the physical properties of the reservoir, which confirms how physically they control the flow and storage capacity of the rock.

On the other hand, the P_c curves were classified by rock type, using the FZI parameter (Amaefule *et al.*, 1993). Rock types 4, 5 and 6 were classified altogether as rock type 4, since only a sample of types 5 and 6 was available, thus making it impossible to model them.

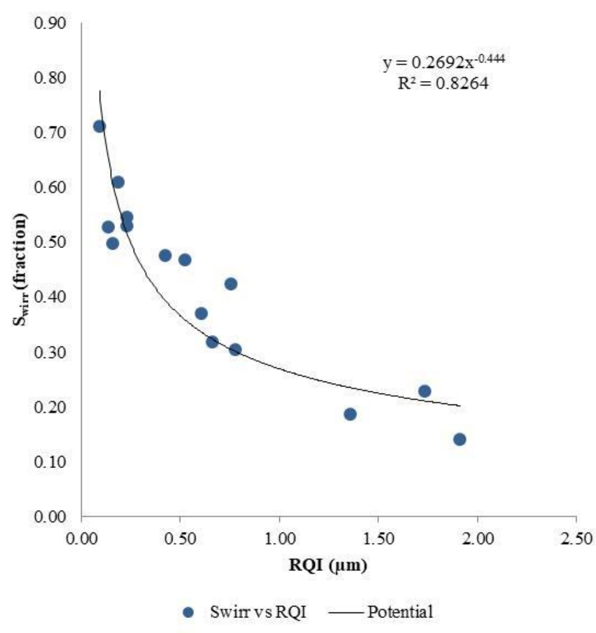

Figure 2. Irreducible water saturation of each drainage capillary pressure sample versus the Reservoir Quality Index calculated for each sample.

Phase IV: determination of S_{wi} model of LUZ reservoir from the P_c tests by rock type

As a reference, Figure 3 shows the selection of the model in rock type 1. To the left of the graph are listed the defined equations and the error found between the water saturation of each point and the one modeled by the fitted function. In general, the evaluated models generated very low errors; however, the Leverett model was chosen because it fits the shape of the curves and better reproduces the value of S_{wirr}.

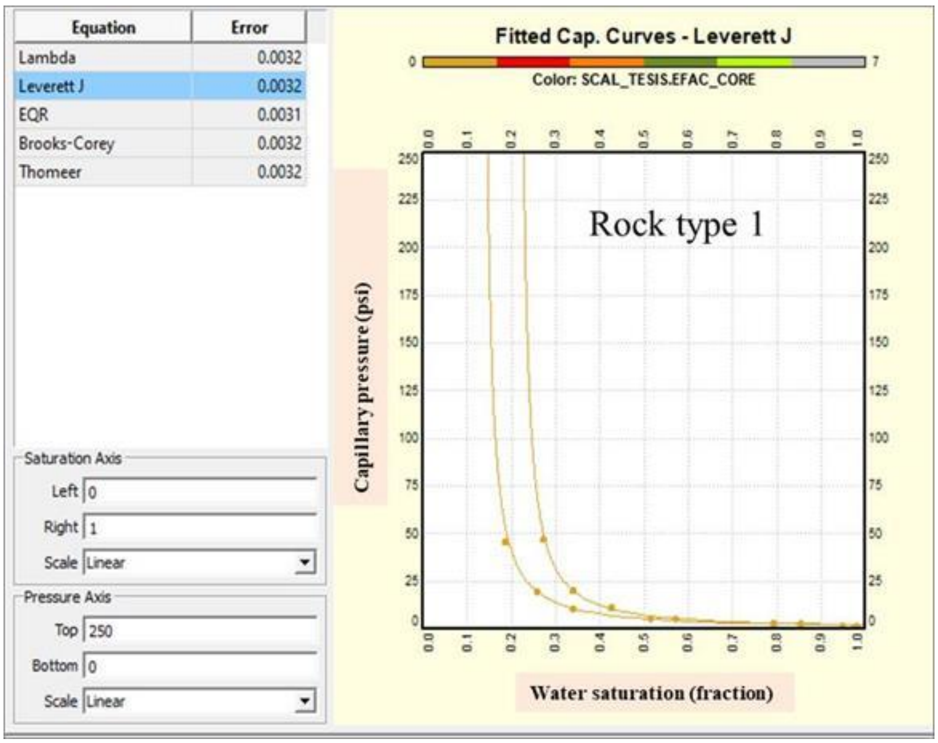

Figure 3. P_c curves corresponding to rock type 1 from the LUZ reservoir. J – Leverett correlation.

