Drilling through long salt intervals in Campos Basin-Brazil

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1. SUMMARY

This paper proposes a methodology for designing drilling fluid density and casing for oil wells drilled with the purpose of exploring at great depths through very thick salt layers. Computer modeling to evaluate the creep behavior of salt rocks submitted to high differential stress and high temperature is applied. Results obtained by the numerical simulations was used to predict the evolution of the well closure with time for various drilling fluid densities and analyze several technically feasible alternatives of casing capable of supporting salt creep.

2. INTRODUCTION

The presence of evaporite sections in locations for oil exploration is, in itself, a factor that increases the probabilities of success in the area due to favorable conditions for the generation and trapping of hydrocarbons. On the other hand, the presence of evaporites can cause major operational problems in when special procedures to drill through salt are not used.

Many operational problems, such as stuck pipe and casing collapse have been reported by the oil industry when drilling through salt layers. Historically, in the Campos Basin, several deep wells have been drilled through great salt intervals. In the 80's, the lack of reliable ways to predict salt behavior at high temperatures and high differential stresses led to the loss of wells and very high drilling costs [1].

Salt deformation prediction and its effects in open and cased wells is of major importance for the drilling design, it allows the design of the drilling fluid weight at levels to keep creep under control without fracturing formations above and below the salt zone. Furthermore, the need to run intermediate casing strings before and after the salt layer can be evaluated, in order to maintain the integrity of those formations.

The undergoing exploration program for the Campos Basin includes the drilling of deep wells to reach productive zones below the salt layer at depths greater than 3700 m below the sea bottom.

To support this exploration program computer modeling of a typical well during drilling has been performed.

This paper reviews the results from numerical predictions to provide design information of such deep wells in the Campos Basin.

The numerical simulations have been done through the application of an in-house developed code based on the finite element method [2].

3. MECHANICAL PROPERTIES

The evaporite zone of the chosen scenario for the study is a thick pure halite layer to be drilled at the interval of 3745 m to 4145 m below the sea bottom, or 4107 to 4507 in relation to the drilling rig. Figure 1 illustrates the geological profile used in the analysis.

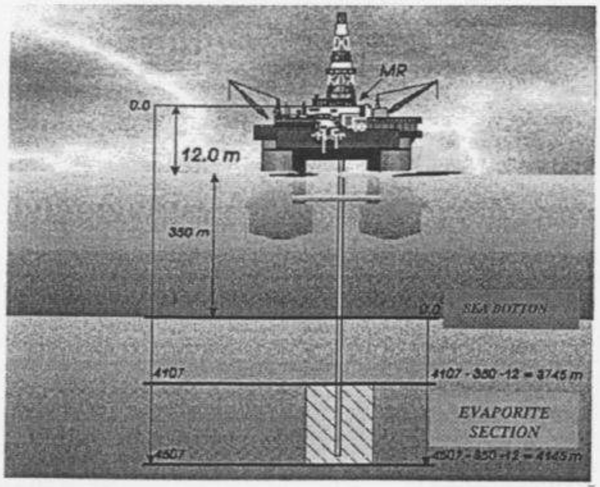

Figure 1 – Simplified Geological profile used in the analysis

Halite is analyzed according to the elasto/viscous-elastic behavior, adopting the double mechanism creep law [3-5].

Creep Equation

$$\varepsilon = \varepsilon_0 \cdot \left(\frac{\sigma_{ef}}{\sigma_0}\right)^n . e^{\left(\frac{Q}{RT_0} - \frac{Q}{RT}\right)}$$

(1)

ε = strain rate due to creep at the steady state condition

ε_0 = reference strain rate due to creep at the steady state condition

σ_{ef} = creep effective stress

σ_0 = reference effective stress

Q - activation energy (kcal/mol) Q = 12 kcal/mol [4]

R - Universal gas constant (kcal/mol.°K)
R = 1.9858 E-03

T_0 - reference temperature (°K)

T - absolute temperature of rock (°K)

The salt properties were based upon the underground potash mining design experience in Brazil, correcting the strain creep rate with the thermal activation factor [2].

