Qatar Univ. Sci. J. (1994), 14 (2): 381-385

SEISMIC REFLECTION COEFFICIENT PARAMETER-THEORETICAL AND PRACTICAL APPROACH

By

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خالد شهاب المختار

تمت دراسة تأثير المسامية والسائل المسامي على قيمة معامل الإنعكاس (R) وتم التوصل إلى عدد من الصيغ الرياضية . ونتيجة لذلك فقد تم التوصل إلى صيغة جديدة للتعبير عن تأثير هذه المتغيرات على قيمة (R) .

إضافة لذلك فرضت عدد من الأنماط الجيولوجية والتخليقية وتم تدوين عدد من الخصائص التي تثبت التأثير البارز الذي تلعبه المسامية والإشباع بالغاز على (R) وهذه بلاشك ستساعد في إكتشاف التجمعات الهيدروكربونية .

Key Words: Seismic reflection coefficient, Porosity, Pore Filler, Saturation, Synthetic models.

ABSTRACT

In this study, the effect of porosity and pore filler on the reflection coefficient parameter (R), are well deduced and some mathematical expressions were developed. This leads to the establishment of new expression of (R) which take these effects into account.

Moreover, two -and three -horizons models have been assumed and accordingly their seismic synthetic models have been constructed. Many characters were deduced which confirms the prominent effect of porosity and gas saturation on (R), and aid in the detection of hydrocarbons accumulations.

INTRODUCTION

The energy of incident seismic wave on an interface is divided into longitudinal, transversed refracted and reflected energies. This distribution is produced at each time when the wave arrived at an interface separating two media. The reflected energy of normal incident seismic wave on an interface, which separates two media of acoustic impedances r_1, r_2, could be described by the reflection coefficient, R [1-6].

$$R = \frac{r_2 - r_1}{r_2 + r_1} = \frac{v_2 d_2 - v_1 d_1}{v_2 d_2 + v_1 d_1} = \frac{A_r}{A_i} \qquad (1)$$

where:

v_1 & v_2 are the seismic velocities of first and second media.

d_1 & d_2 are the densities of first and second media.

A_i & A_r are the consequent amplitudes of incident and reflected rays.

The contrast in acoustic impedance between the two media determine the polarity of the reflected signals. R varies from positive when $r_2 > r_1$ to negative when $r_2 < r_1$. The negative value is an indicator of the phase inversion (shifting of the phase by 180°).

THEORETICAL PRESENTATIONS

The basic objective of this presentation is to introduce the influence of porosity and pore filler on the reflection coefficient equation. For this purpose we assumed two media, the lower one is porous of porosity, ϕ, and it is considered as a medium of two phases:

- Solid phase or matrix with a velocity V_m and density d_m.

- Fluid phase (liquid or gas) with a velocity V_f and density d_f.

In order to explain the effect of porosity and presence of fluids on the acoustic impedance value and then on R, we consider the following hypothesis:

1. $V_m = V_2$, and $d_m = d_2$ for $\phi = 0$

2. The average density of the second medium is given by the formula

$$d_{a2} = \phi . d_f + (1-\phi) d_2 \tag{2}$$

3. Wyllie's equation (time-average eq.) relates the velocity of seismic waves V_{a2} in porous medium is expressed as follows:

$$\frac{1}{V_{a2}} = \frac{\phi}{V_f} + \frac{1-\phi}{V_2} \tag{3}$$

If $\phi = 0$, then:

$V_{a2} = V_2 = V_m$

$d_{a2} = d_2 = d_m$

When the medium-2 is saturated, therefore its acoustic impedance becomes:

$$r_2 = V_{a2} d_{a2} = \frac{\phi d_f + (1-\phi) d_2}{\dfrac{\phi}{V_f} + \dfrac{(1-\phi)}{V_2}} = \frac{\phi(d_f - d_2) + d_2}{\phi\left(\dfrac{1}{V_f} - \dfrac{1}{V_2}\right) + \dfrac{1}{V_2}} \quad \text{...... (4)}$$