The P_c curves modeled using the J-Leverett function with constant coefficients for the different rock types, are shown in Figure 4. The fit parameters of the S_w equation by rock type were obtained with the RQI of each P_c sample, using the module for coefficients´ fitting of the used software. The proposed equations are shown in table 3. In Figure 5, a one to one plot between the S_w obtained by Leverett model versus the S_w of the P_c curve measured in laboratory for each rock type is showed, where each graph shows a unit slope line that passes through the origin; as the points get closer to that trend, the model has a better fit.

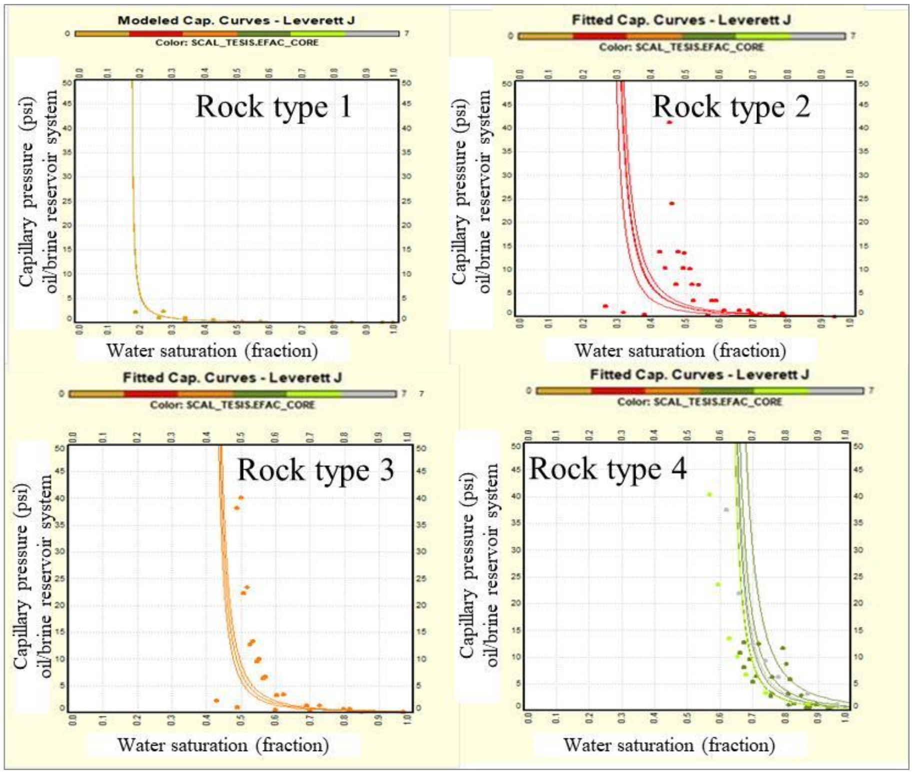

Figure 4. P_c Curves of LUZ reservoir by J-Leverett model and constant coefficients.

Table 3. Proposed equations to determine the water saturation by rock type in LUZ reservoir, using the J – Leverett model.

Rock type 1

Model Sw Equation

Sw Equation (0.170311)+(1-(0.170311))*(1.165030)*(PC*SQRT(PERMEABILITY/POROSITY))**-(0.809578)

Parameter	Model	Intercept	Gradient	Regression Equation
SWI	Constant	0.170311		SWI=0.170311
A	Constant	1.165030		A=1.165030
N	Constant	0.809578		N=0.809578

$$S_w = 0.170311 + (1-0.170311)*1.165030*\left(P_c * \sqrt{\frac{k}{\phi}}\right)^{-0.809578}$$

Rock type 2

Model Sw Equation

Sw Equation (0.246833)+(1-(0.246833))*(0.931334)*(PC*SQRT(PERMEABILITY/POROSITY))**-(0.428113)

Parameter	Model	Intercept	Gradient	Regression Equation
SWI	Constant	0.246833		SWI=0.246833
A	Constant	0.931334		A=0.931334
N	Constant	0.428113		N=0.428113

$$S_w = 0.246833 + (1-0.246833)*0.931334*\left(P_c * \sqrt{\frac{k}{\phi}}\right)^{-0.428113}$$