The creep constants adopted in simulations are:

$n = n_1 = 3.0\,;\quad \sigma_{ef} \leq \sigma_0$

$n = n_2 = 5.8;\quad \sigma_{ef} > \sigma_0$

$\sigma_0 = 12000$ kPa

$\varepsilon_0 = 9.07 \times 10^{-6}\ (\text{hour})^{-1}$

Elastic Properties of materials

Halite

E = 20.7 GPa	$\nu = 0.36$	
Steel		
E = 210 GPa	$\nu = 0.15$	$\sigma_y = 758000$ kPa
Cement		
E = 21 GPa	$\nu = 0.25$	

Casings are analyzed according to the linear elastic behavior and their structural integrity is checked by the use of von Mises' plastic yielding criterion.

According to von Mises' plastic yielding criterion, the yielding coefficient is given by:

$$J_2 = 0.5\left(S_x^2 + S_y^2 + S_z^2\right) + \tau_{xy}^2$$

(2)

$$f(\sigma) = \frac{\sigma_y^2}{3}$$

(3)

$$\text{ratio} = \sqrt{\frac{J_2}{f(\sigma)}}$$

(4)

where

E – Young's modulus

ν – Poisson's ratio

σ_y – plastic yield stress of the casing steel

J_2 – second invariant of deviation stresses

The value of 13.19 KN/m^3 as the specific weight of the drilling fluid is used in the casing design for the typical well. For the lithostatic column the average specific weight of 22.56 kN/m^3 and a horizontal thrust coefficient equal to 1 are used.

4. WELL DRILLING DESIGN

This paper analyses the results for three different cases. The following hypothesis are used: the plain strain condition; the formation was assumed to be pure halite; and the drilling fluid weight was equal to 13.2 kN/m^3.

CASE 1

- Well diameter - 14 ¾"
- Casings - 11 ¾", 9 $^5/_8$" and 7".

CASE 2

- Well diameter - 14 ¾"
- Casing - 10 ¾"

CASE 3

- Well diameter - 12 ¼"
- Casings - 9 $^5/_8$" and 7".

4.1 Finite Element Model

432 quadratic isoparametric elements and 1281 nodal points were used in the finite element model as shown in Figure 2.

Initially, the well was drilled at instant t = 0.0 and the elements corresponding to casing are placed at pre-defined instants during the simulation.

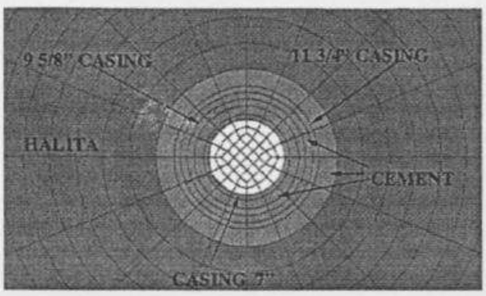

Figure 2- Structural model for the analysis of Case 1

4.2 Analysis of Results during Drilling Design

To evaluate the influence of the casing to prevent the well closure, 14 ¾" well behavior (case 1) with and without casing, assuming only the 11 ¾" casing, was simulated. Figure 3 shows well closure for both conditions. The presence of the casing decreases well closure significantly. It is also necessary to evaluate if the casing is under the elastic or the plastic regime in this condition.

Figure 4 shows the comparison of well closure for two different casings: 11 ¾" and 10 ¾". It seems that there is no significant difference in closure between both models. However, the final choice between the two casings will be based on the collapse condition by analyzing the evolution of the yielding coefficient with time.

Figure 5 is the comparison of the yielding coefficient at a point located on the outer casing, for the three cases. Case 2 (14 ¾" well + 10 ¾" casing) presents the smallest yielding coefficient. Note that the structural efficiency in case 3 (12 ¼" well + 9 $^5/_8$" and 7" casings) is greater than case 1(14 ¾" well + 11 ¾", 9 $^5/_8$" and 7" casings).

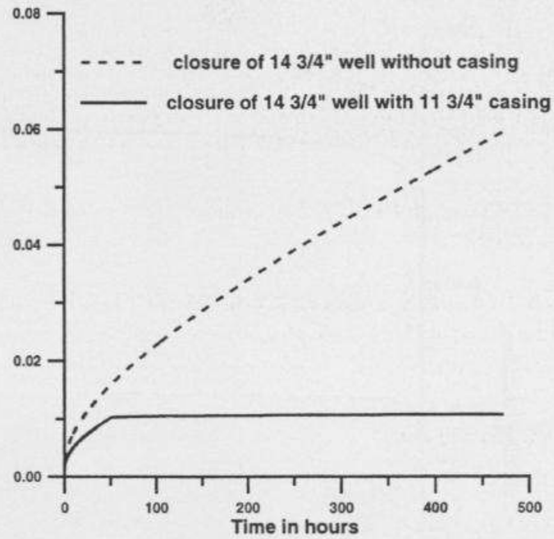

Figure 3 - Influence of 11 ¾" casing to prevent the closure of the 14 ¾" well.