By substituting the acoustic impedance value of equation-4, hence the new reflection coefficient, $\bar{R}$:

$$\bar{R} = \frac{V_{a2} d_{a2} - V_1 d_1}{V_{a2} d_{a2} - V_1 d_1}$$

$$= \frac{\phi . d_f + (1-\phi) d_2 - V_1 d_1 \left[\dfrac{\phi}{V_f} + \dfrac{1-\phi}{V_2}\right]}{\phi . d_f + (1-\phi) d_2 + V_1 d_1 \left[\dfrac{\phi}{V_f} + \dfrac{1-\phi}{V_2}\right]}$$

$$\phi\left[(d_f - d_2) - V_1 d_1 \left(\frac{1}{V_f} - \frac{1}{V_2}\right)\right] + d_2 - \frac{V_1 d_1}{V_2}$$

This equation could be expressed as follows:

$$\bar{R} = \frac{A\phi + B}{C\phi + D}$$

NUMERICAL APPLICATIONS

A. Two-horizons model

In order to relate the effect of both nature of fluids and porosity on the calculated value of R, we assumed two horizons; their acoustic impedances are r_1 and r_2. By considering that r_1 value remains constant, i.e., equal 6000 m/s. gm/cm³ (V_1=3000m/s, d_1 =2 gm/cm³) while r_2 value equal 8000 m/s. gm/cm³ when $\phi = 0$ and will be verified this problem four different cases are assumed in Table 1.

Table 1

The effect of different pore filler types filling the second horizon on the R-values when the porosity is kept constant equal to 15%.

ϕ %	pore filler*	r_2	R
0	-	8000	0.189
15	water	6516	0.041
15	oil	6227	0.018
15	gas	3000	-0.3

** We denote W for water, O for oil and g for gas. Also the following values were assumed in the computation.*

$V_w = 1500$ m/s, $V_o = 1300$ m/s, $V_g = 400$ m/s

$d_w = 1$ gm/cm³, $d_o = 0.9$ gm/cm³, $d_g = 0.9 \times 10^{-3}$ gm/cm³

The cases mentioned at Table 1 are presented as models given in Fig. 1. Of these, it was shown the effect of the pore filler on the reflectivity of an interface separating the two horizons. Moreover, when the pore filler as gas, this will cause a polarity reversal (R<0) of the highly observed reflectivity. Whereas it seems difficult to detect directly the presence of oil or water as pore filler, and to distinguish between them.

B. Three-horizons model

If there is an reservoir bed surrounded by two beds, there will be two contrasts of acoustic impedance. Consequently two seismic reflections will be existed one at the top and the other at the bottom of the intermediate layer. The reflection coefficient R_1, and R_2 for the seismic events could be positive or negative.

The reasonable cases are twelve (Fig. 2a) which represents all the expected situations that could be met by the interpreter during the interpretation of three- horizons model problems. From equation 1, it could be revealed all factors which could increase the contrast in acoustic impedance, such as lithology, pore filler and porosity, resulted in increasing R. The same cases are displayed again in Fig. 2b after convolved the obtained reflection coefficient by a Ricker wavelet.

To show the dependence of R on the nature of fluids fillings the intermediate porous bed we examine the following two cases:

1. Saturation of the intermediate porous bed with water

The acoustic impedance equation of porous medium (eq. 4) could be written again when the pore filler is water, as follows:

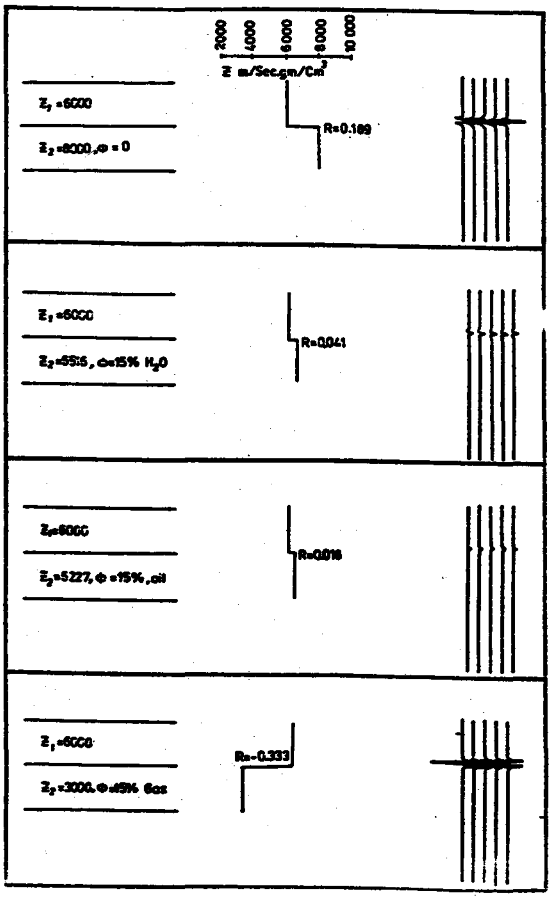

Fig. 1: Geologic and synthetic models showing the effect of different types of fluids on the reflectivity of an interface separating two horizons.

(In this case $d_f = 1$ gm/cm³ and $V_f = 1500$ m/s)

$$V_{a2}d_{a2} = \frac{\phi(1-d_2)+d_2}{\phi(\frac{1}{1500}-\frac{1}{V_2})+\frac{1}{V_2}}$$

In assuming the following values of acoustic impedance for the three successive beds: $r_1 = 5000$, $r_2 = 6000$ ($V_2 = 3000$ m/s, $d_2 = 2$ gm/cm³), and $r_3 = 12000$ m/s gm/cm³, where this assumption is based on neglecting the effect of porosity, i.e. f = 0. To show the effect of water when the porosity is varied at the intermediate bed, four cases of porosity are included (f = 0, 10, 20, 30%). For each three case the correspondent R values at the top (R_1) and at the bottom (R_2) of this bed are presented in Table 2.

Data listed in Table 2 illustrated the decreasing of R_1 with increasing porosity until the inversion of polarity meanwhile R_2 increases with porosity. Furthermore, the interval two-ways time for the second bed is presented, where it indicates clearly the augmentation of time with increasing of porosity producing a time-sag phenomenon. The seismic models at the right side of Fig. 3 clarify the seismic signals as a function of porosity.

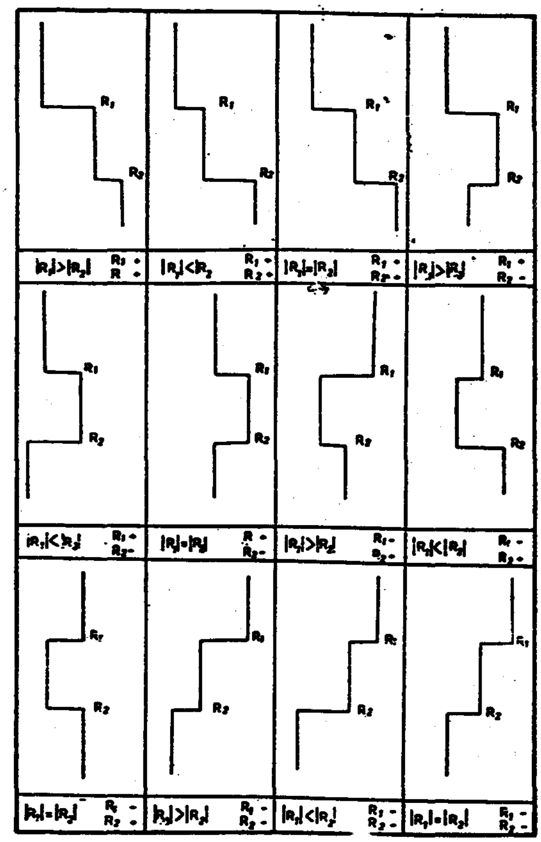

Fig. 2a: Table giving an idea on the different expected cases for reflection coefficient parameter taken in consideration three successive layers.