Rock type 3

Model Sw Equation

Sw Equation (0.398200)+(1-(0.398200))*(0.813689)*(PC*SQRT(PERMEABILITY/POROSITY))**-(0.475428)

Parameter	Model	Intercept	Gradient	Regression Equation
SWI	Constant	0.398200		SWI=0.398200
A	Constant	0.813689		A=0.813689
N	Constant	0.475428		N=0.475428

$$S_w = 0.398200 + (1-0.398200)*0.813689*\left(P_c * \sqrt{\frac{k}{\phi}}\right)^{-0.475428}$$

Rock type 4

Model Sw Equation

Sw Equation (0.600000)+(1-(0.600000))*(0.832188)*(PC*SQRT(PERMEABILITY/POROSITY))**-(0.461089)

Parameter	Model	Intercept	Gradient	Regression Equation
SWI	Constant	0.600000		SWI=0.600000
A	Constant	0.832188		A=0.832188
N	Constant	0.461089		N=0.461089

$$S_w = 0.6 + (1-0.6)*0.832188*\left(P_c * \sqrt{\frac{k}{\phi}}\right)^{-0.461089}$$

The models by rock type are represented in 3D (Figure 6), so that each model predicts the S_w as a function of P_c and Z values of RQI. The model has a good fit to the data points, since the P_c curves are located on or near the surface. Figure 6 shows the integration of all the parameters involved in Leverett's S_w equation, where it is worth mentioning that as the RQI is higher, the water saturation decreases, but this in turn is smaller as the P_c increases. So, S_w at a specific point in the reservoir will depend on the height from such point to the FWL; this will be noticed when the transformation from P_c to height is made. On the other hand, each rock type has a transition zone; this will depend on its quality, that is, as the RQI is higher (larger pores), the water-oil zone is narrower.

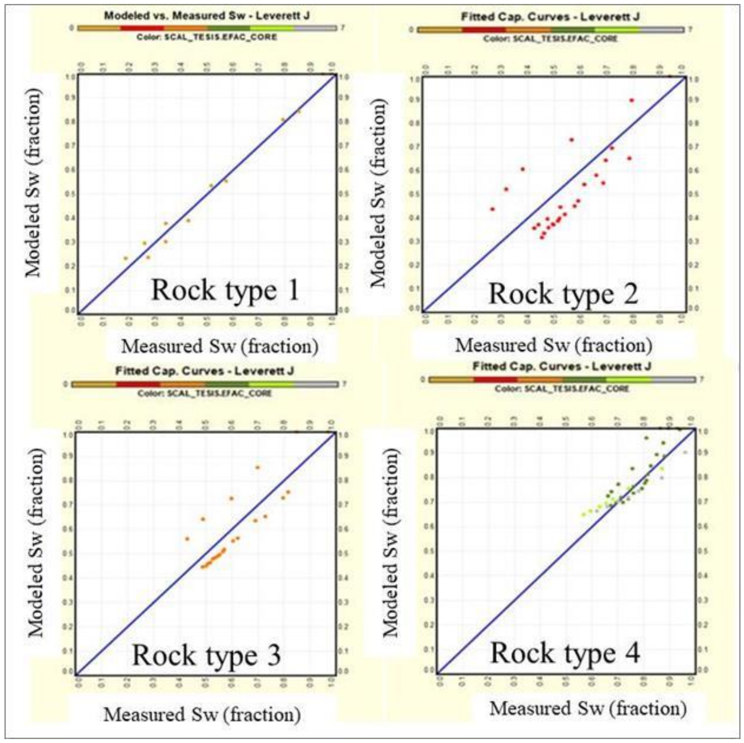

Figure 5. Modeled S_w from the J – Leverett function versus laboratory - measured S_w, corresponding to LUZ reservoir