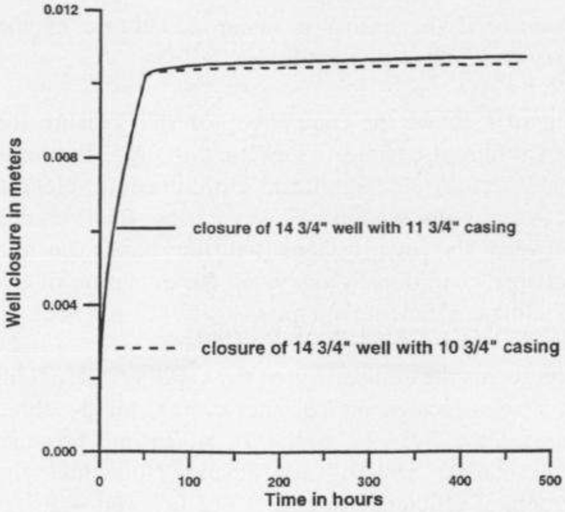

Figure 4 - Comparison of the 14 ¾" well closure for two different casings: 11 ¾" and 10 ¾"

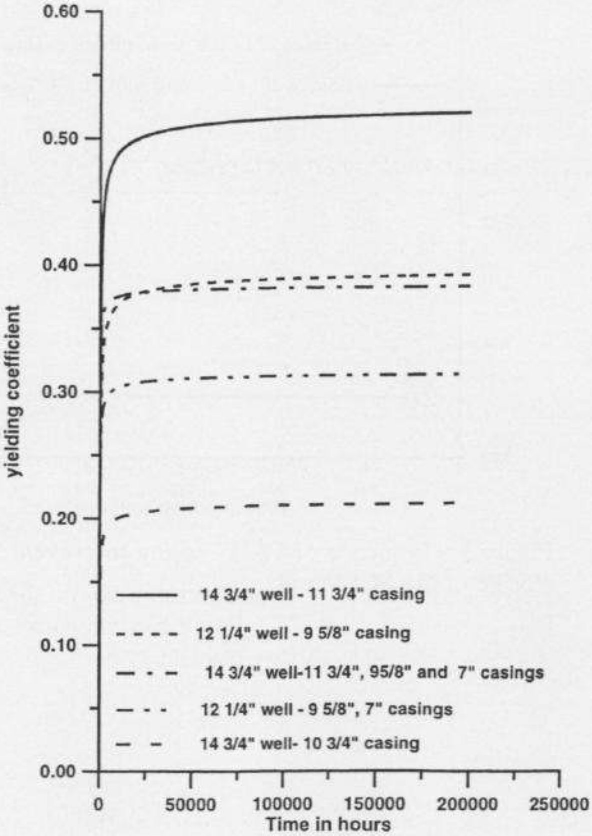

Figure 5 – Evolution with time of the yielding coefficient for several casing sizes.

Figure 6 shows the distribution of the yielding coefficient for casings in case 1 after 20 years of the drilling of the well. Taking into account the results obtained from numerical simulations and also the presence of other factors such as high pressure, high temperature, deep geological corrosive gases, case 3 was adopted as the basis of drilling design of the well.

5. DESIGN OF DRILLING FLUID DENSITY TO PREVENT STUCK PIPE DURING DRILLING

Casing design, taking into account the effect of salt creep, was carried out assuming 13.2 kN/m^3 drilling fluid to simulate the use of a lower density fluid below the salt zone to avoid formation damage at the productive zone. Additional simulations were performed to investigate the well closure rate during drilling the salt zone with different drilling fluid weight.

To guide drilling through the salt zone the behavior of salt creep as a function of drilling progress was simulated using an axisymmetric model.

Several drilling fluid densities were tested leading to the conclusion that the use of 16.98 kN/m^3 fluid could provide safe conditions for drilling the salt zone and running the casing as a result from a significant reduction in well creep closure.

5.1 Description of the finite element model

The axisymmetric model comprises 400 m of evaporite interval and 200 m of thick hard rock, below and above the salt layer.

8800 quadratic isoparametric elements and 26422 nodal points were used in the finite element model.