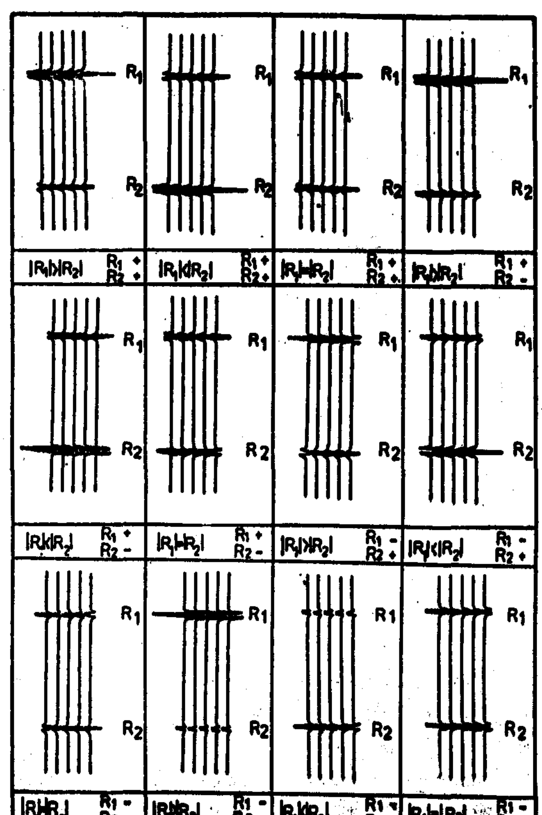

Fig. 2b: A display showing the expected cases of reflected signals in the studied three layer model.

Table 2
The effect of porosity variation in the intermediate bed saturated with water on R-values and on the interval two-ways time.

Porosity %	R-values		Two-way time
	R_1	R_2	(τ) in mesc.
0	0.091	0.333	333.2
10	0.020	0.395	384
20	-0.052	0.454	444
30	-0.124	0.510	510

2. Saturation of the intermediate porous bed with gas

For the same previous model, if the second intermediate porous bed is now filled with gas then the calculated R_1 and R_2 are listed on Table 3.

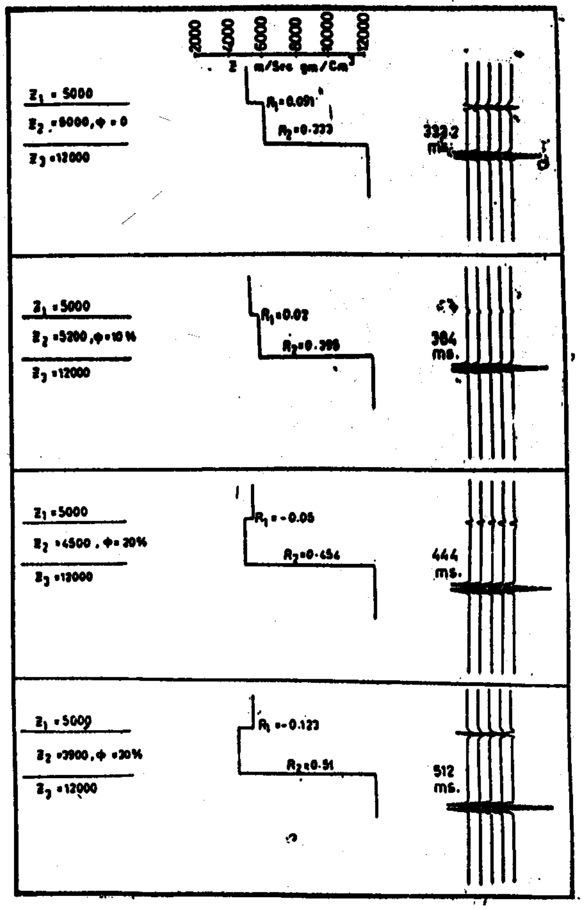

Fig. 3: Models for three layers case illustrate the effect of porosity variation when the second bed is saturated with water, on the reflectivity.