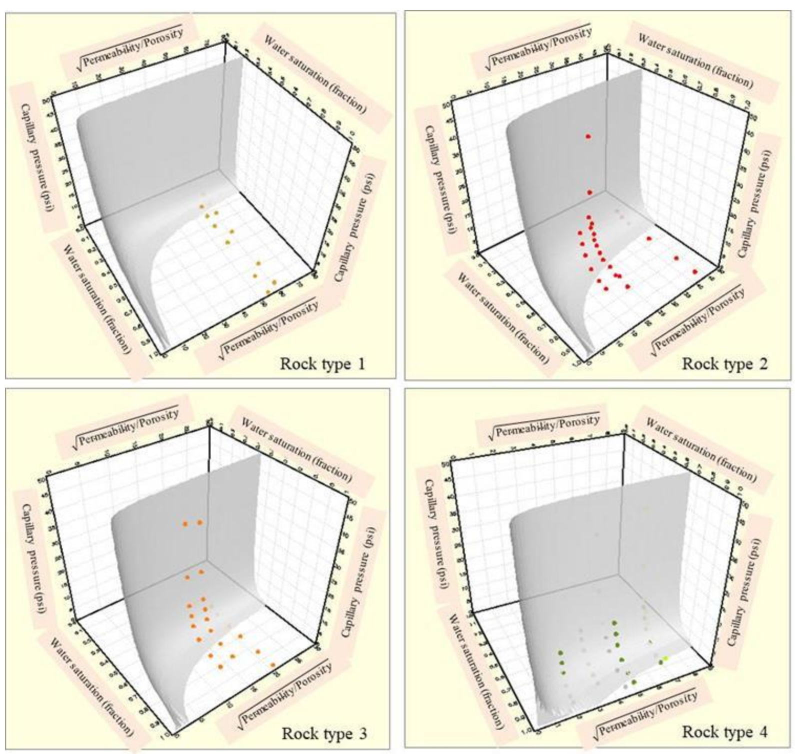

Figure 6. 3D S_w model for all rock types in LUZ reservoir.

The log information from the first drilled wells in the study area (Figure 7) was obtained several decades prior to the beginning of LUZ reservoir´s production (1992), therefore this information had not been affected by the drainage of the reservoir. When predicting the S_w above the FWL in these wells and contrasting it with the log information, the following can be mentioned: in LUZ0512 and LUZ0584 wells there is a good match between the P_c-derived curve (dark blue) and the log (light blue), present in track 10 of the well´s petrophysical evaluation; however, small differences are present in LUZ0512 well, since it involves Long Normal and Short Normal resistivity logs, which, due to non-focused electrodes configuration, they always have a depth shift. On the other hand, in LUZ0267 well there is an important difference between these two curves, due to the low vertical resolution of the resistivity tool, being affected by neighbors' beds. The results are considered satisfactory and validate the S_w model based on P_c and, consequently, the range of amplitude of the rock types

As is well known and has been referenced by multiple authors (Walsh *et al.*, 1993; Whitman, 1995; Griffiths *et al.*, 2000), the quality of the well log information will depend on factors such as tool vertical resolution and bed thickness; for example, when the bed´s thickness is less than the vertical resolution of the tool, neighboring beds affects the property measured value, not being this value representative. This effect can be seen in old logs (approximately of 60's decade), especially in the old generation Induction logs and no-focused devices with very poor vertical resolution, which is around 8 feet. In old wells, the tool type plays an important role, because the vertical resolution of a Dual Laterolog log is better than that of an Induction log. Additionally, it is necessary to consider the drilling mud properties; Induction logs work better with fresh water-based muds, while galvanic logs, such as the Dual Laterolog, work with saline water-based muds. All this indicates that the data obtained from logs are not always reliable, and the methodology used in this work is a valid option to reduce the uncertainty in the quantification of the STOOIP.

Phase V: estimation of STOOIP in the basal sand of LUZ reservoir, P-1 area

Table 4 shows the comparison of the STOOIP obtained from the S_w, based on P_c with that calculated in a conventional manner (S_w derived from logs), in which a difference of 5.21 MMBN (19.8 %) is observed. This is due to the fact that the STOOIP obtained from log-derived S_w is affected by the drainage of the reservoir (this is observed in new wells), not being the most representative. To better illustrate this, in Figure 8 both STOOIP are represented and it can be observed that the STOOIP calculated with log-derived S_w, is diminished to the East of the area, while the value of the STOOIP obtained with the proposed S_w model remain high in that same area. By using the log-derived S_w of all associated wells, the STOOIP would be underestimated, and oil recoverable reserves could be even less than cumulative oil production. To minimize these problems, a better quantification is obtained through P_c models by rock type, as developed by Obeida *et al.* (2005), as well as Gonzalez *et al.* (2016). Therefore, a better estimation of the STOOIP for area P-1, in the basal sand of the reservoir, results in 26.28 MMBN.