5.2 Analysis of results

Figure 7 shows the evolution of the well closure rate as a function of the rock bit progress. At a determined depth, closure becomes significant after the bit has already drilled that depth. After 10 days, the maximum predicted closure is about 0.42 cm. These curves have being used during the drilling in order to guide the operations, so that well closure above the bit does not cause the drill string to get stuck.

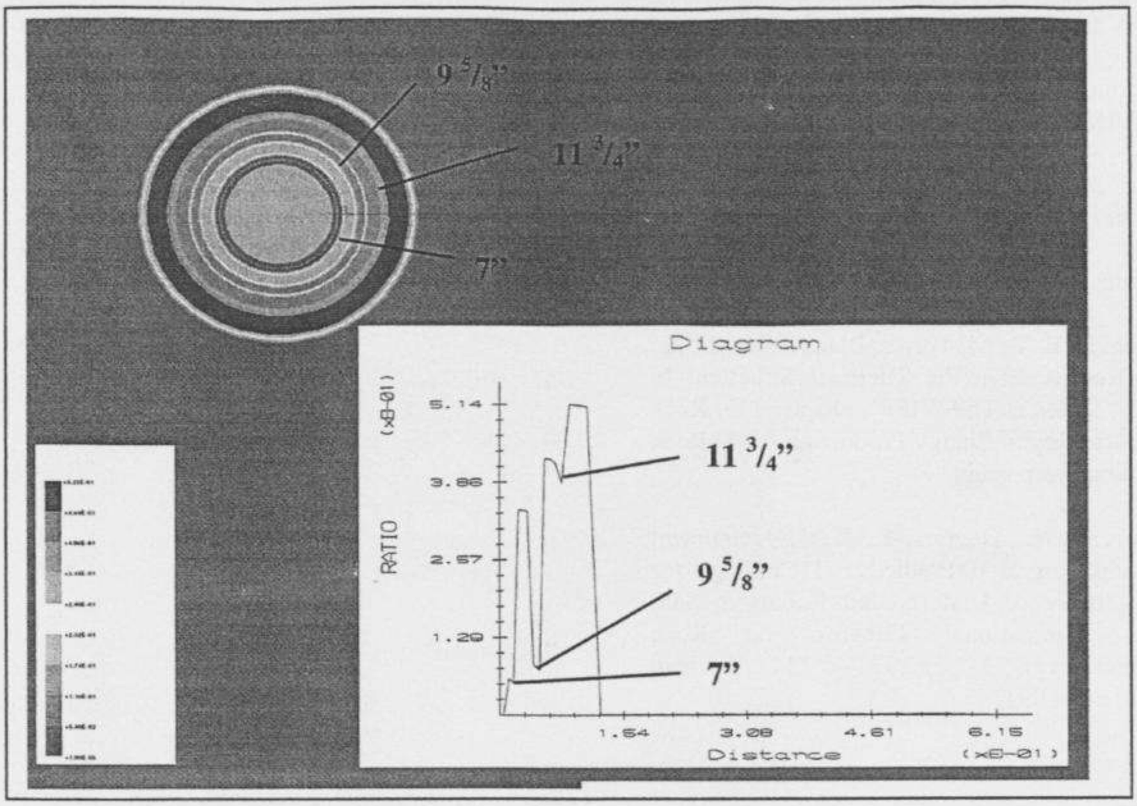

Figure 6 - Yielding coefficient distribution on casings for case 1

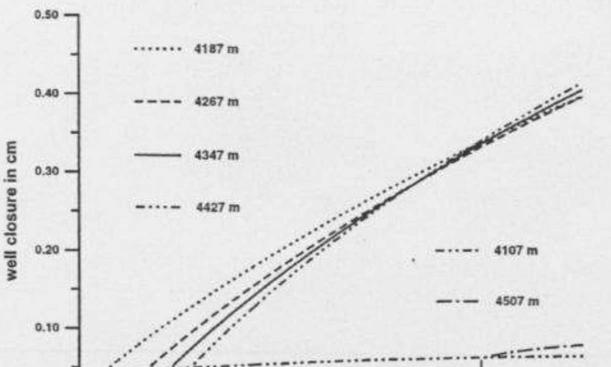

Figure 7 - Well closure prediction during drilling through the salt interval (4107 - 4507 m)

6. CONCLUSION

The methodology presented herein has been used successfully to design the drilling of deep wells in the Campos Basin. The risk of casing collapse and stuck pipe due to salt creep was minimized and drilling costs were reduced.

The numerical results of well closure evolution with time were compared with caliper measurements and have been proved to be very reliable.

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