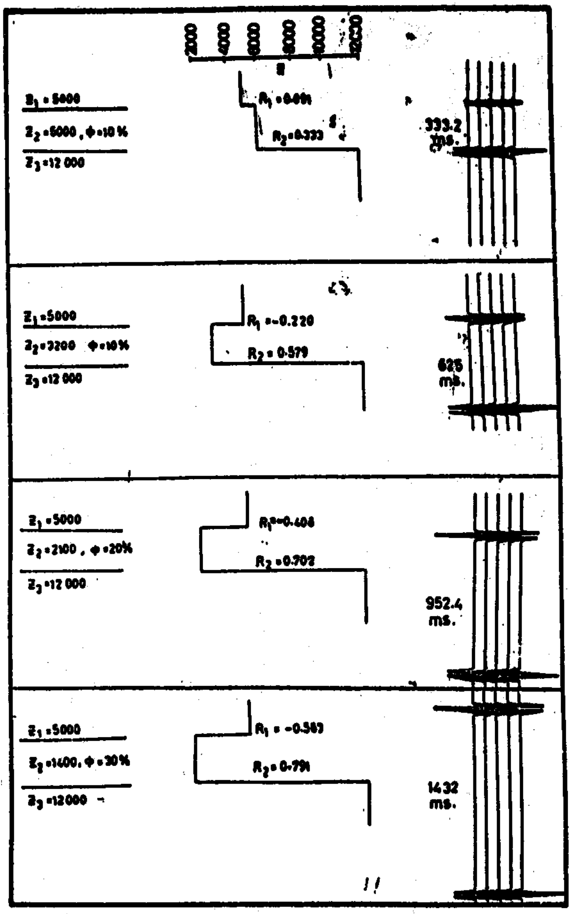

Fig. 4: The same models of Fig. 3 but here the second bed is saturated with gas.

Table 3
The effect of porosity variation of the intermediate bed saturated with gas on R-values and the interval two-ways time.

Porosity %	R-values		Two-ways
	R_1	R_2	time (τ).
0	0.091	0.333	333.2
10	-0.220	0.579	625
20	-0.408	0.702	952.4
30	-0.563	0.791	1432

From these results which are illustrated again in Fig. 4, the considerable effect of gas on acoustic impedances and R-values is clear. R_1 polarity becomes negative with high values, meanwhile the positive R_2 values are increased with a higher rate than that of water saturation. Also the interval time between the upper and lower interfaces increases as function of porosity, of about twice or more than that in the water saturation case.

RESULTS AND DISCUSSIONS

The results of the present work can be summarised as follows:

1. The porosity and fluid type effects on the acoustic impedance value of a certain medium were introduced. Consequently, a new reflection coefficient equation which takes these variables in consideration, was established. The presence of gas as well as increasing of porosity at a certain bed can reduce the acoustic impedance value, and then a negative strong R is obtained at the top of the reservoir while its bottom gives a positive strong R.

2. Many characters were noticed. These are related to the reflection coefficient and considered as a hydrocarbons indicators. Phase inversion of seismic signal is produced when the polarity of the reflection coefficient becomes negative. The reflection at the top of gas bearing medium gives negative reflections. This indicates the validity and usefulness of following the polarity of reflections and its inversion in the interpretation of seismic data.

   Velocity pull-down phenomenon is produced in the gas bearing beds and it is attributed to the low velocity of gas relative to the other fluid types. This allows the observation of lensing effect in the gas bearing reservoirs. The occurrence of this phenomenon is also related to the thickness of gas and its lateral extension. Therefore, the effect of pull-down is laterally varied. Finally, the average velocity for the reflections located under the gas reservoir is expected to be low.

REFERENCES

[1] **Al-Mukhtar, K., 1984.** Contribution à l'étude stratigraphique des sequences sedimentaires et à la recherche des accumulations d'hydrocarbures à partir des données sismiques D.Sc. Thesis presented to Bordeaux-l University, Unpublished.

[2] **Anstey, N., 1976.** The new seismic interpreter, course notes, I.H.R.D.C., Boston.

[3] **Backus, C., 1975.** Flat spot exploration. Geophysical Prospecting, V. 23: 533-577.

[4] **Lindsy, A., 1974.** Bright spot: a progress report and look a head, World oil, 81-83.

[5] **Mossman, R., 1973.** Reflection amplitude variance, direct hydrocarbons exploration conference, Houston.

[6] **Sheriff, R.E., 1974.** Seismic detection of hydrocarbons. The underlying physical principles, Offshore-technology Conf. 2001, 637-645,