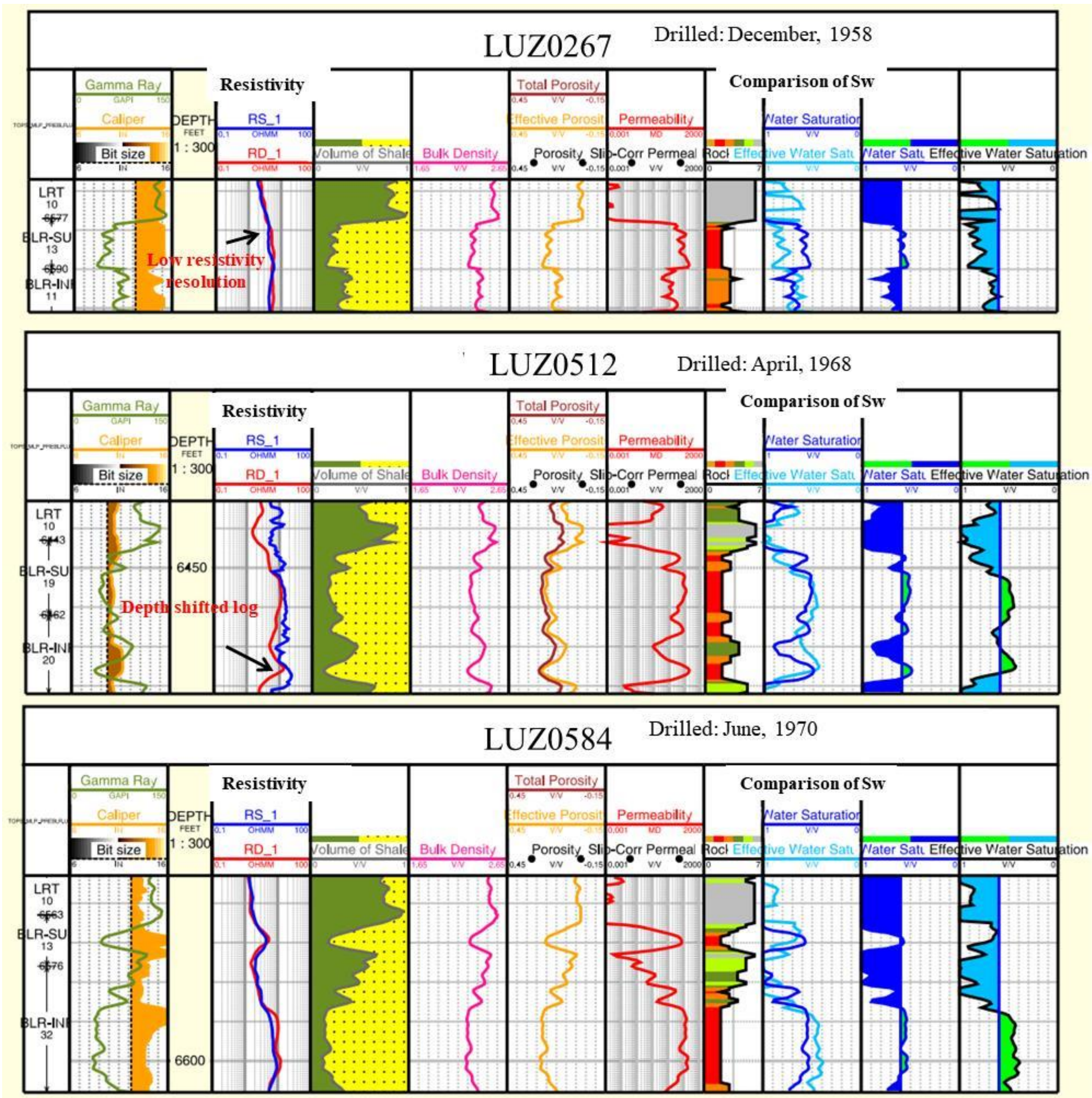

Figure 7. Comparison of the S_w curve, obtained from the P_c, and the log-deriverd S_w curve. First drilled wells in the study area.

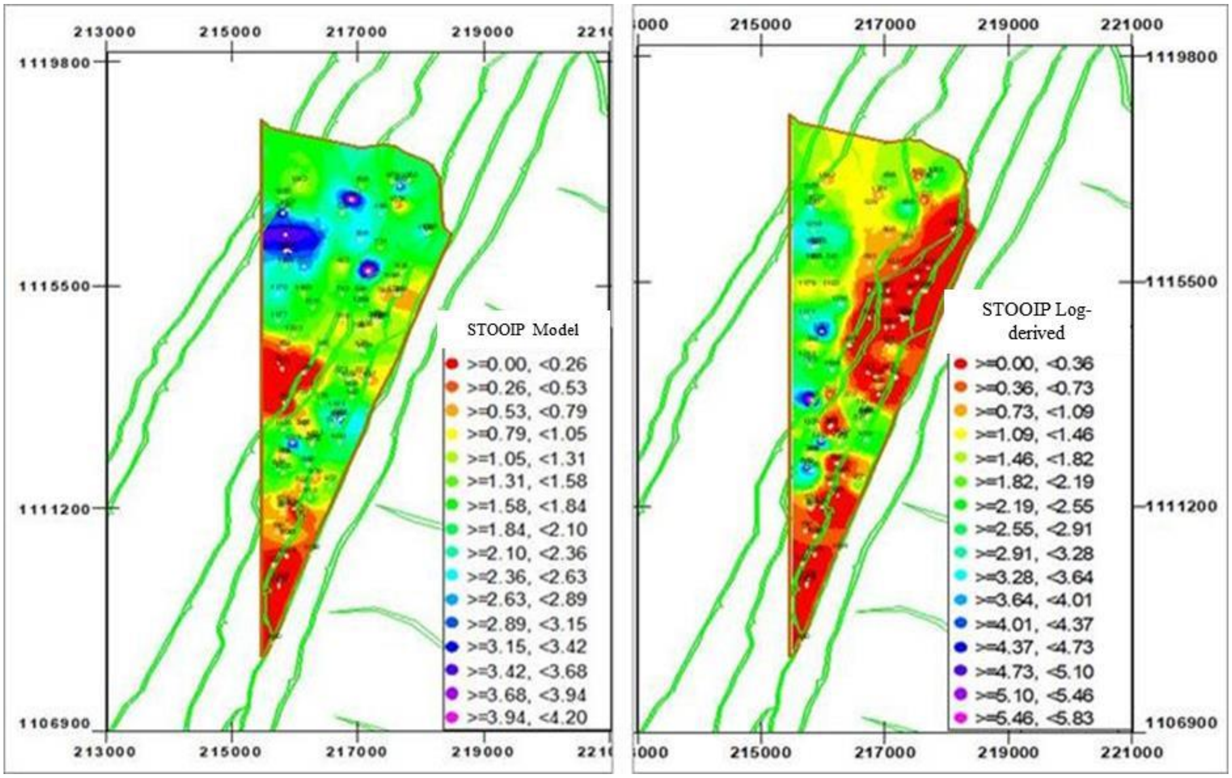

Figure 8. STOOIP map of the study area with S_w from the proposed model and log-derived $S_{w.}$

Table 4. Average values used in the STOOIP calculations of the study area.

Average thickness (feet)		**Average effective porosity (fraction)**		**Average water saturation (fraction)**		**STOOIP (MMBN)**	
Model	**Log**	**Model**	**Log**	**Model**	**Log**	**Model**	**Log**
10.09	8.96	0.20	0.16	0.54	0.59	26.28	21.07

Conclusions

Six rock types were identified in LUZ reservoir.

The J Leverett model fits better to the P_c curves for all rock types, so with this model S_{wi} equations were established for the modeled rock types.

The comparison between the S_w curves based on P_c with the log-derived S_w curves in the first drilled wells, showed a good fit. The differences observed in some of them were due to problems associated with the logs, such as the effect of neighboring beds, depth shift, among others.

The STOOIP estimated in the P-1 area, in the basal sand of the reservoir, using the S_w of the proposed model and the one log-derived, represented a difference of 19.8 %, which highlights the importance of a robust model, such as the one presented in this work to increase the certainty in the calculation of reserves.

Acknowledgements

The authors would like to express our recognition to PDVSA, Western Management of Exploration and Integrated Reservoir Studies for providing the information and authorizing the publication of this work. We also would like to extend our gratitude to Prof. Edgar Pereira (Petroleum Engineering School of the University of Zulia) for his valuable collaboration in the preparation of this article.

References

Adams, S., Van den Oord, R. (1993). *Petrophysics. Capillary pressure and saturation-height functions*. The Hague: Shell International Petroleum Maatschappij B.V

Amaefule, J., Altunbay, M., Tiab, D., Kersey, D., Keelan, D. (1993). *Enhanced reservoir description: using core and log data to identify hydraulic (flow) units and predict permeability in uncored intervals/wells*. SPE26436, 68th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers (SPE). Texas, USA, 205-220

Core Laboratories Venezuela, S.A. (2000). *Estudio de las propiedades de la roca para PDVSA Exploración y Producción del pozo LUZ1348.* Maracaibo: Petróleos de Venezuela (PDVSA).

Core Laboratories Venezuela, S.A. (2008). *Estudio de propiedades avanzadas de la roca para PDVSA, pozo LUZ1542*. Maracaibo: Petróleos de Venezuela (PDVSA).

Gonzalez, J., Perozo, A; Medina, F. (2016). *Quantification of the distribution of initial water saturation through Leverett J function to calculate hydrocarbon reserves*. SPE-181177-MS, SPE Latin America and Caribbean Heavy and Extra Heavy Oil Conference. Lima, Peru, 1-14.

Griffiths, R., Barber, T., Faivre, O. (2000). *Optimal evaluation of formation resistivities using array induction and array laterolog tools.* SPWLA-2000-BBB, SPWLA (Society of Petrophysicists and Well Log Analysts) 41st Annual Logging Symposium. Dallas, USA, 1-13.

Jones, S. (1988). Two-point determinations of permeability and PV vs net confining stress. *SPE Formation Evaluation*. 3(1), 235-241.

Obeida, T., Al-Mehairi, Y., Suryanarayana, K. (2005).*Calculations of fluid saturations from log-derived J-functions in giant complex Middle East carbonate reservoir*. IPTC 10057, International Petroleum Technology Conference. Doha, Qatar. 1-5.

Omni Laboratories de Venezuela, C.A. (1997). *Reporte final de análisis especiales de núcleos, pozo LUZ1246.* Maracaibo: Petróleos de Venezuela (PDVSA).

Omni Laboratories de Venezuela, C.A. (2007). *Reporte final de análisis convencionales de núcleos, pozo LUZ1542*. Maracaibo: Petróleos de Venezuela (PDVSA).

Paradigm™; Epos® 4.1 Data Management (2011). *Core analysis*. Geolog® 7 program help module. Houston: Emerson.

PDVSA. (2005). *Manual del participante en el curso de OFM (oilfield manager) intermedio-avanzado v-2005.* Maracaibo: Petróleos de Venezuela (PDVSA).

PDVSA. (2019). *Petrophysical characterization project database for the LUZ reservoir.* Maracaibo: Western Exploration and Integrated Reservoirs Studies Management, Petróleos de Venezuela (PDVSA).

Rider, M., Kennedy, M. (2011). The geological interpretation of well logs. Third edition. Glasgow: Rider-French Consulting.

Uguru, C., Udofia, A., Oladiran, O. (2004). *Estimating irreducible water saturation and relative permeability from Logs*. SPE 140623, 34th Annual SPE International Conference and Exhibition. Calabar, Nigeria, 1-6.

Valenti, N., Valenti, R., Koederitz, L. (2002). *A unified theory on residual oil saturation and irreducible water saturation*. SPE 77545, Annual Technical Conference and Exhibition. Texas, USA, 1-6.

Walsh, J., Brown, S., Asquith, G. (1993). *Analyzing old electric logs in shaly sand formations.* SPE-25508-MS, SPE Production Operations Symposium. Oklahoma, USA. 919-926.

Whitman, W. (1995) Interpretation of unfocused resistivity logs. *Petrophysics - The SPWLA Journal of Formation Evaluation and Reservoir Description,* 36(1), 35 -39.

Xu, C., Torres, C. (2012). *Saturation height and invasion consistent hydraulic rock typing using multi-well conventional logs*. 53rd SPWLA Annual Logging Symposium. Cartagena, Colombia, 1-16.

UNIVERSIDAD DEL ZULIA

REVISTA TECNICA

OF THE FACULTY OF ENGINEERING
UNIVERSIDAD DEL ZULIA

Vol. 44. N°3, Sep - Dec, 2021

This Journal was edited and published in digital format on August 2021 ***by Serbiluz Editorial Foundation***

www.luz.edu.ve
www.serbi.luz.edu.ve
www.produccioncientificaluz.org